IncognitOS

A Practical Unikernel Design for Full-System Obfuscation in Confidential Virtual Machines

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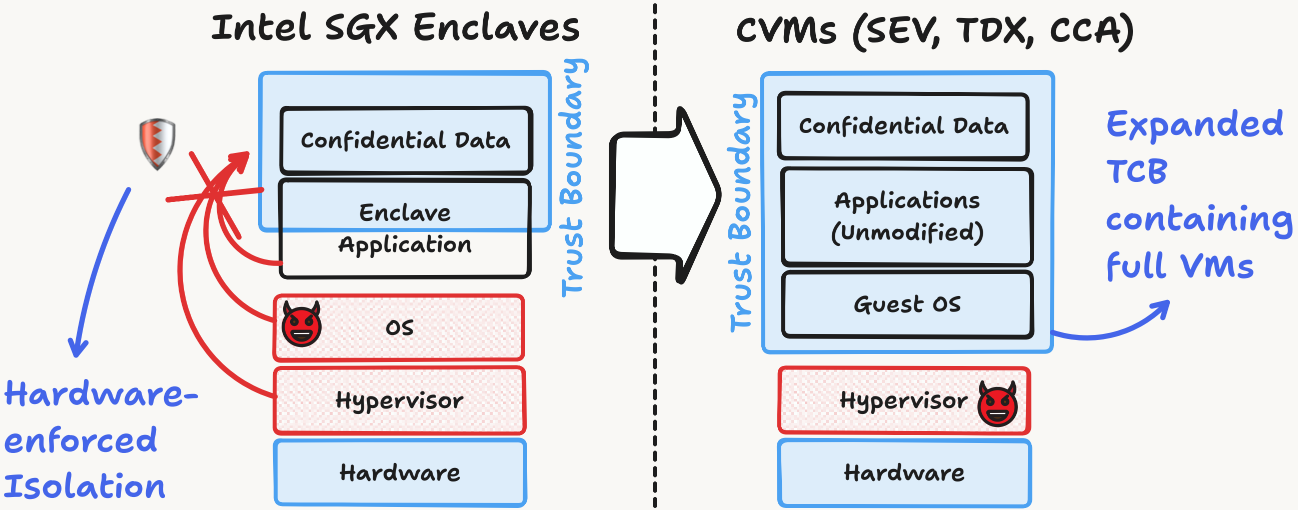
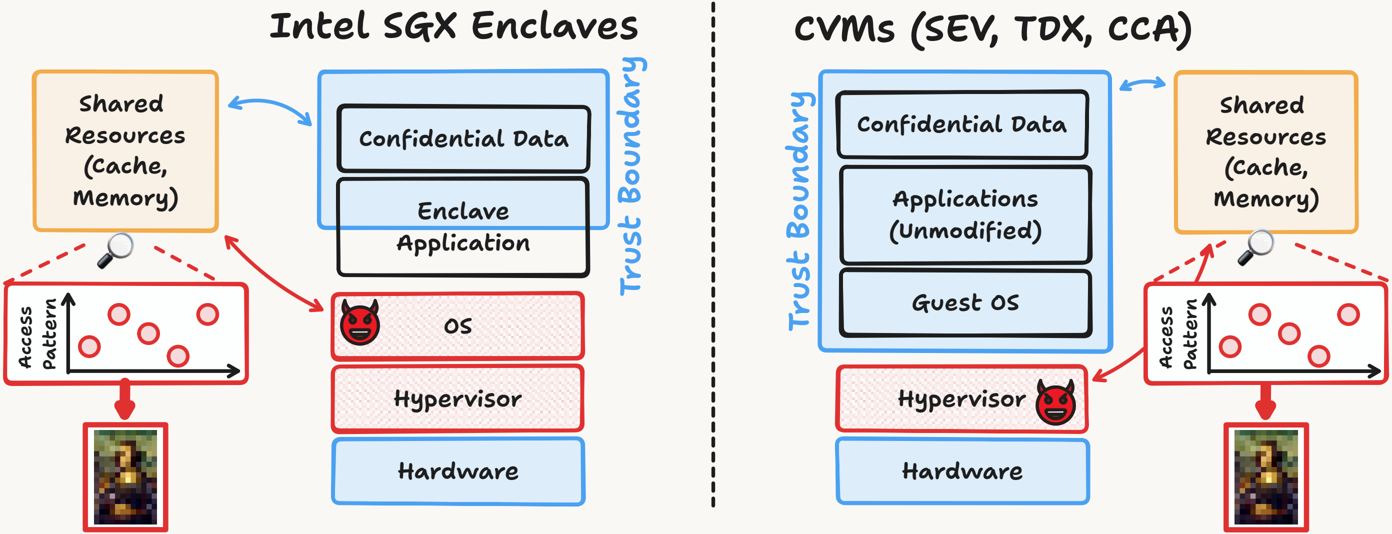
Today's Confidential Computing Landscape



