Heterogeneous Isolated Execution for Commodity GPUs

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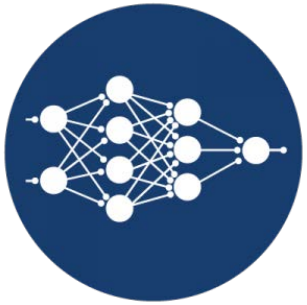
Architecture Trend: Heterogeneous Computing

- Heterogeneous computing is emerging (**GPUs**, FPGAs, etc)



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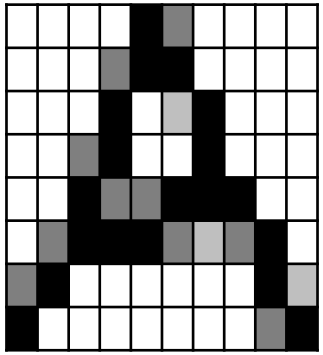

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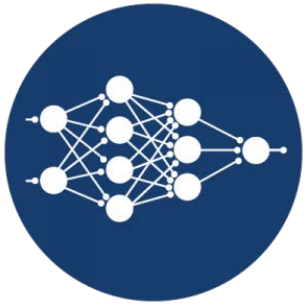

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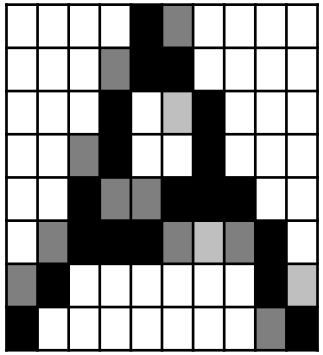

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Untrusted Kernel Space

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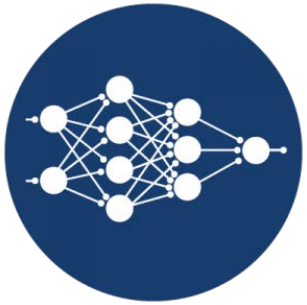

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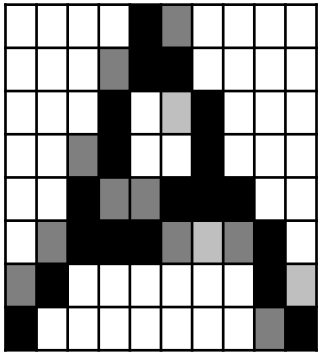

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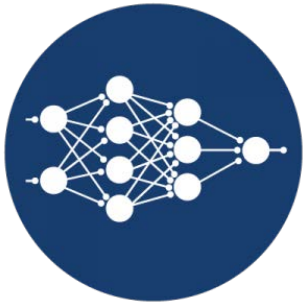

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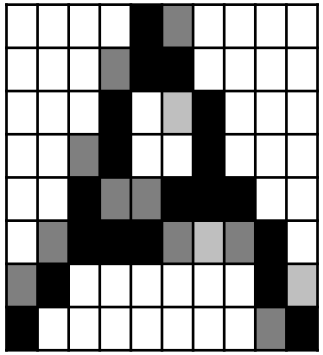

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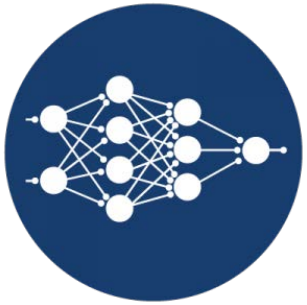

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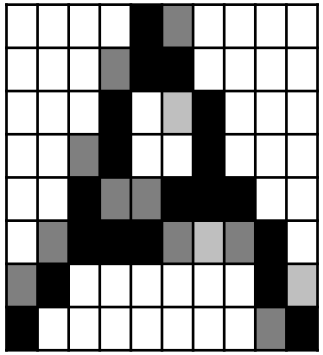

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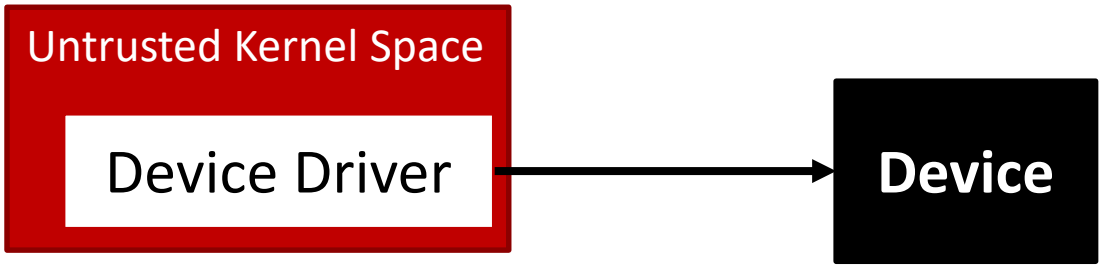

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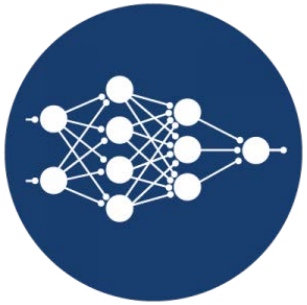

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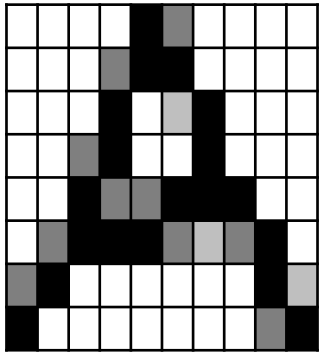

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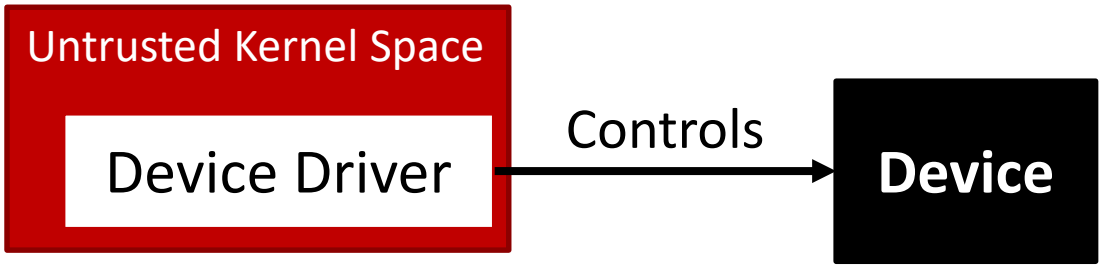

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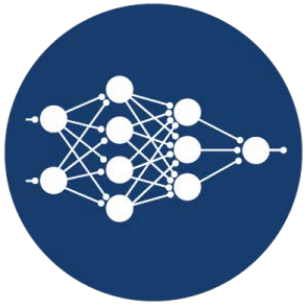

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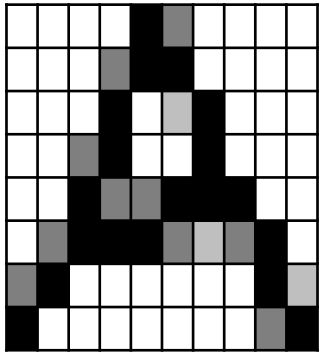

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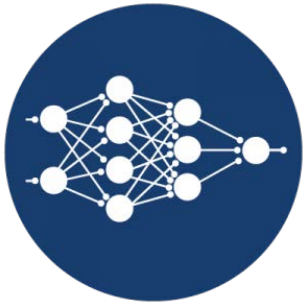

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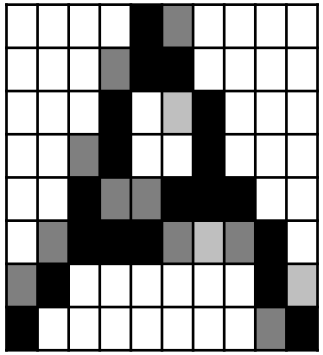

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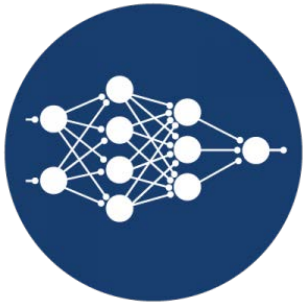

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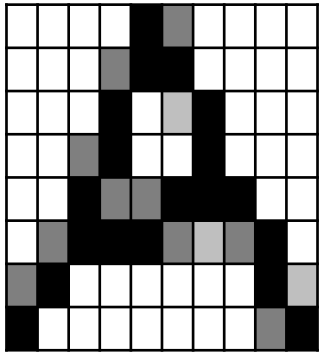

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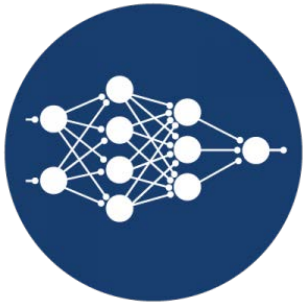

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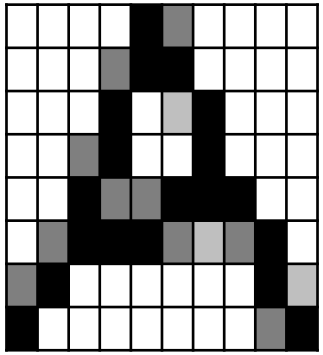

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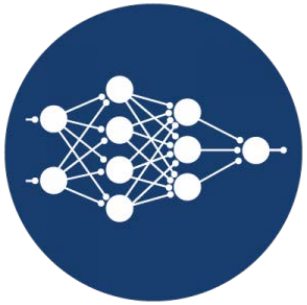

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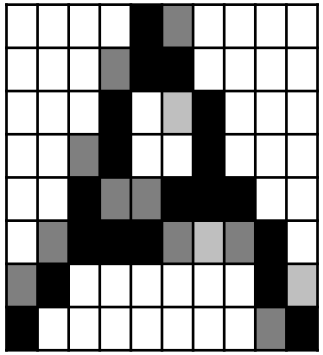

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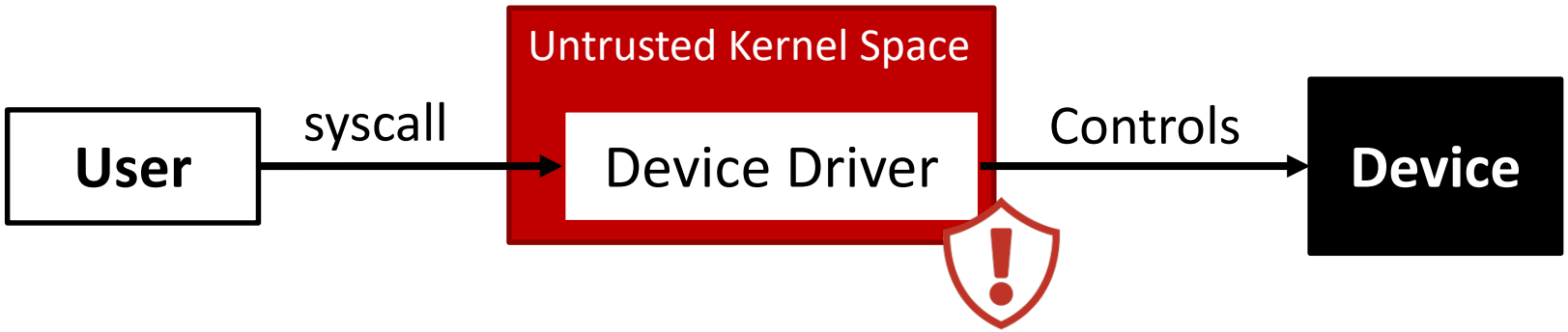

How to Provide TEE to Devices?

