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(Mostly) Exitless VM Protection from Untrusted Hypervisor through Disaggregated Nested Virtualization

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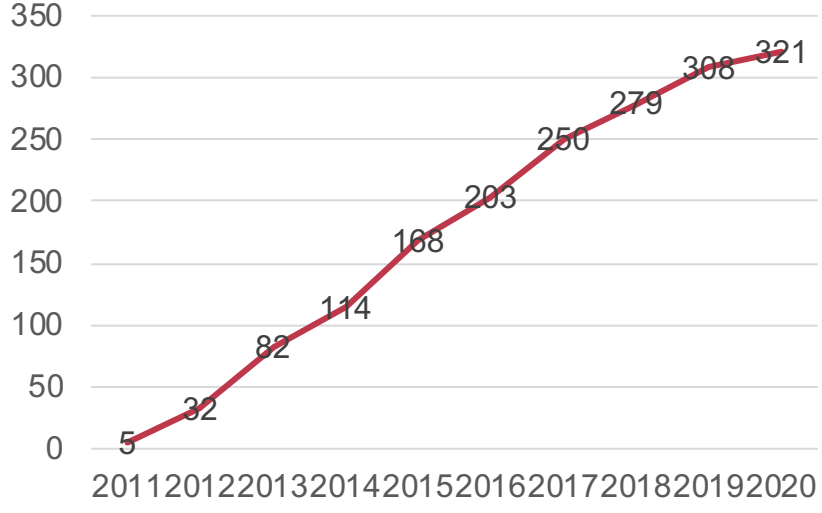
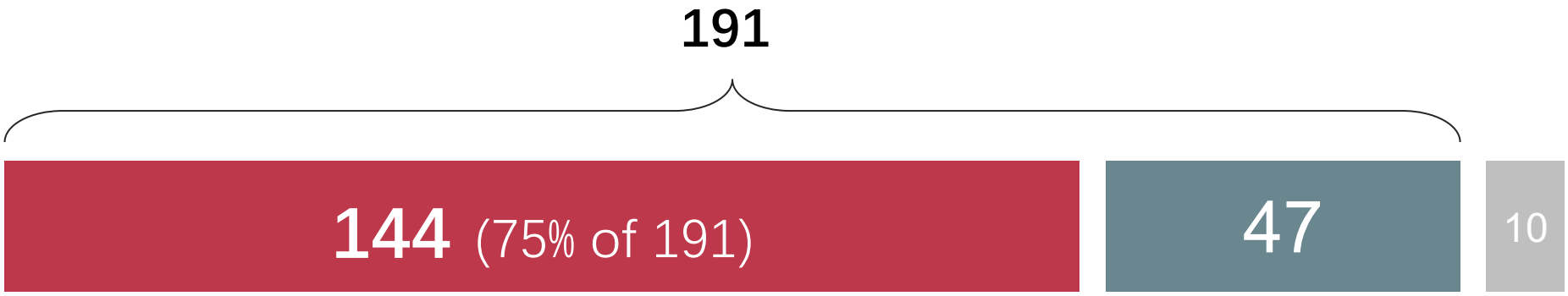
Vulnerable Commercial Hypervisors

- **Xen CVE is growing**
  - LoC: from 45K (v2.0) to 2,649K (v4.14.0)
  - 321 XSA
- **KVM and VMware**
  - KVM: 110+ CVE
  - VMware: 140+



https://xenbits.xen.org/xsa/

Analyzing 201 of Xen's Vulnerabilities (XSA)