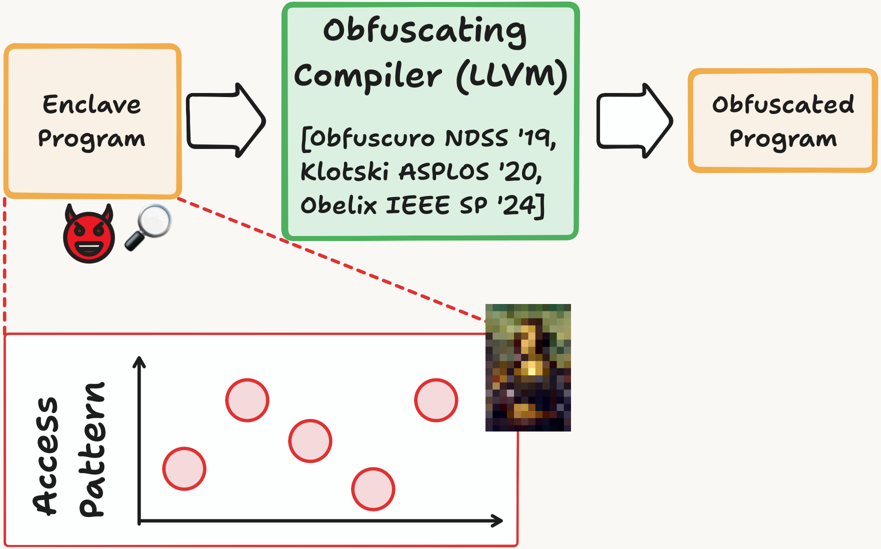
Shift from userspace enclaves to confidential virtual machines (CVMs)

Side-channel Attacks Against Trusted Execution



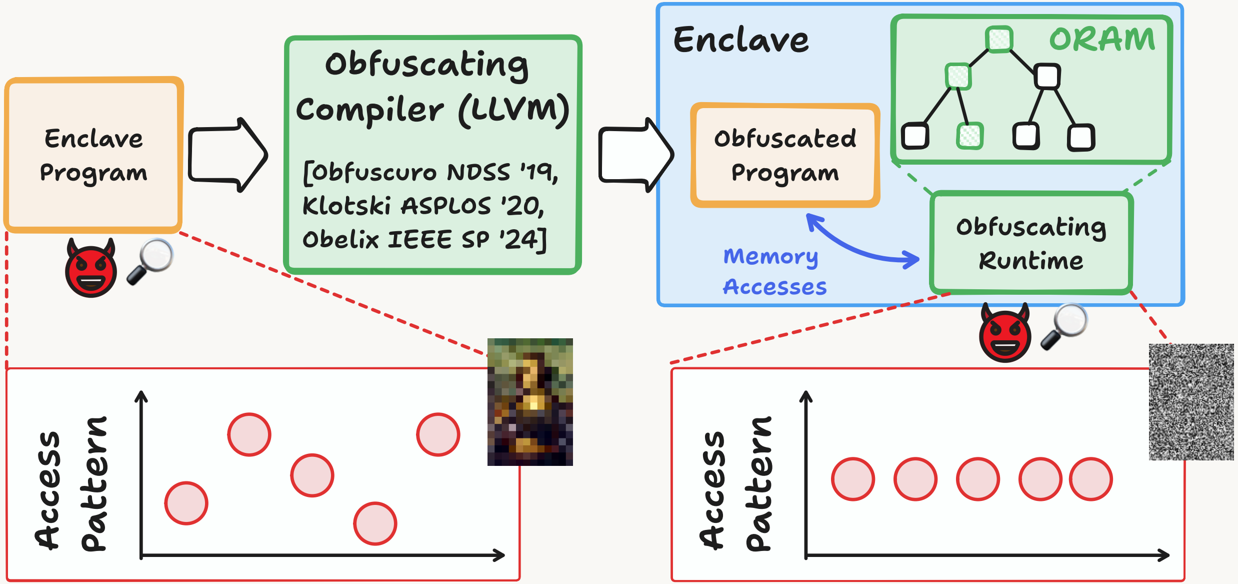
Side-channel attacks threaten enclaves and CVMs alike