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  - **Graviton** [Volos, OSDI'18]: use **a modified GPU** with a root of trust

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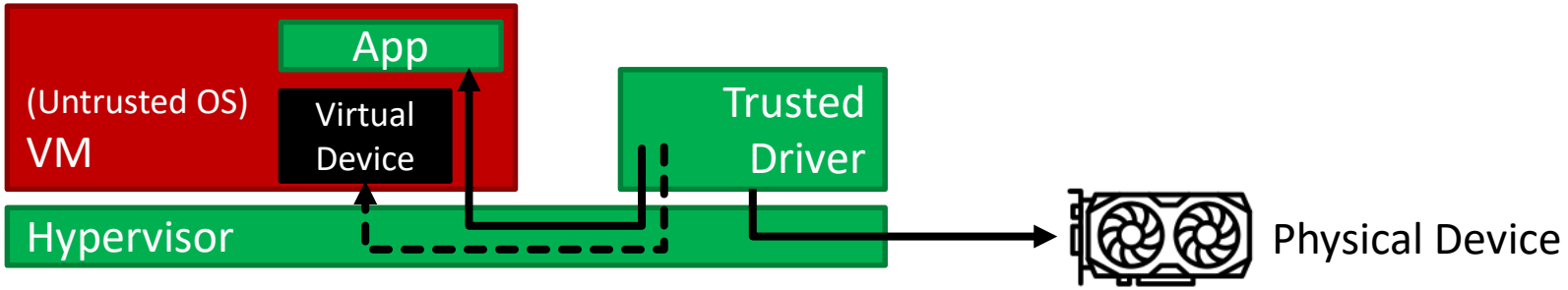

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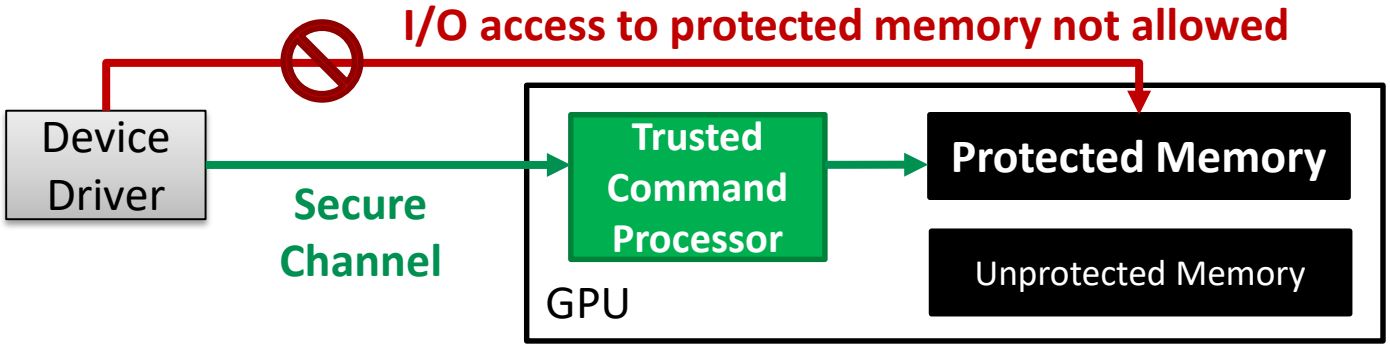

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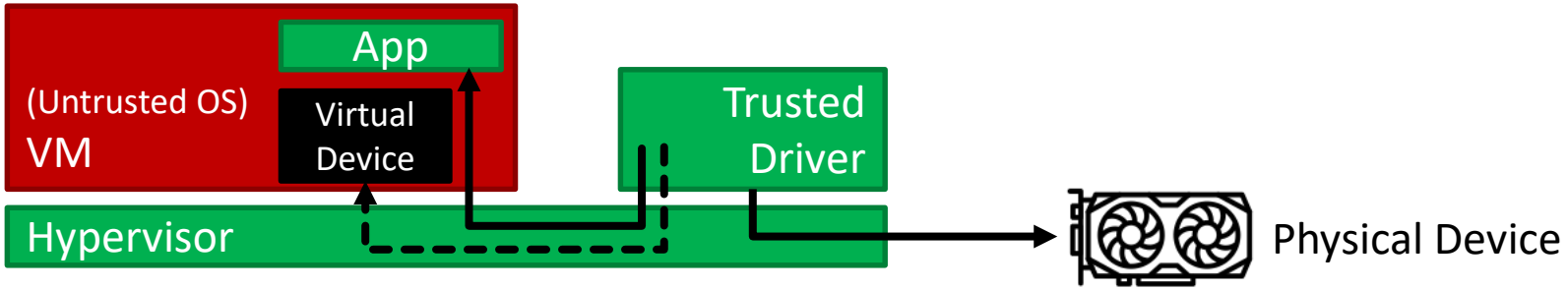

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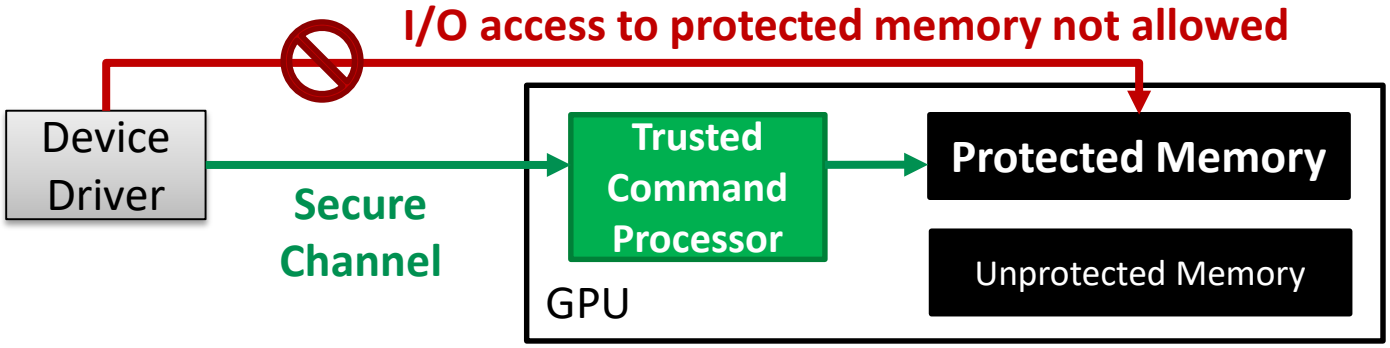
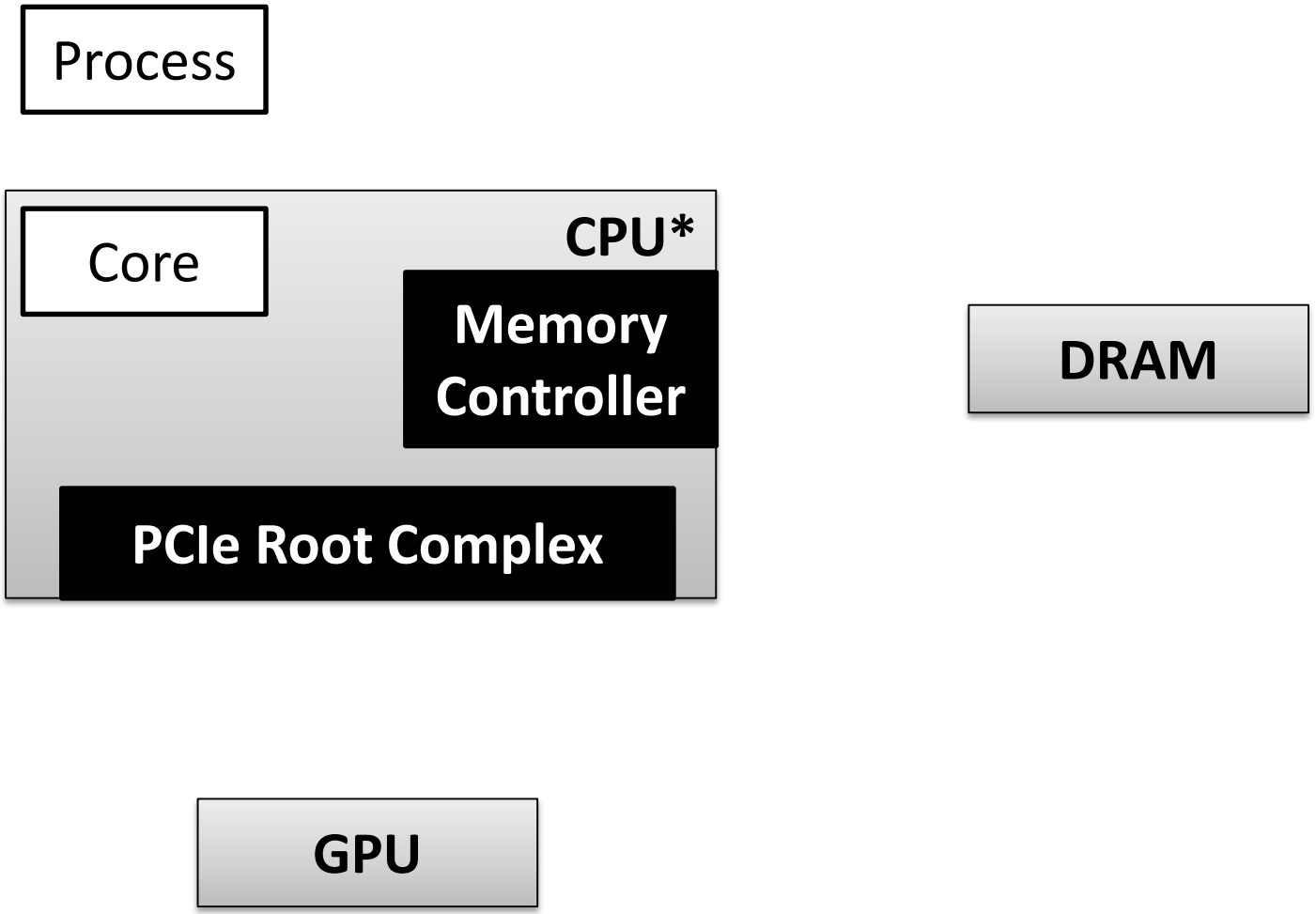


Our Apporach: Securing I/O Path

- All device I/O accesses from software are **handled by CPU**



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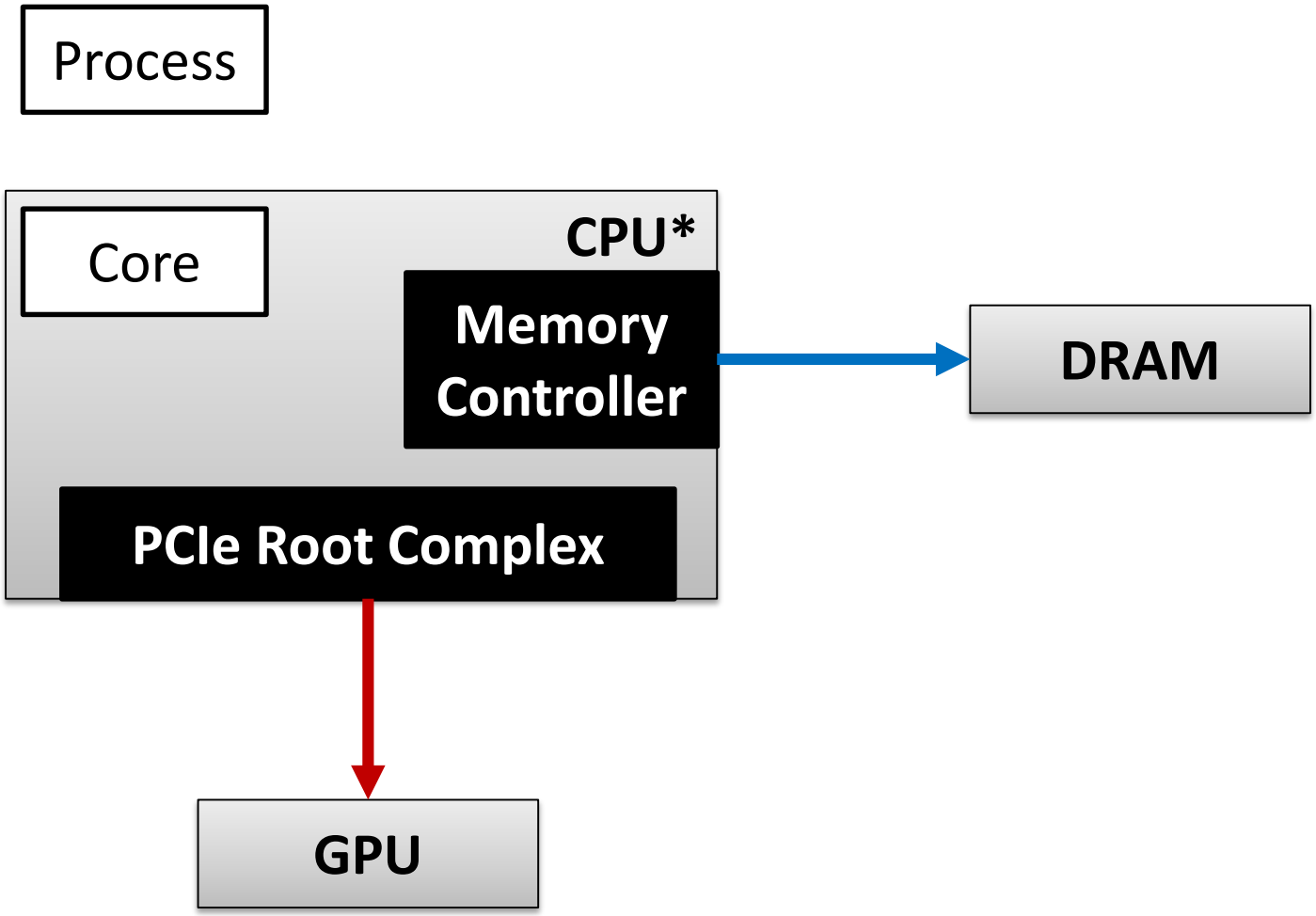