144 are in the hypervisor

- E.g., Host DoS, privilege escalation, etc.
- Use hypervisor to attack VM

47 are not in hypervisor

- Some are in Domain-0
- Some are in Qemu

10 are ignored

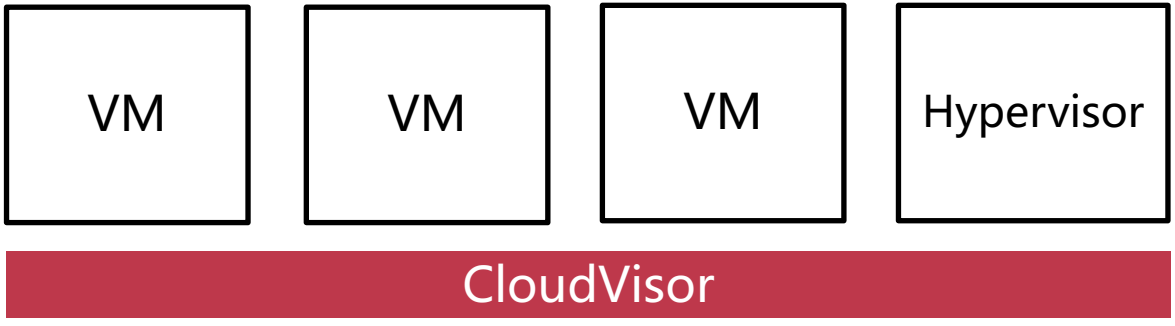
Shi L, Wu Y, Xia Y, et al. Deconstructing Xen. NDSS. 2017.

Existing Approaches

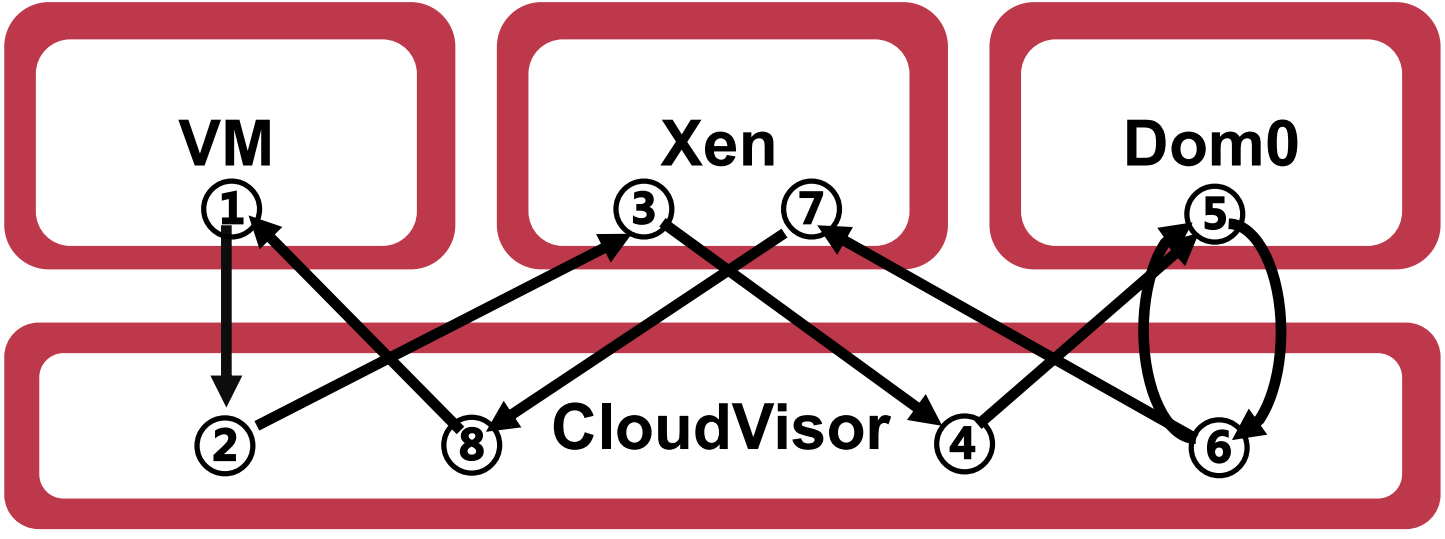
- **Software Method**
  - In-the-box: harden the hypervisor layer
    - Cannot eliminate the risks of exploiting hypervisor vulnerabilities
  - Out-of-the-box: nested virtualization
    - Numerous VM exits bring performance overhead
- **Hardware Method (Intel SGX)**
  - Only available to run in user mode
  - Limited EPC memory incurs significant performance overhead