Existing Defense: ***Obfuscation Engines***



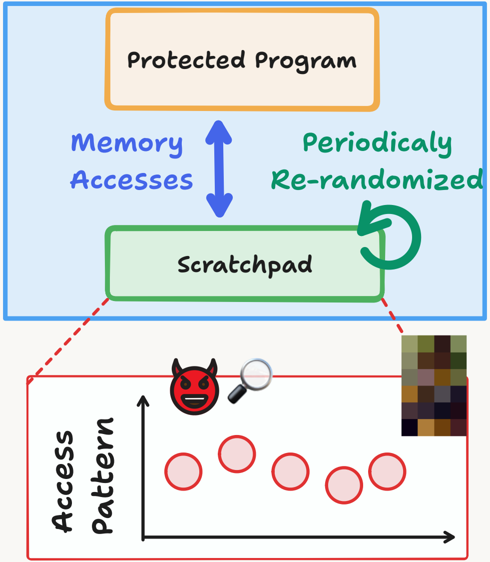
Workflows of obfuscation engines [1, 6, 7]

Existing Defense: ***Obfuscation Engines***



Workflows of obfuscation engines [1, 6, 7]

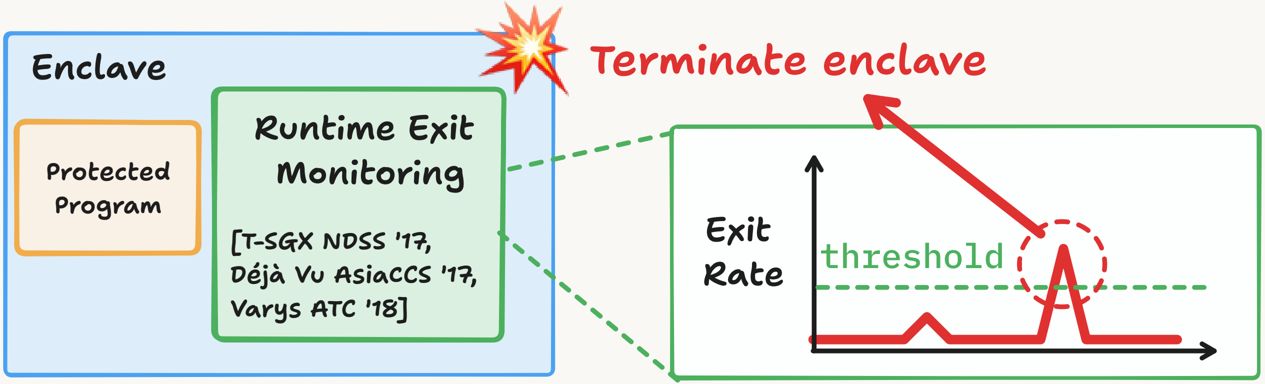
Existing Defense: ***Periodic Re-randomization***



- Strict obfuscation policies introduces prohibitively *high overheads* to protected programs
- *Periodic re-randomization* policies [2, 7] render obfuscation practical

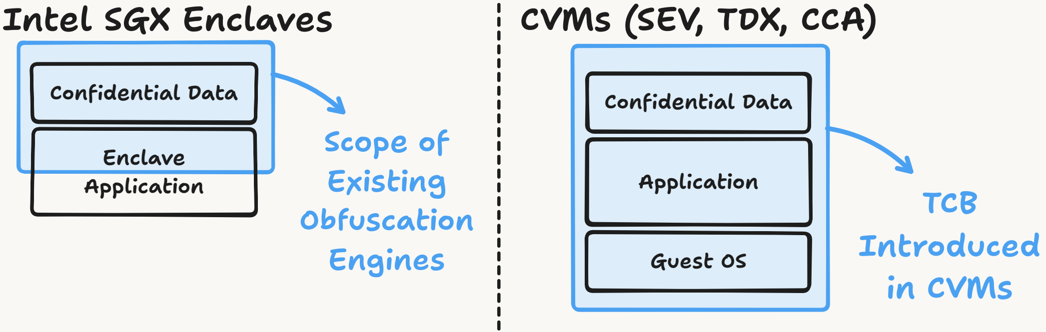
Existing Defense: ***Threshold-based Termination***