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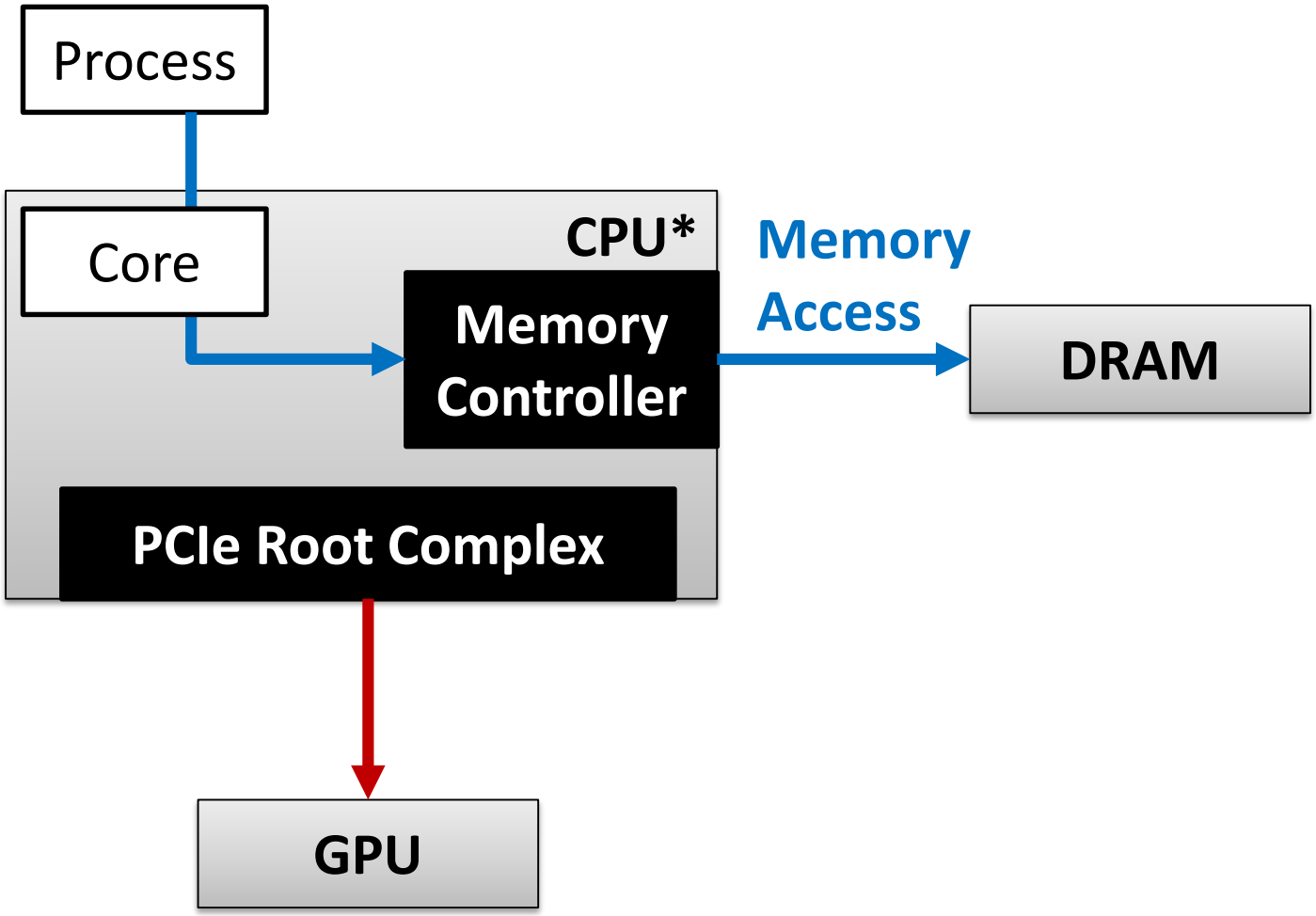

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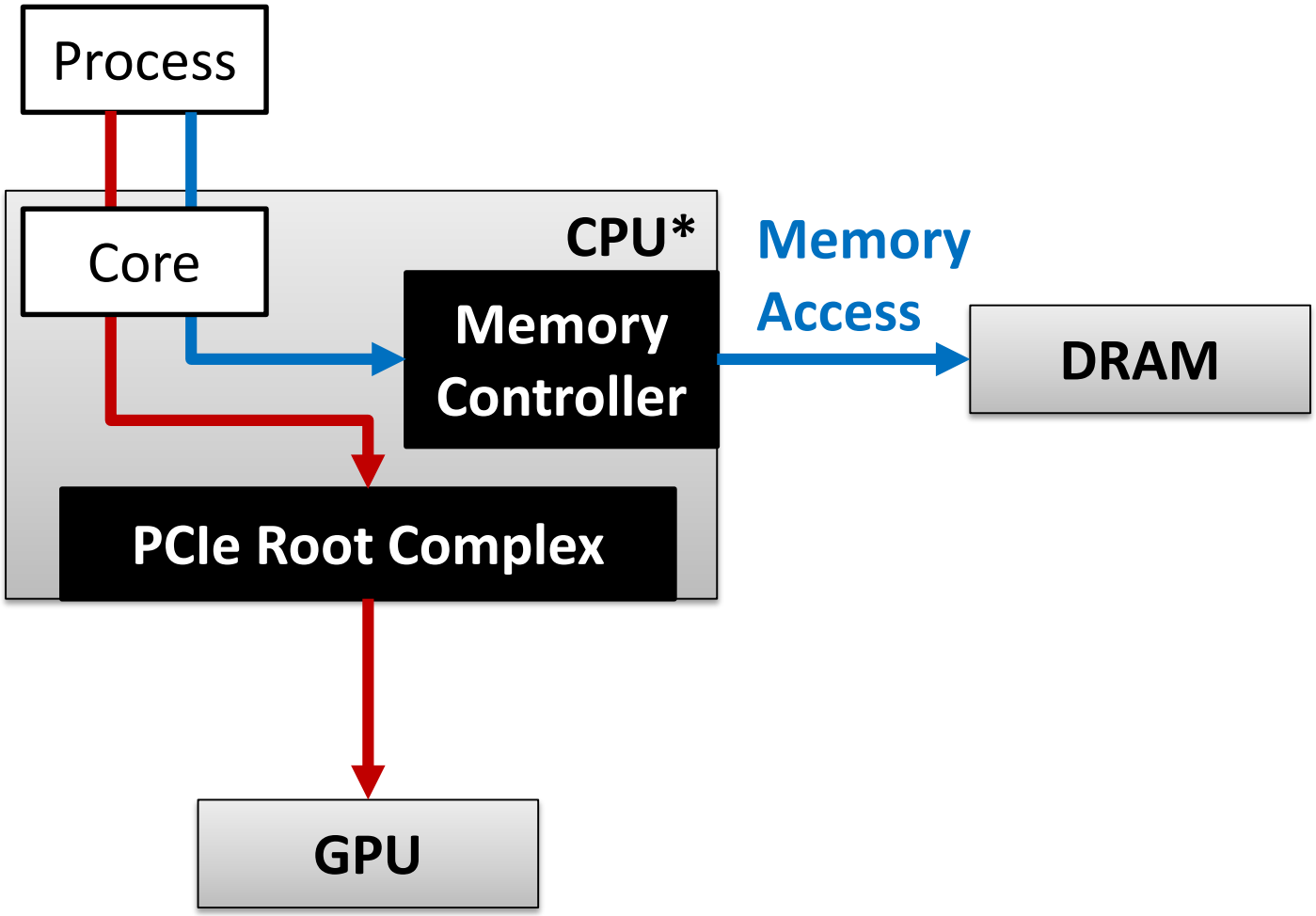

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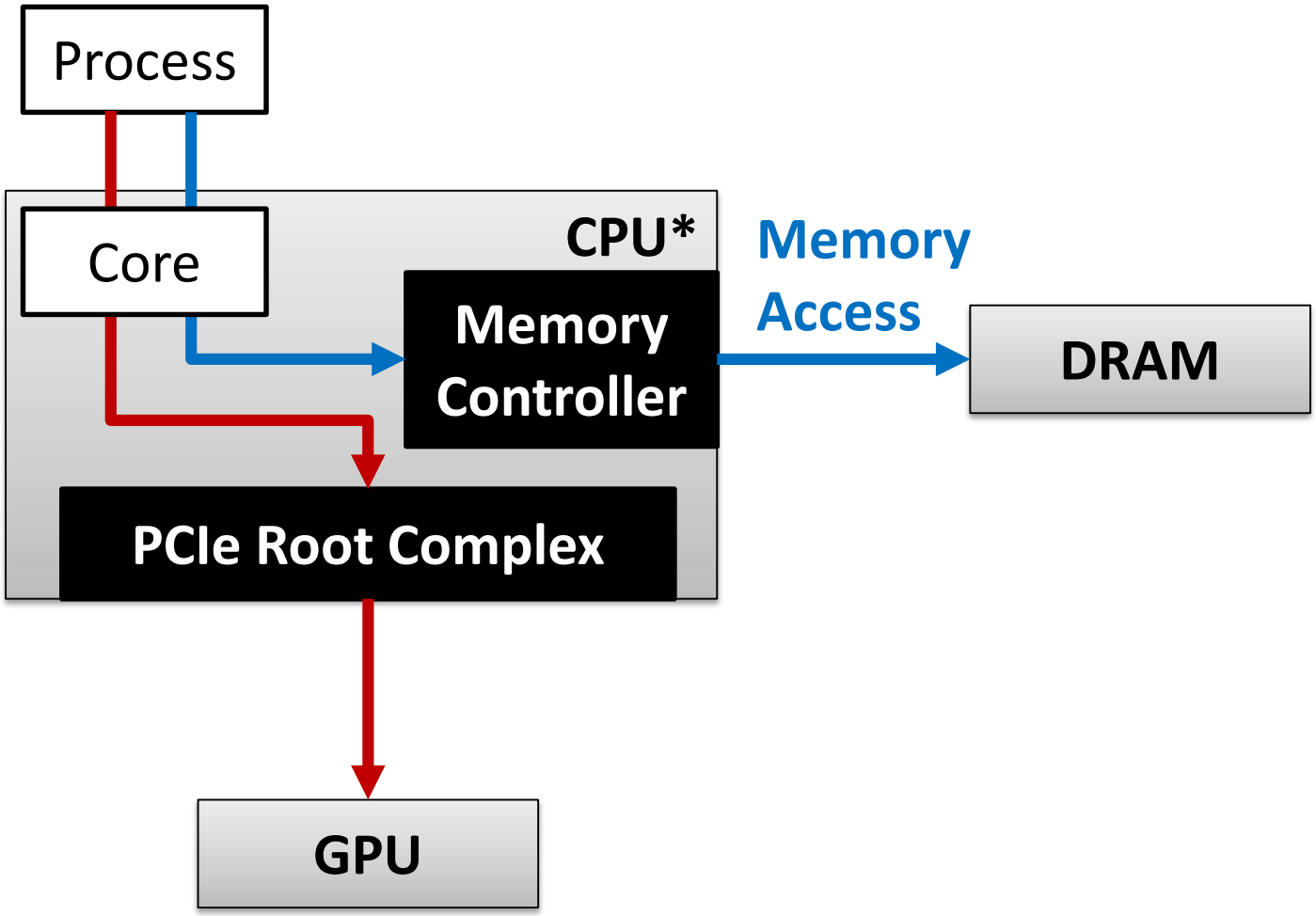