CloudVisor (SOSP' 11)

- **Observation: protection logics for VMs are mostly fixed**
- **Idea: Separate management from protection**
  - Deprivilege the commercial hypervisor to non-root mode
- **Result: Minimized TCB**
  - VMM and CloudVisor separately designed and evolved



The Cost of Protection: Excessive VM Exits



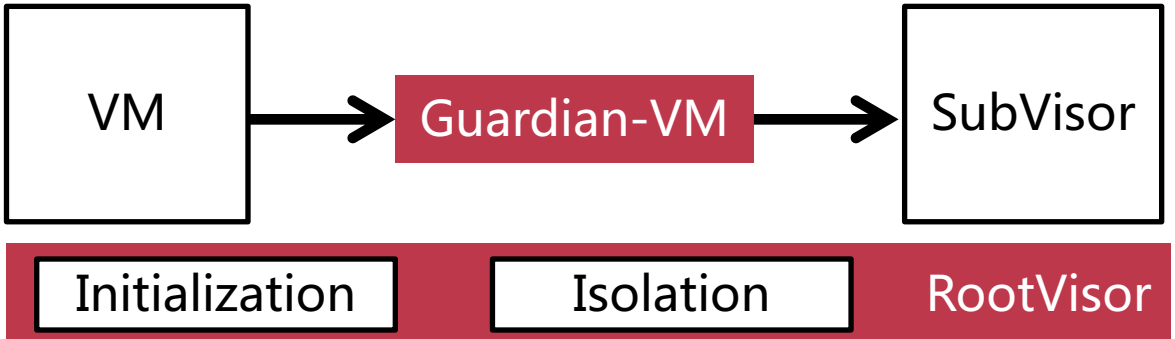
Operation	Times
Hypercall	>= 2X
EPT Violation	2 – 6 X
DMA Operation	>= 2X

CloudVisor-D: No Compromise for Security & Performance

- **A secure and efficient design to shield VM in untrusted clouds**
  - Do not trust the commercial hypervisor
  - Introduce negligible overheads compared to the Xen hypervisor
- **Disaggregated nested virtualization**
  - Deprivilege the hypervisor through **nested virtualization**
  - Disaggregate the nested hypervisor
    - **Offload** VM operations and their protection work to the non-privileged mode

Architecture of CloudVisor-D

- **A tiny nested hypervisor in root mode**
- **A Guardian-VM for each VM in non-root mode**
- **Most VM ops offloaded to Guardian-VM**
  - Hypercalls
  - Memory virtualization
  - I/O operations