Observation: Most SGX attacks rely on *frequent enclave exits (AEXs)* (e.g., timer interrupts, page faults)



Threshold-based enclave termination[3–5]

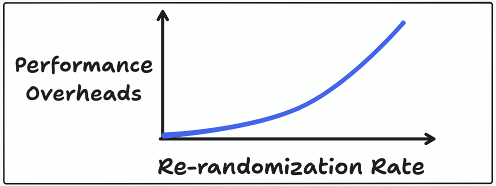
Challenges of CVMs Obfuscation: **Expanded TCB**



- Support for *full-VM protection* (guest OS + application) remains unsolved
- Potential *high overheads* with user + kernel obfuscation

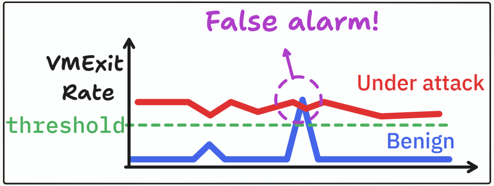
Policy-Wise Limitations

Fixed-rate Re-randomization



- Inherent *trade-offs* between *security* and *performance*

Threshold-based Termination



- *False-alarms* under normal CVM workloads

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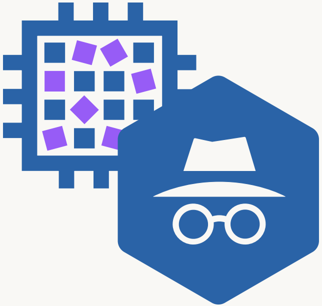
Introducing IncognitOS

IncognitOS is a design for practical full-VM obfuscation of CVM workloads



Full-VM Obfuscation

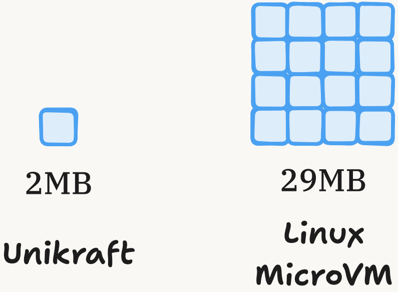
- Embrace *unikernels* as a foundation for OS-level design

Policy Enhancement

- Advance existing policies with an *adaptive obfuscation* strategy

Why Unikernel?

- **Reduced memory footprint**
  → feasible full-system memory randomization
- **No user-kernel separation**
  → efficient accesses to hardware (MMU) and kernel subsystems



Memory footprint of Unikraft unikernel vs. Linux MicroVMs[1]

1: https://unikraft.org/docs/concepts/performance

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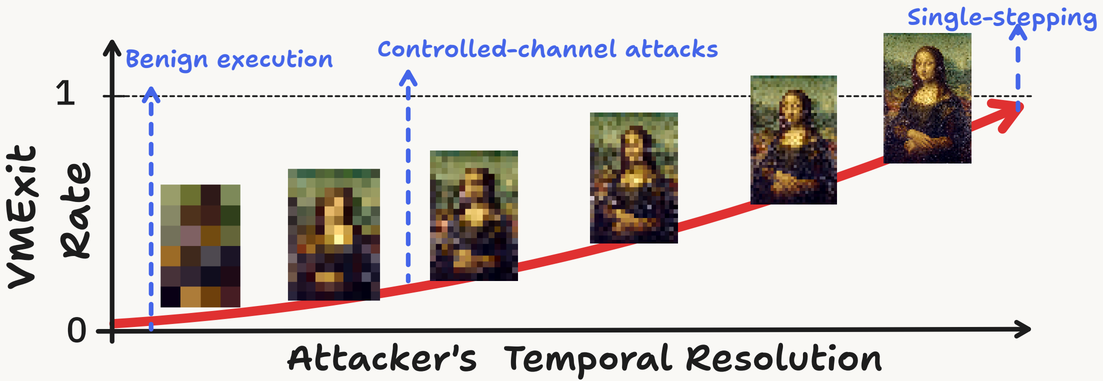
Adaptive Obfuscation