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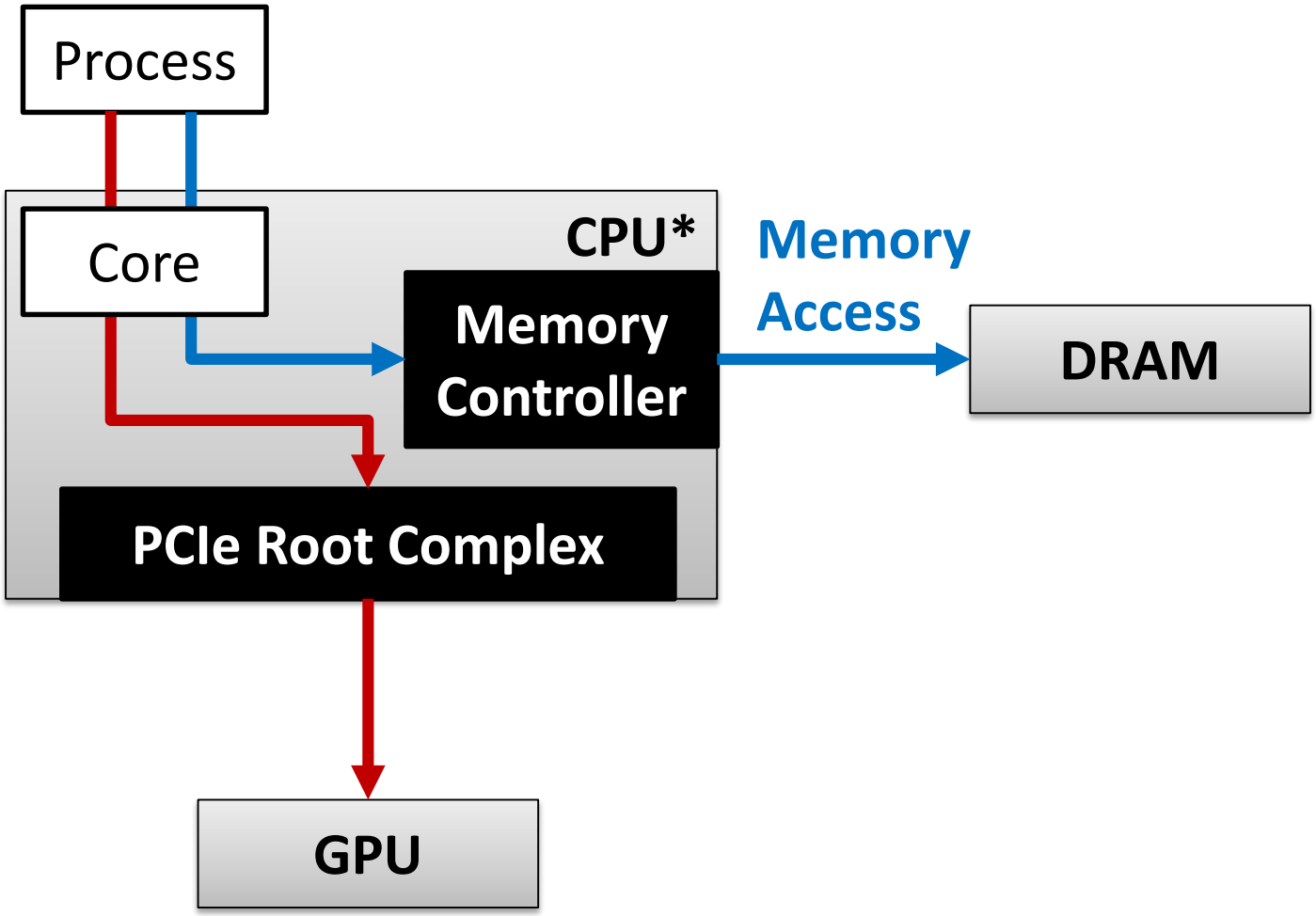

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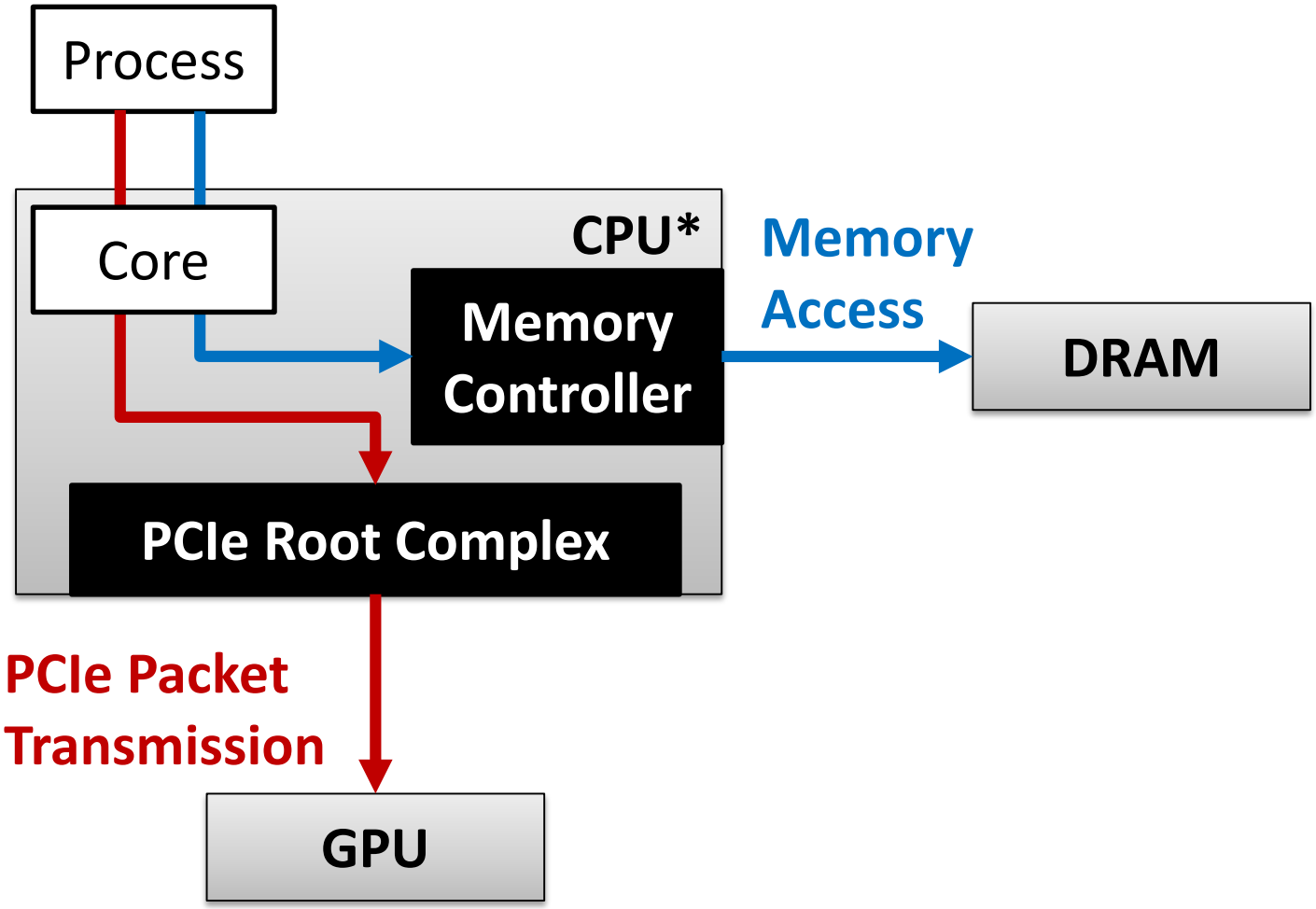

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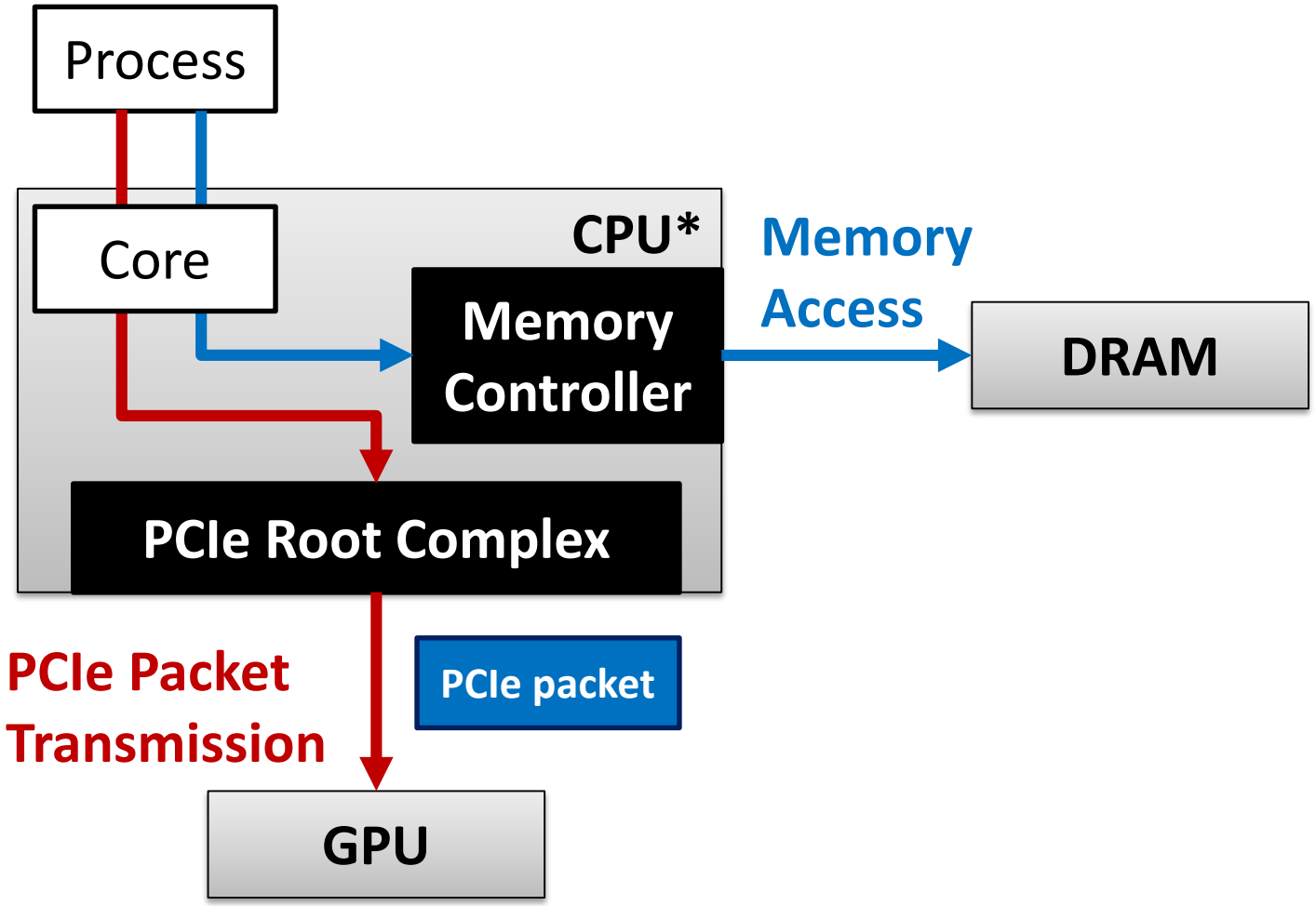