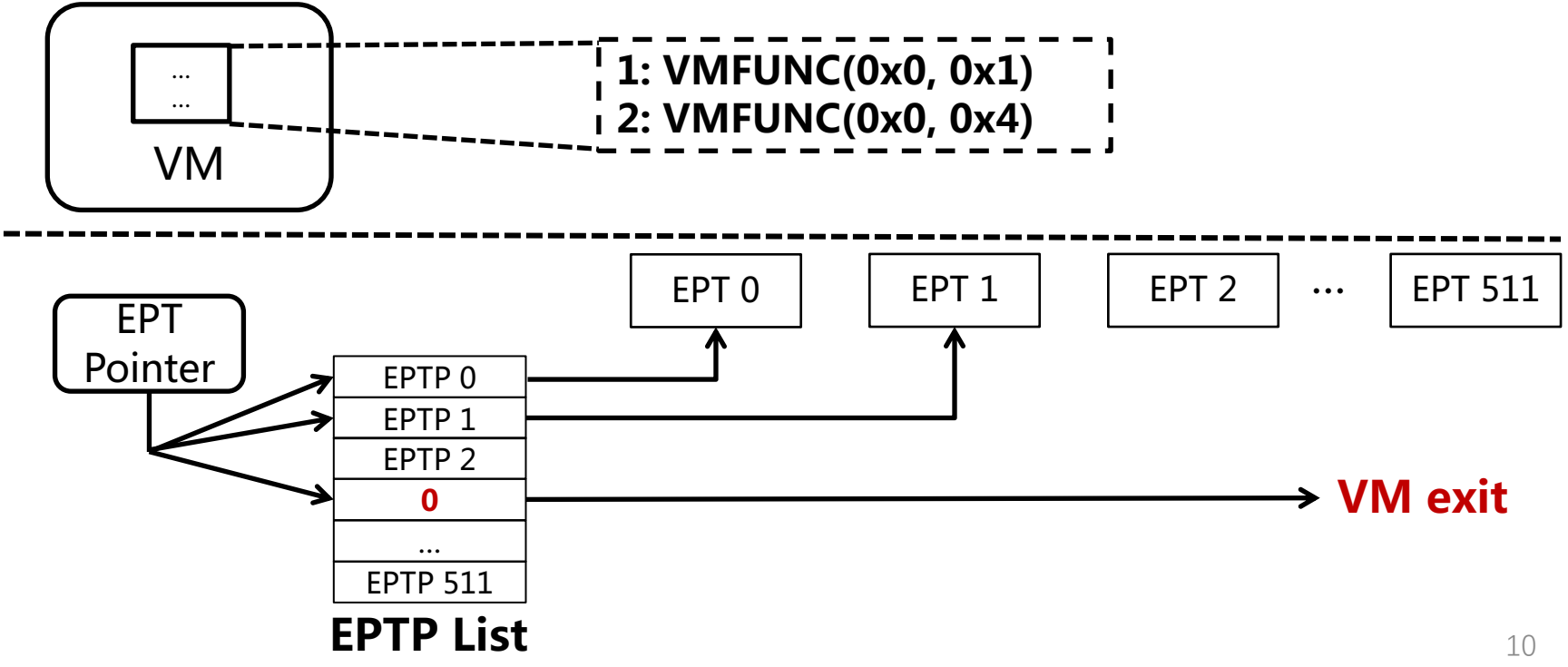


Threat Model

- **TCB: RootVisor and each Guardian-VM**
- **Distrusing: SubVisor and all guest VMs**
- **Out of scope**
  - physical attack
  - Side-channel attacks
  - DoS attacks

Key Secrets: VMFUNC

- Switch EPT efficiently without VM Exits
- Faster than VM exit (134 vs. 301 cycles on Intel Skylake)



CloudVisor-D as Reference Monitor

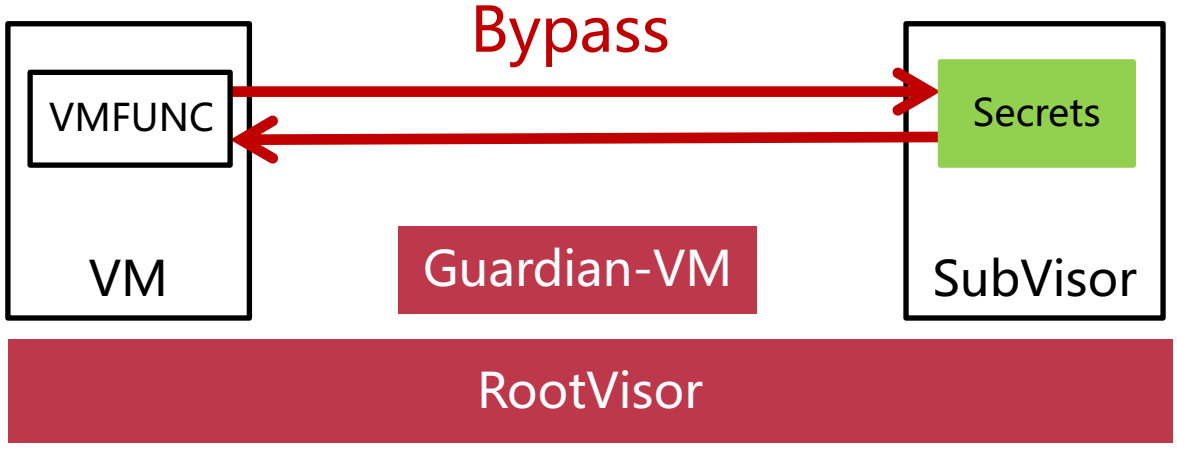
- **CloudVisor-D satisfies two properties**
  - **Tamperproof:** protect RootVisor and Guardian-VM from compromising
  - **Complete Mediation:** interpose on all communication paths between SubVisor and VMs