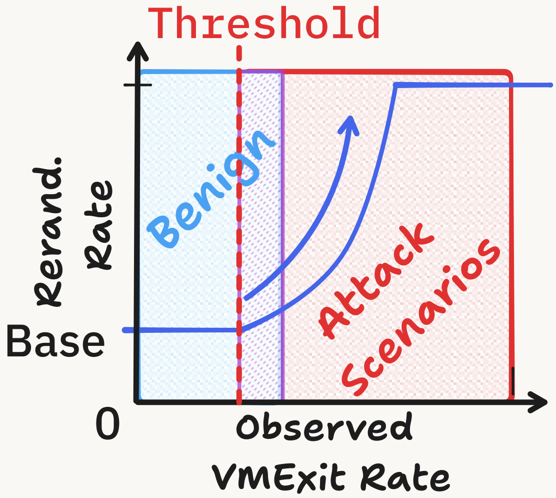
***Key idea:** Adapt memory randomization rate based on VMExit rate measurements.*



Adaptive Obfuscation

An *immune system* against side-channel attacks

- 🙂 **Normal**: Uses sane randomization rate & proactively looks for threats
- 😡 **Threat detected**: Schedules defense (re-randomizations) based on threat level



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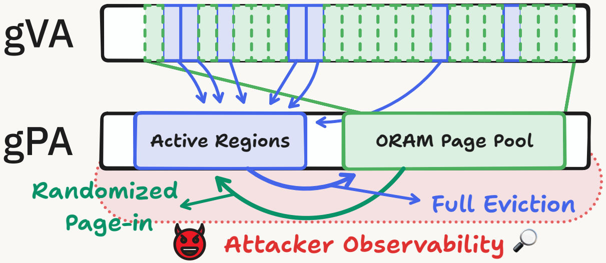
Kernel Subsystems Enforcing Adaptive Defense

Scheduling

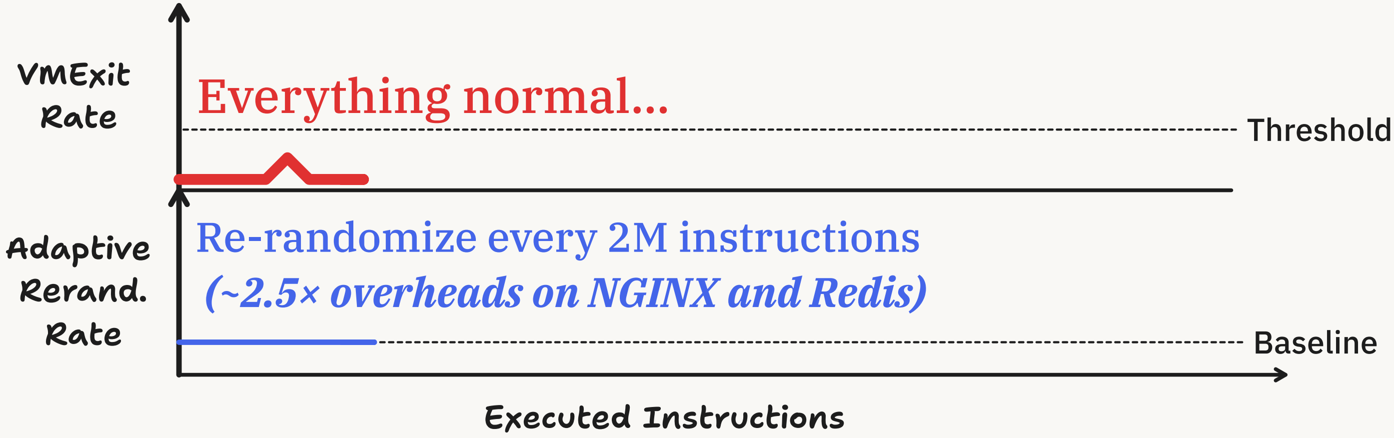
- Samples current VMExit rate *independently of untrusted interrupts* through static binary instrumentation

Paging

- Transparently randomizes physical memory using OS-level access to *hardware MMU*