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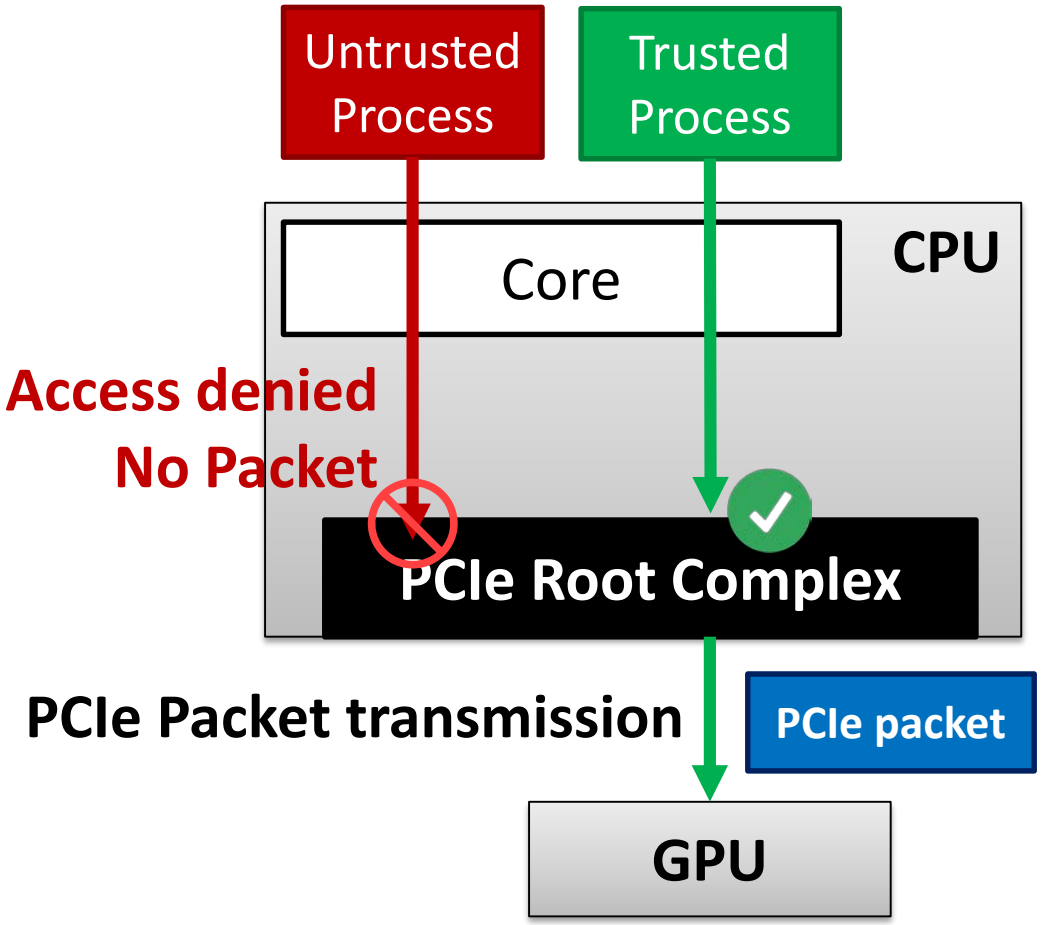
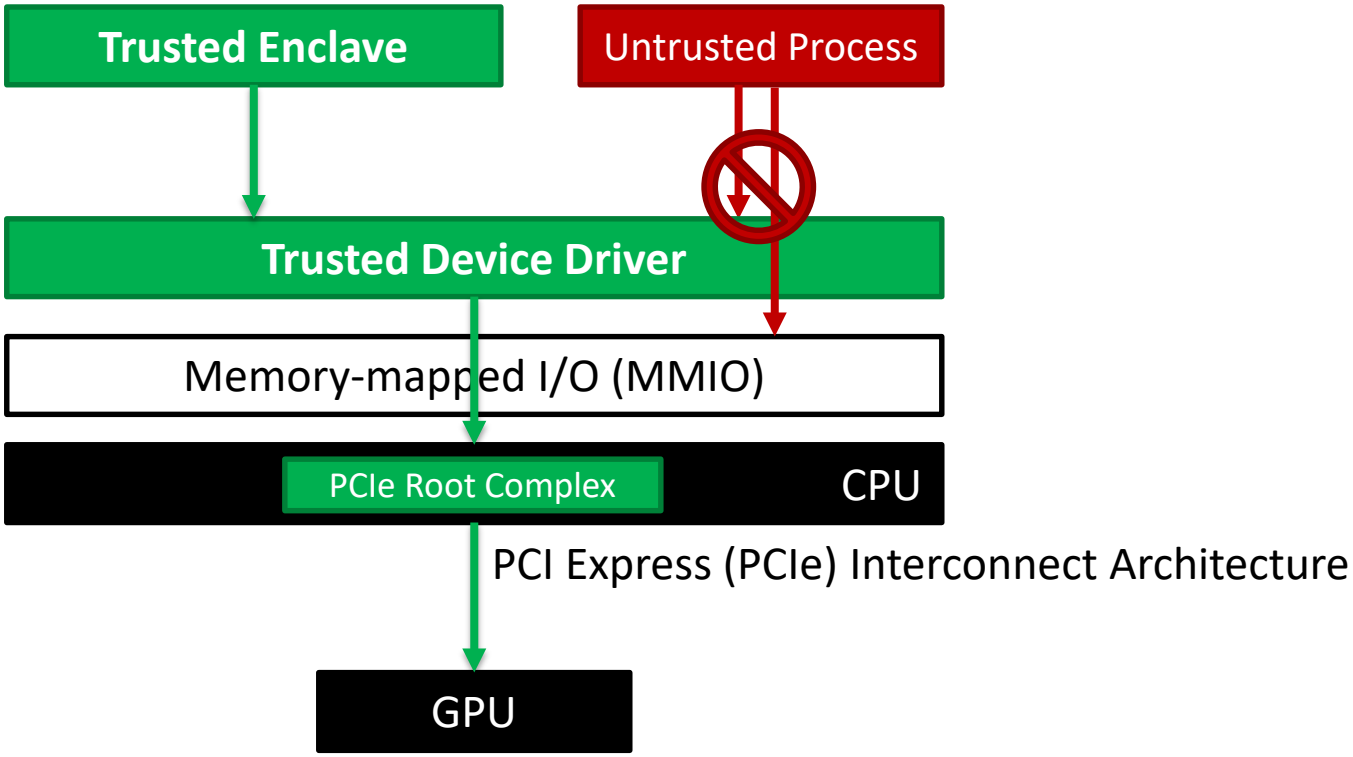


Idea: Prevent I/O from Attackers by Securing I/O Path!

HIX: Heterogeneous Isolated Execution



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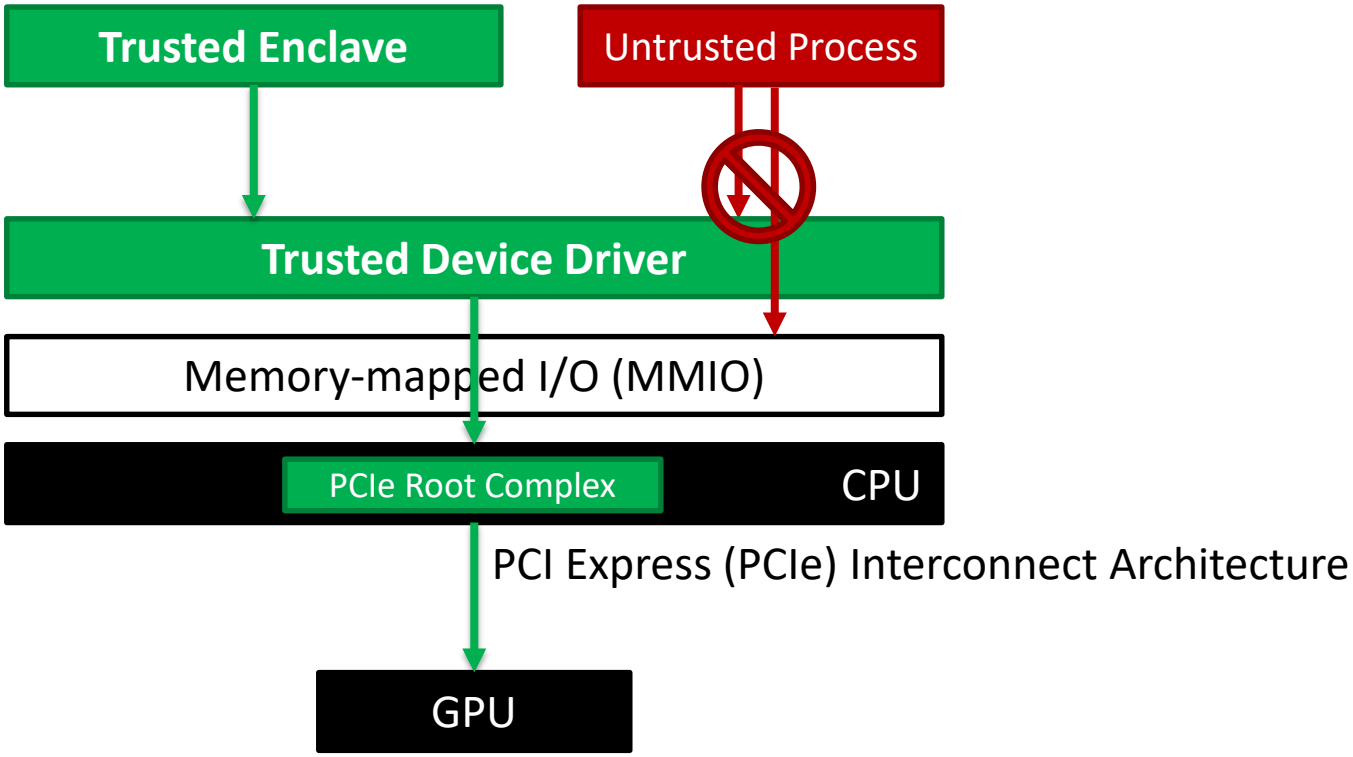

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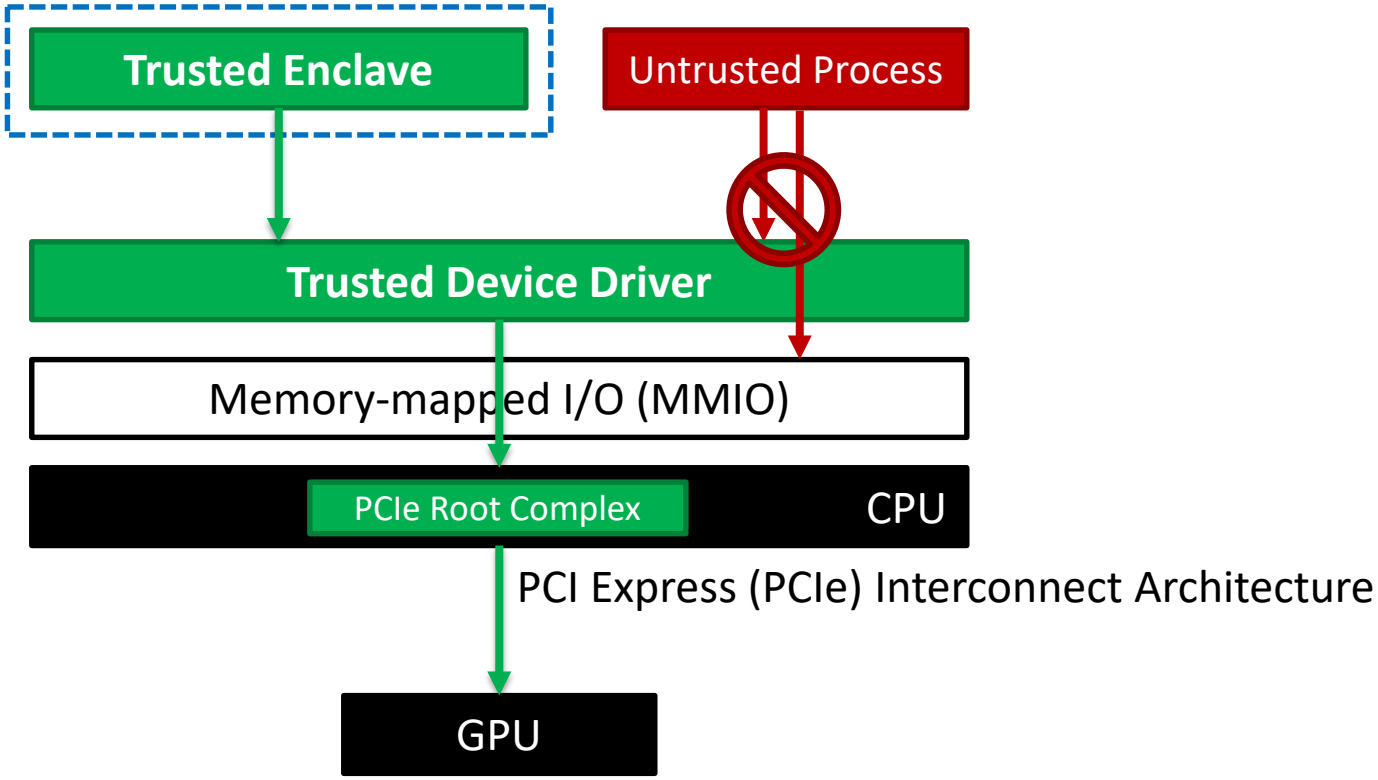