Complete Mediation

- **Two paths**
  - RootVisor Path: VM->RootVisor->SubVisor
  - Guardian-VM Path: VM->Guardian-VM->SubVisor

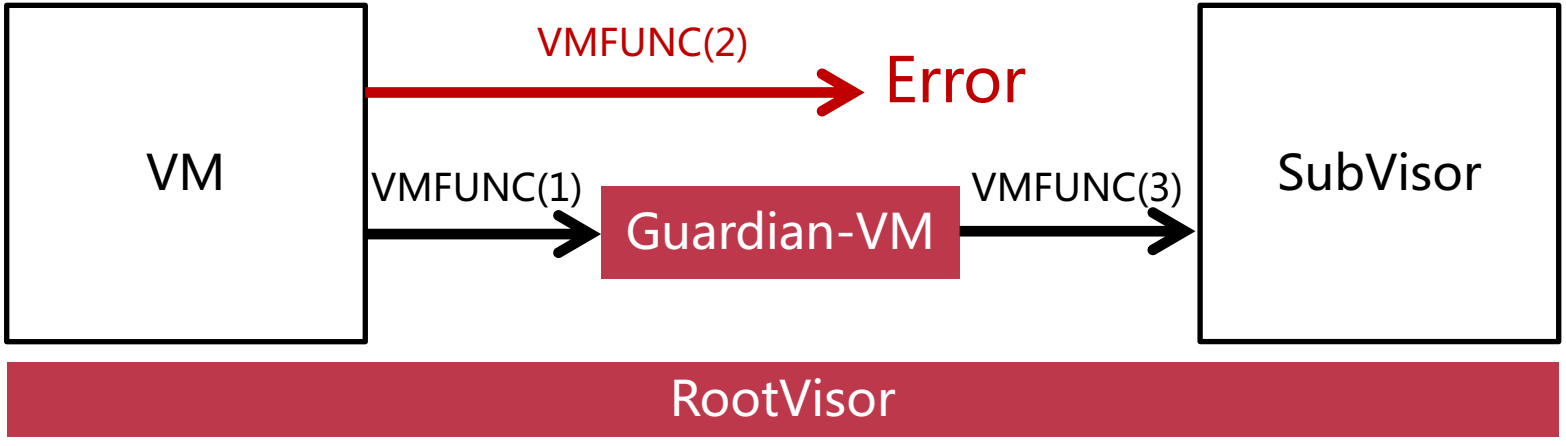
Faking VMFUNC Attacks

- **Type-1: Bypass Guardian-VM**
  - Access arbitrary memory region in VM or SubVisor
- **Type-2: Attack Guardian-VM**