Visualization of Adaptive Obfuscation in Action



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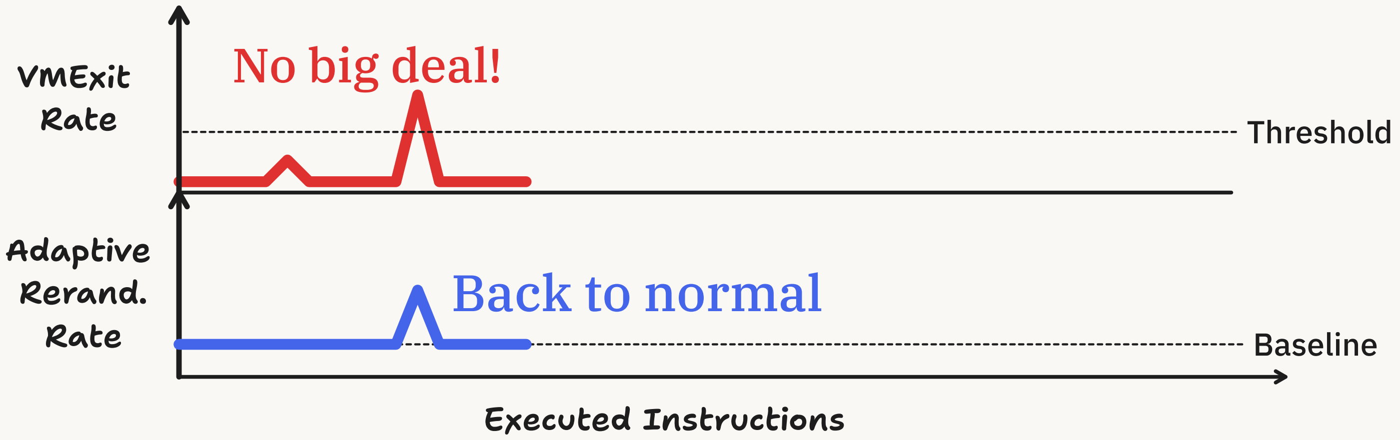

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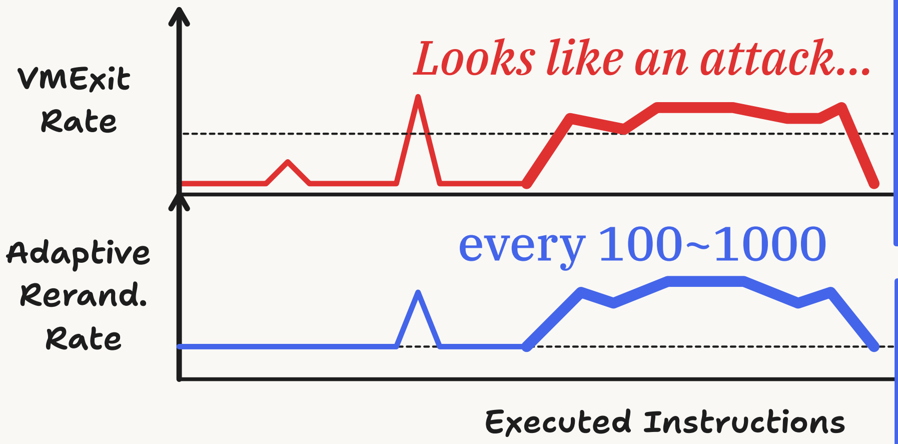