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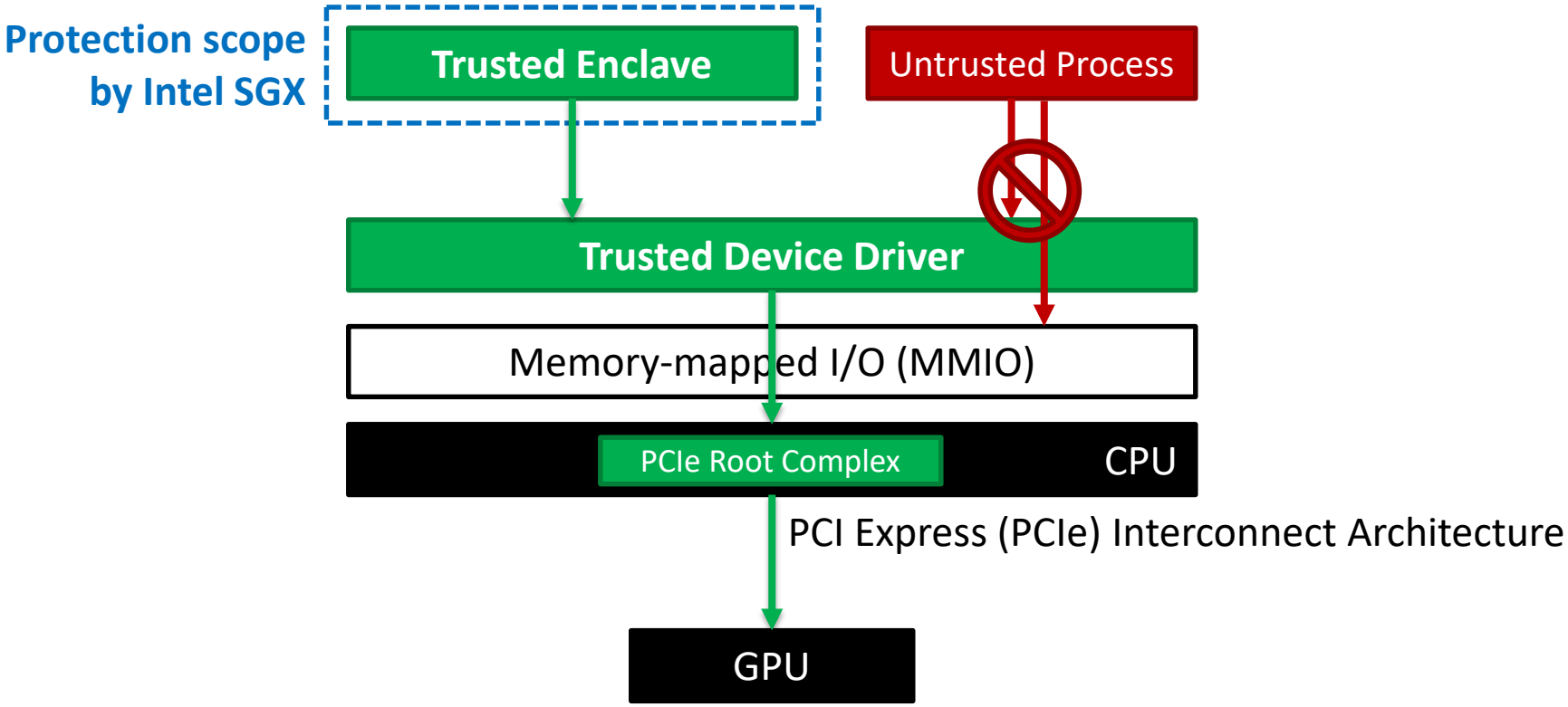

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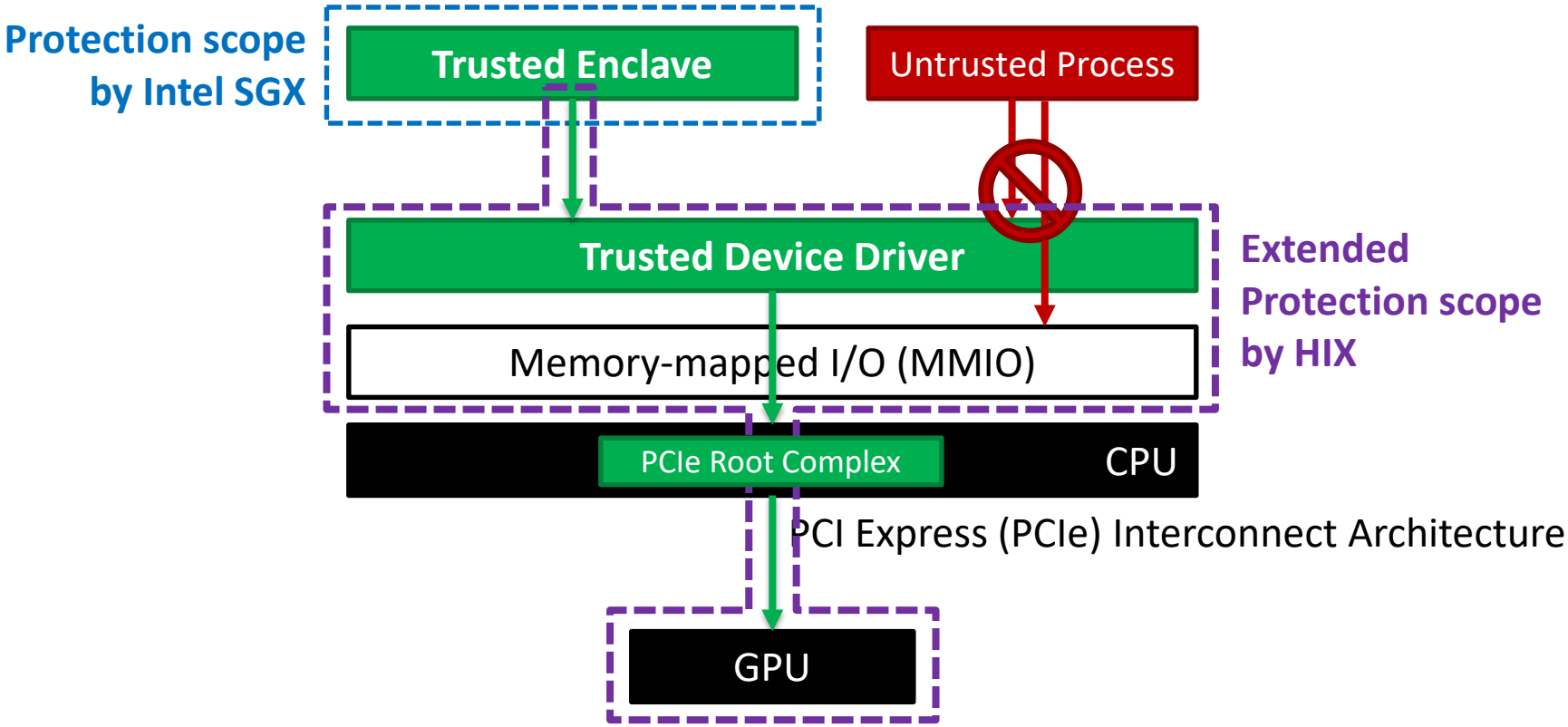

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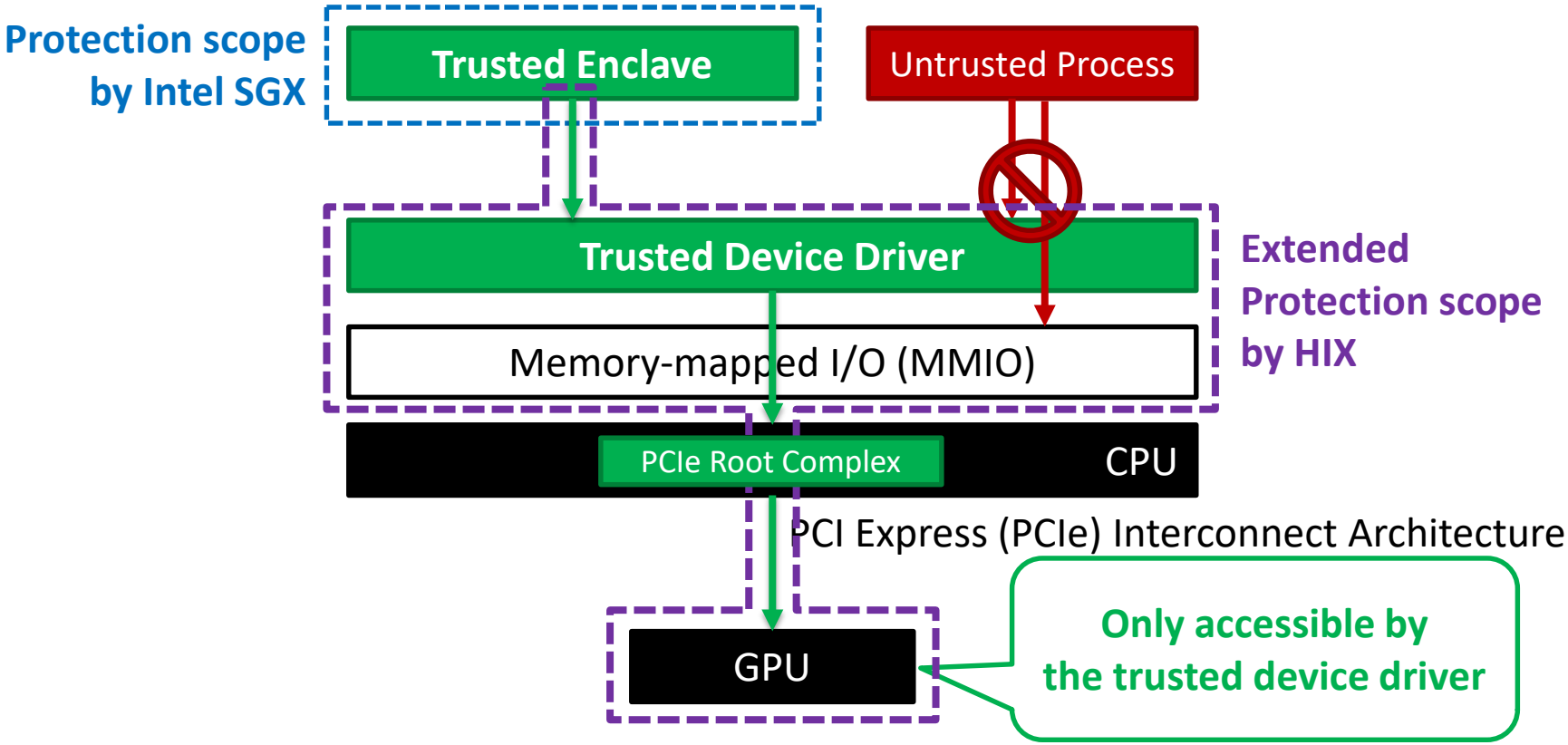

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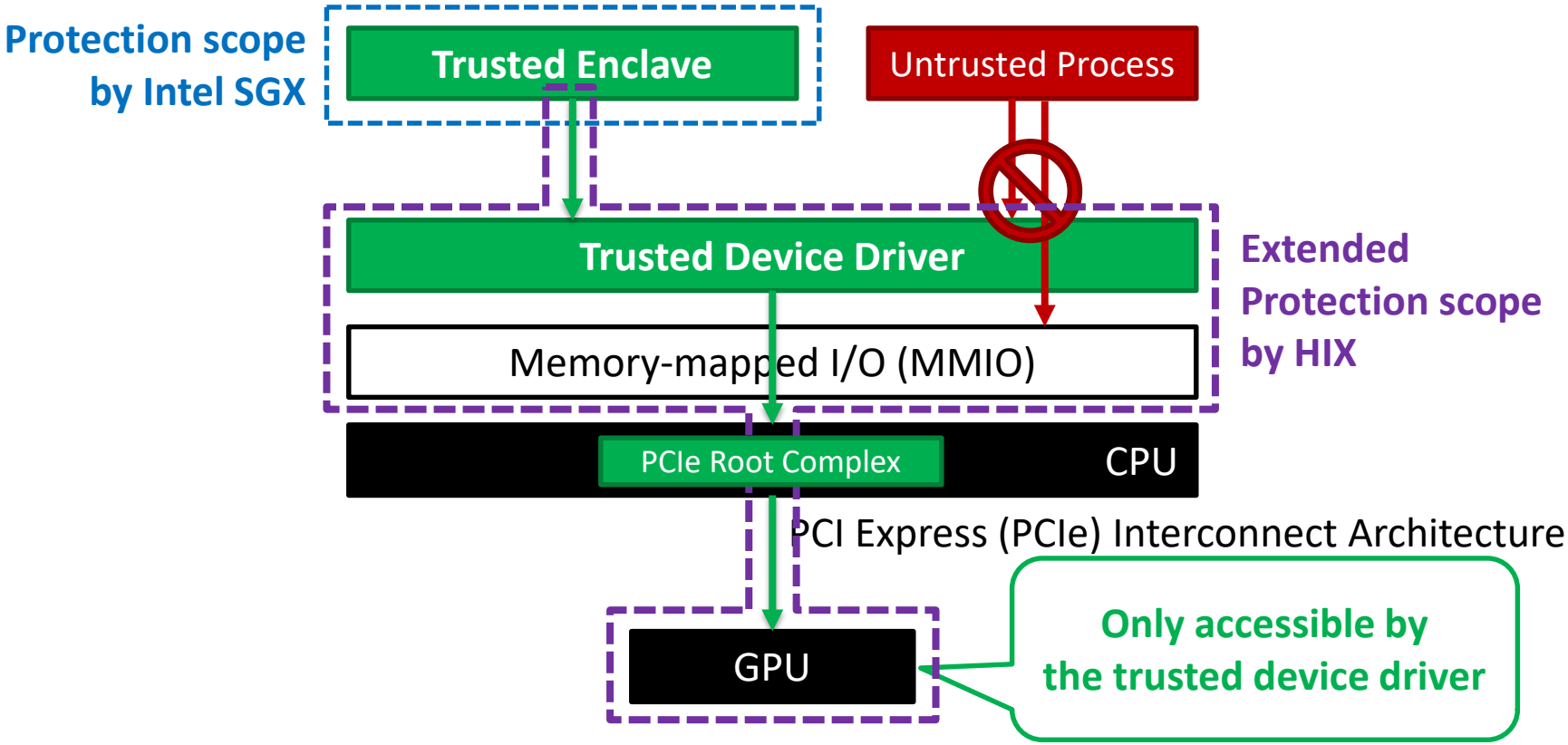