Dynamic EPTP List Manipulation

- **An invalid EPTP entry triggers a VM exit**



0	Guest-EPT
1	Guardian-EPT
2	**0**
…	…
511	0

EPTP List

0	0
1	Guardian-EPT
2	SubVisor-EPT
…	…
511	0

EPTP List

Other Techniques

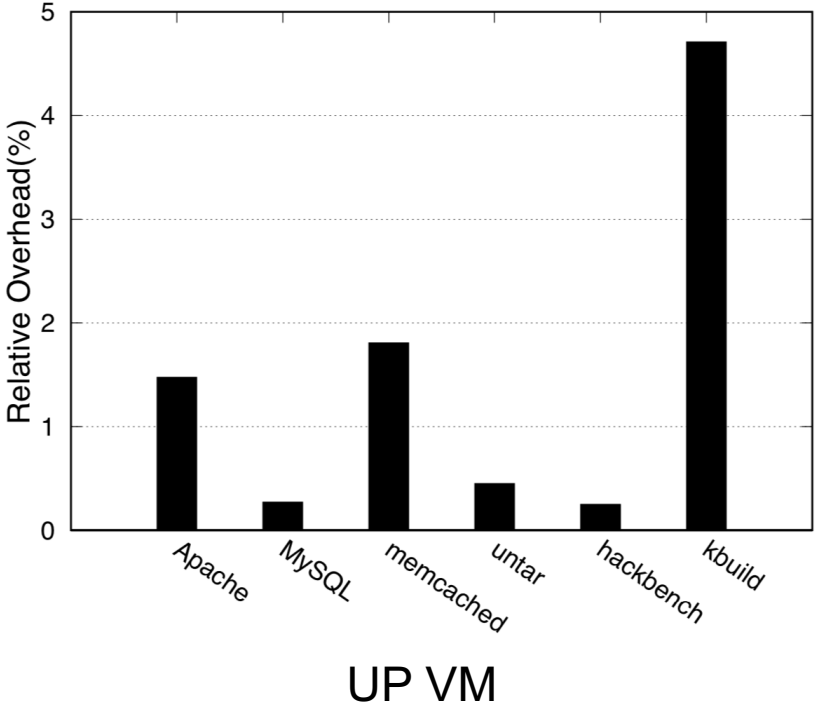
- **Isolated Guardian-VM Page Table**
- **Jump table**
- **Memory virtualization**
  - Shadow EPT and virtualization exception
- **I/O protection**
  - Compatible with PV I/O model
  - Encryption and integrity guarantee

Microbenchmark

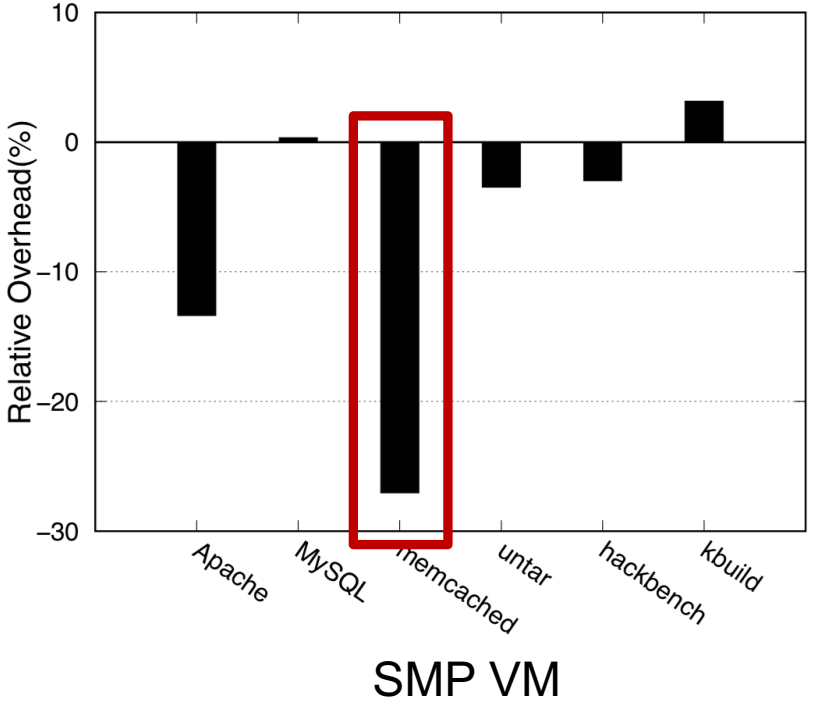
Operation	Xen	CloudVisor	CloudVisor-D	Speedup
Hypercall	1758	4681	1810	61.3%
EPT violation handling	5374	66301	9929	85.0%
Virtual IPI	11214	21344	13331	37.5%