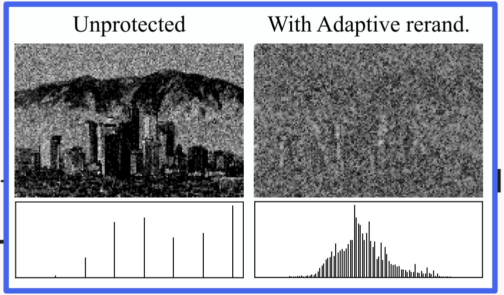

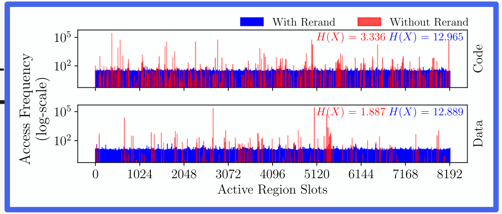

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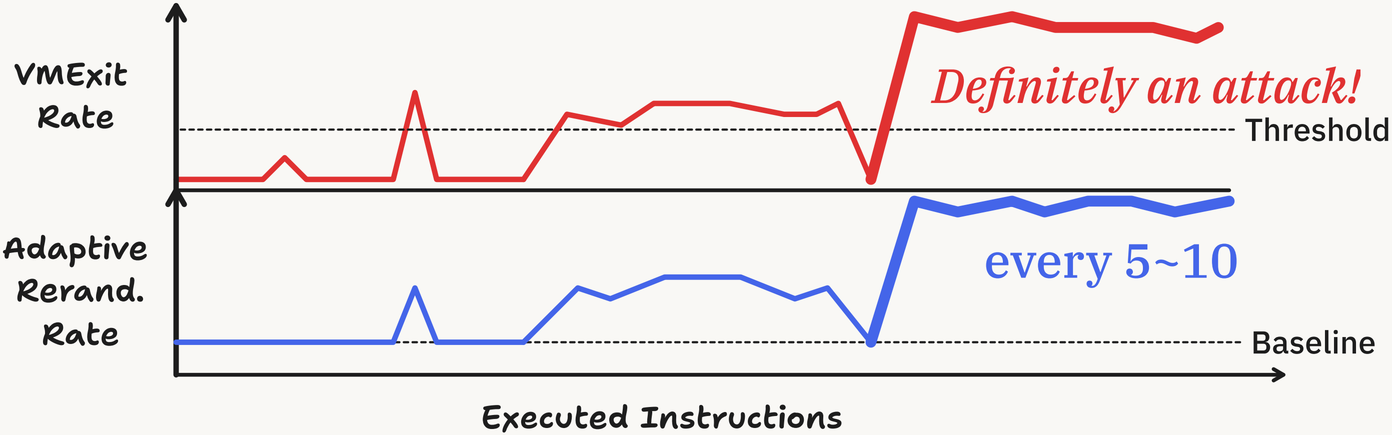

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The End

- Check out the paper for more details, e.g.,
  - Kernel subsystems inner working
  - Implementation based on AMD SEV-SNP CVMs and Unikraft unikernel
  - Detailed evaluations and security analysis
- ❓ Got questions? Meet me at the poster session.

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Job Hunt

- I am expected to finish my Ph.D. later this year
- Looking for a *postdoc or industry* position in *system security*
- Had experiences in *operating systems, TEEs, software compartmentalization* and *software security*

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References

[1] Ahmad, A. et al. 2019. OBFUSCURO: A Commodity Obfuscation Engine on Intel SGX. *Proceedings 2019 Network and Distributed System Security Symposium* (San Diego, CA, 2019).
[2] Brasser, F. et al. 2019. DR.SGX: Automated and adjustable side-channel protection for SGX using data location randomization. *Proceedings of the 35th Annual Computer Security Applications Conference* (San Juan Puerto Rico USA, Dec. 2019), 788–800.
[3] Chen, S. et al. 2017. Detecting Privileged Side-Channel Attacks in Shielded Execution with Déjà Vu. *Proceedings of the 2017 ACM on Asia Conference on Computer and Communications Security* (New York, NY, USA, Apr. 2017), 7–18.
[4] Oleksenko, O. et al. 2018. Varys: Protecting {}SGX{} Enclaves from Practical {}Side-Channel{} Attacks. *2018 USENIX Annual Technical Conference (USENIX ATC 18)* (2018), 227–240.
[5] Shih, M.-W. et al. 2017. T-SGX: Eradicating Controlled-Channel Attacks Against Enclave Programs. *Proceedings 2017 Network and Distributed System Security Symposium* (San Diego, CA, 2017).
[6] Wichelmann, J. et al. 2024. Obelix: Mitigating Side-Channels through Dynamic Obfuscation. *2024 IEEE Symposium on Security and Privacy (SP)* (Los Alamitos, CA, USA, May 2024), 189–189.
[7] Zhang, P. et al. 2020. Klotski: Efficient Obfuscated Execution against Controlled-Channel Attacks. *Proceedings of the Twenty-Fifth International Conference on Architectural Support for Programming Languages and Operating Systems* (New York, NY, USA, Mar. 2020), 1263–1276.