Contributions and Threat Model

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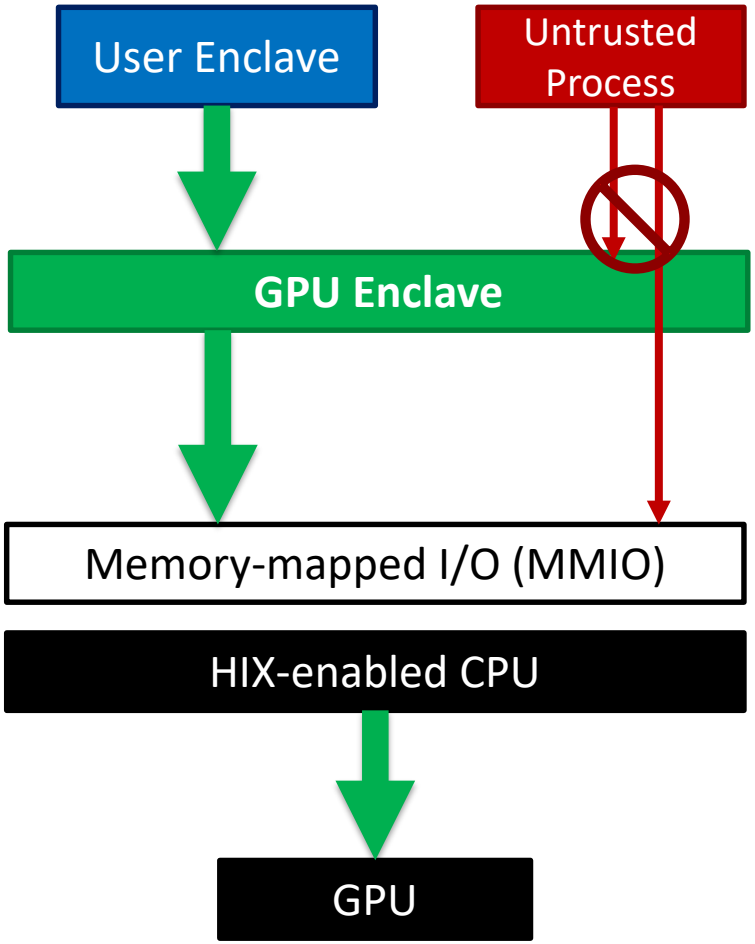
- Provide **confidentiality and integrity** to user data in GPU
- **No GPU modifications** are required
  - Provide GPU TEE by securing I/O path
  - No protection against physical attacks; software based attacks prevented
- **Threat Model**
  - Attackers have all privileged permission on software level
  - Not consider physical attacks on any hardware
  - **Protect the system from privileged software attacks**

HIX Architecture

- Trusted GPU Device Driver: GPU Enclave
- MMIO Protection
- Inter-Enclave Communication

HIX: Architecture Overview

- : Three communication paths to be protected



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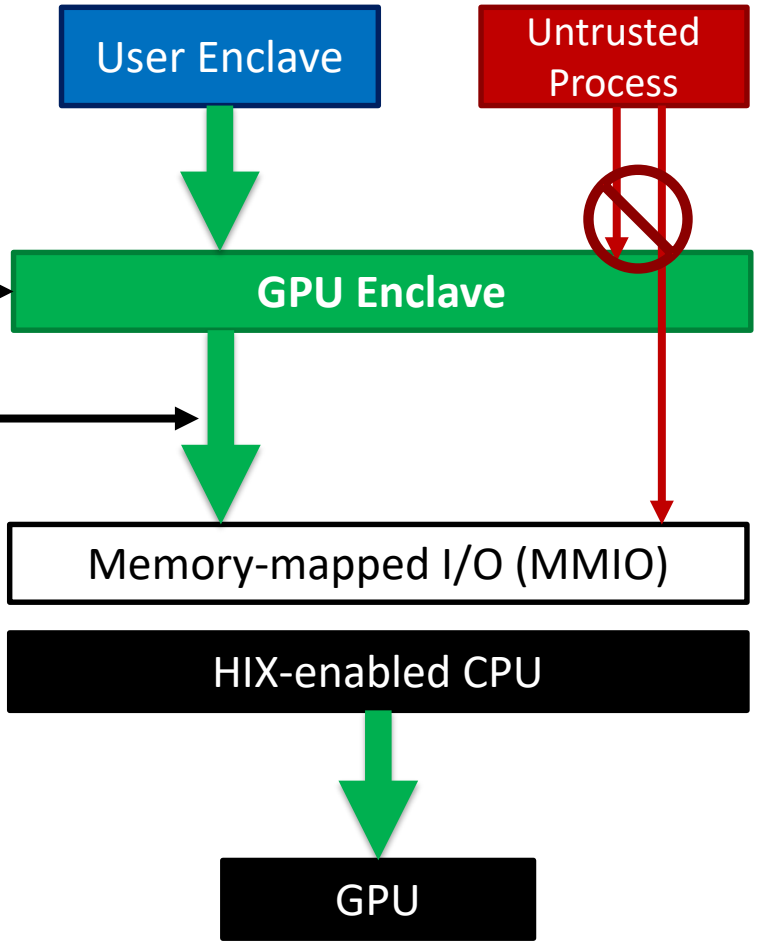
: Three communication paths to be protected

- Inter-enclave communication
- Trusted GPU device driver
- MMIO access validation
- Guaranteed PCIe packet routing



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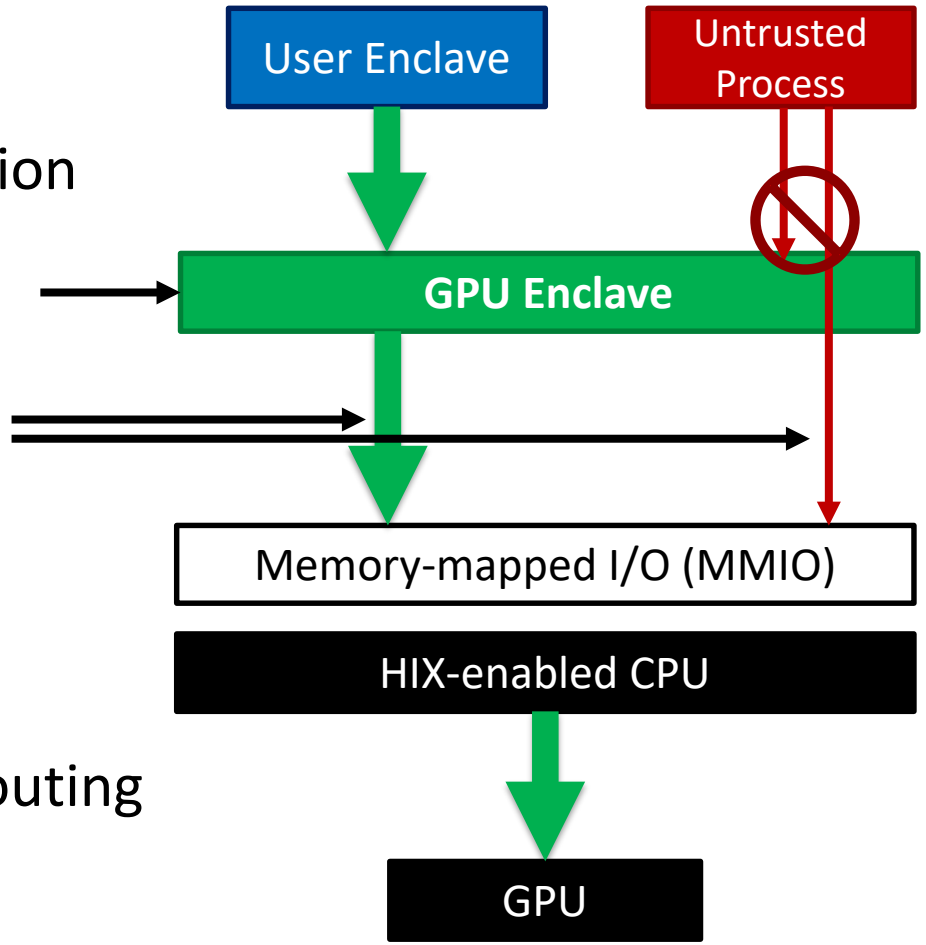

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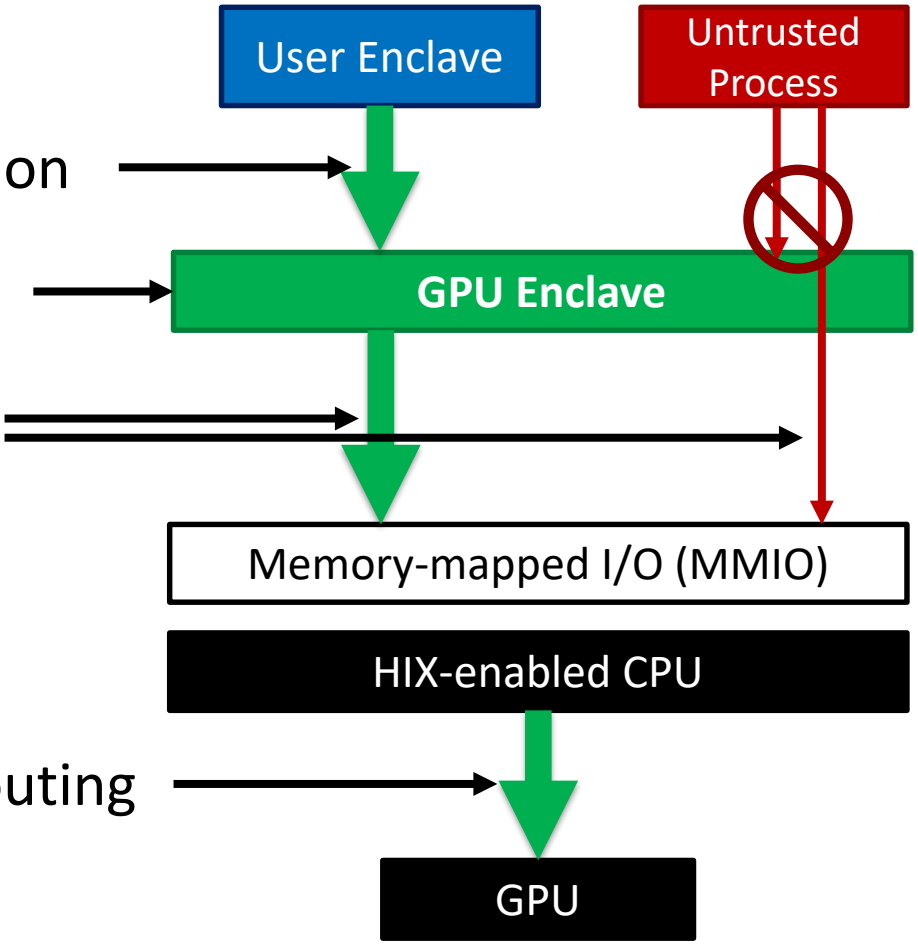