Applications

#VM exits: 1,691,758 -> 63,909

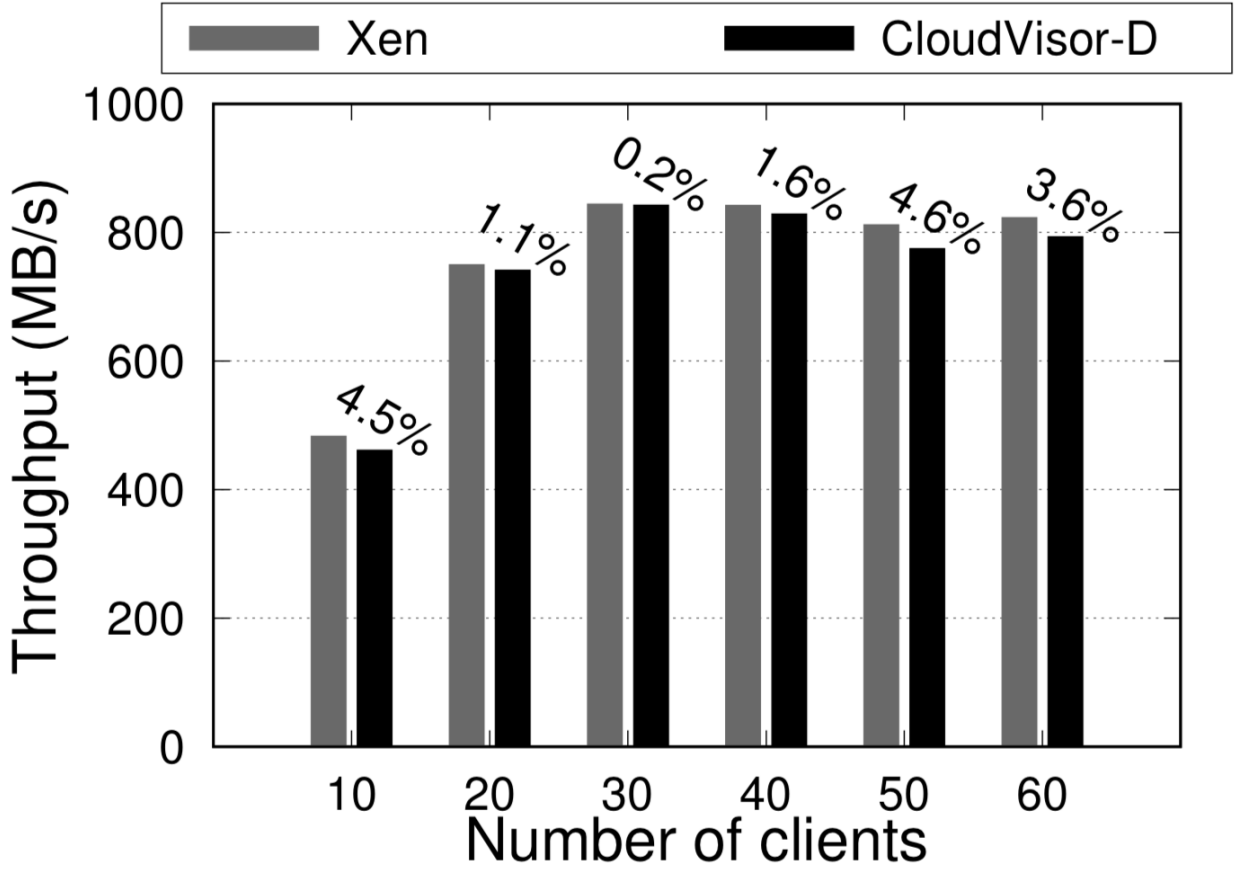


UP VM



SMP VM

dbench: I/O Performance



Conclusion

- **Today's cloud tenants are facing severe security threats**
- **A secure and efficient system to shield VM in untrusted clouds**
  - Disaggregated nested virtualization
  - Same level of security guarantee as nested virtualization
  - Introduce negligible overhead compared with the vanilla Xen

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Thanks!