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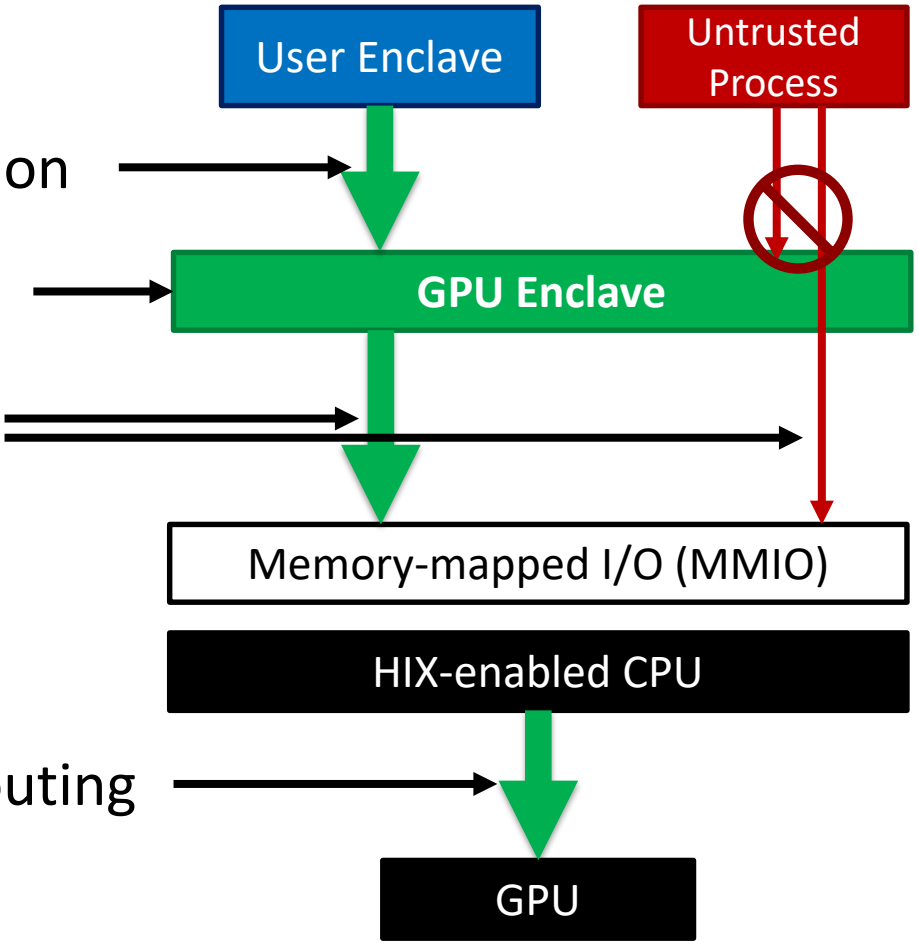

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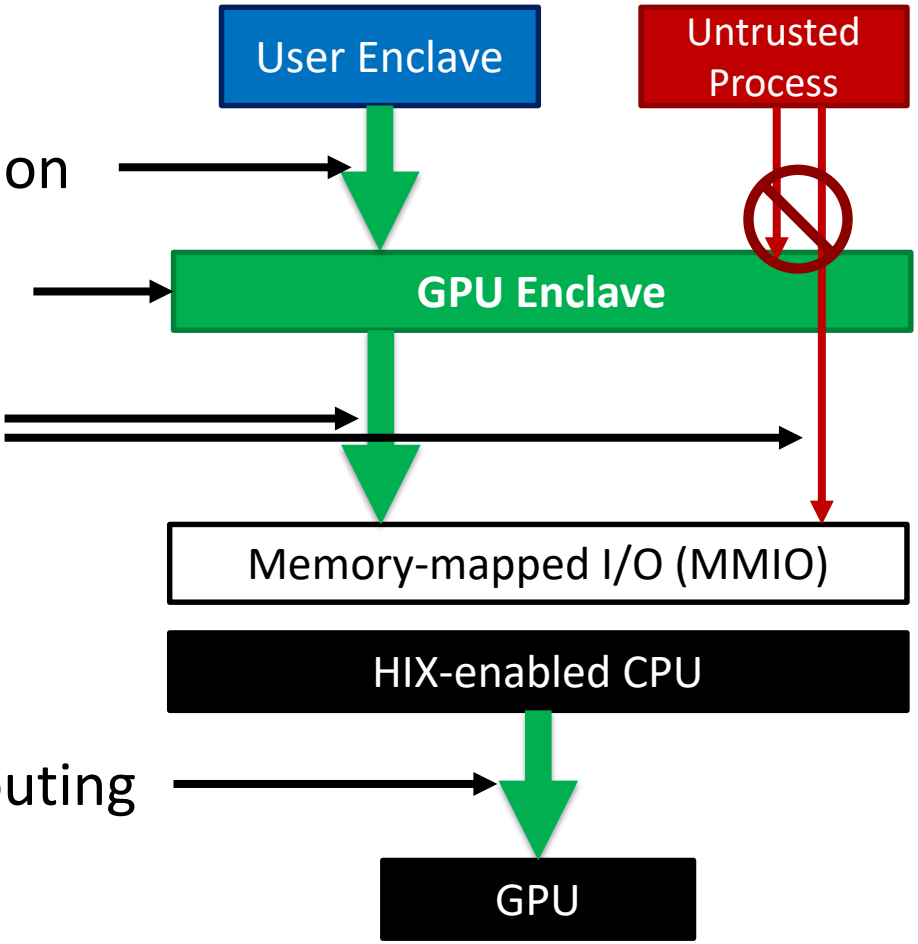

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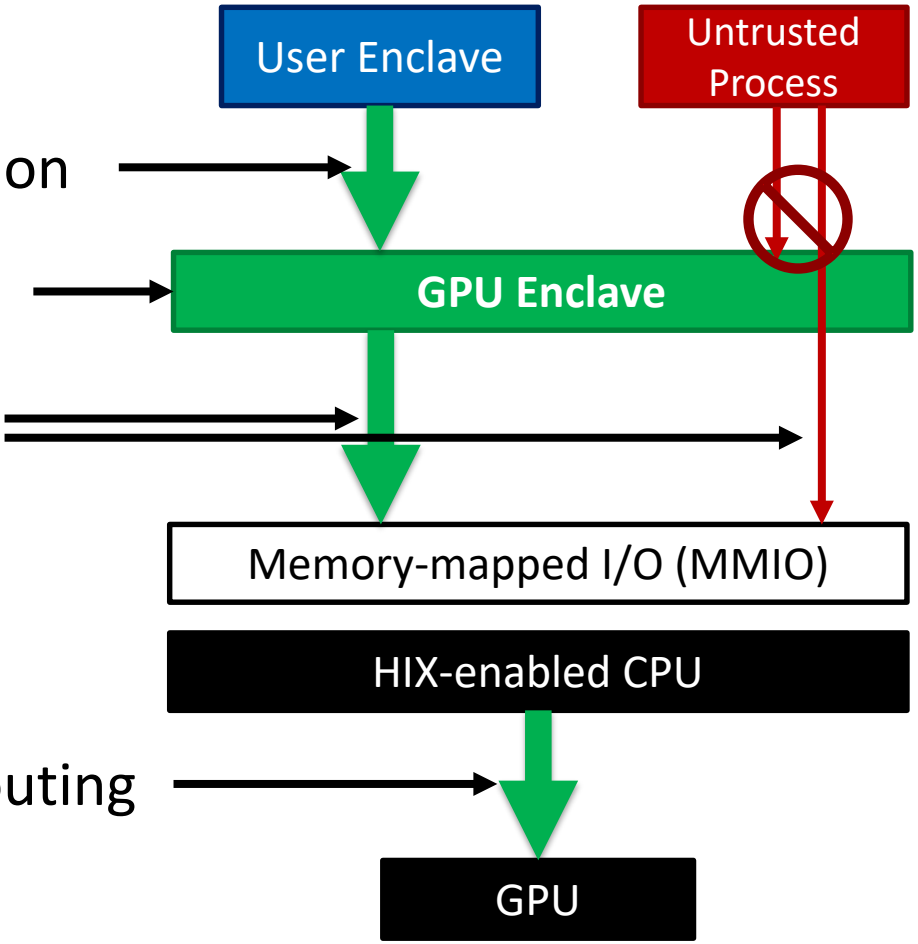

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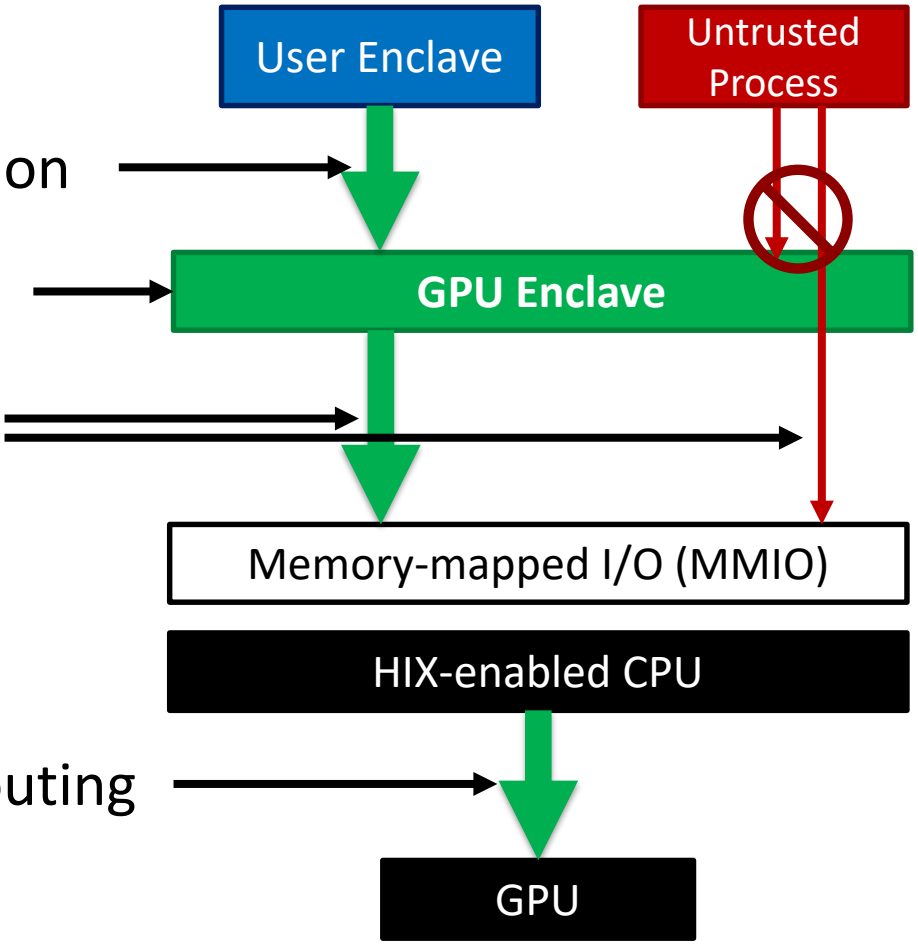

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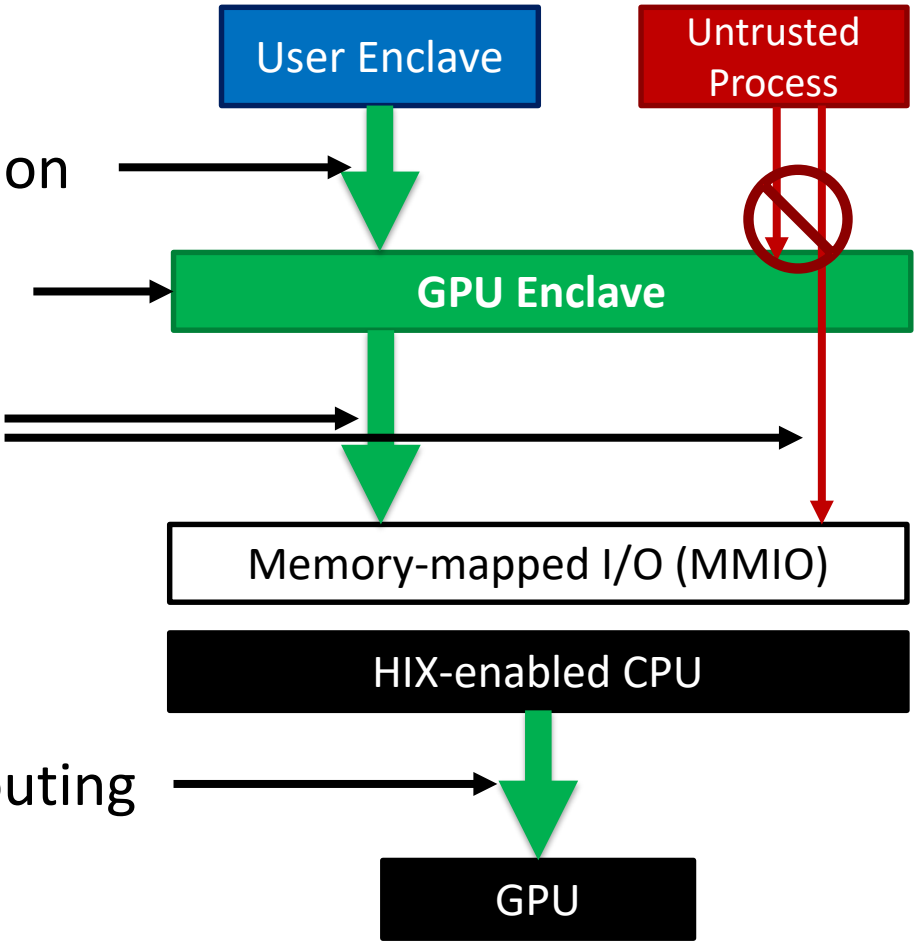

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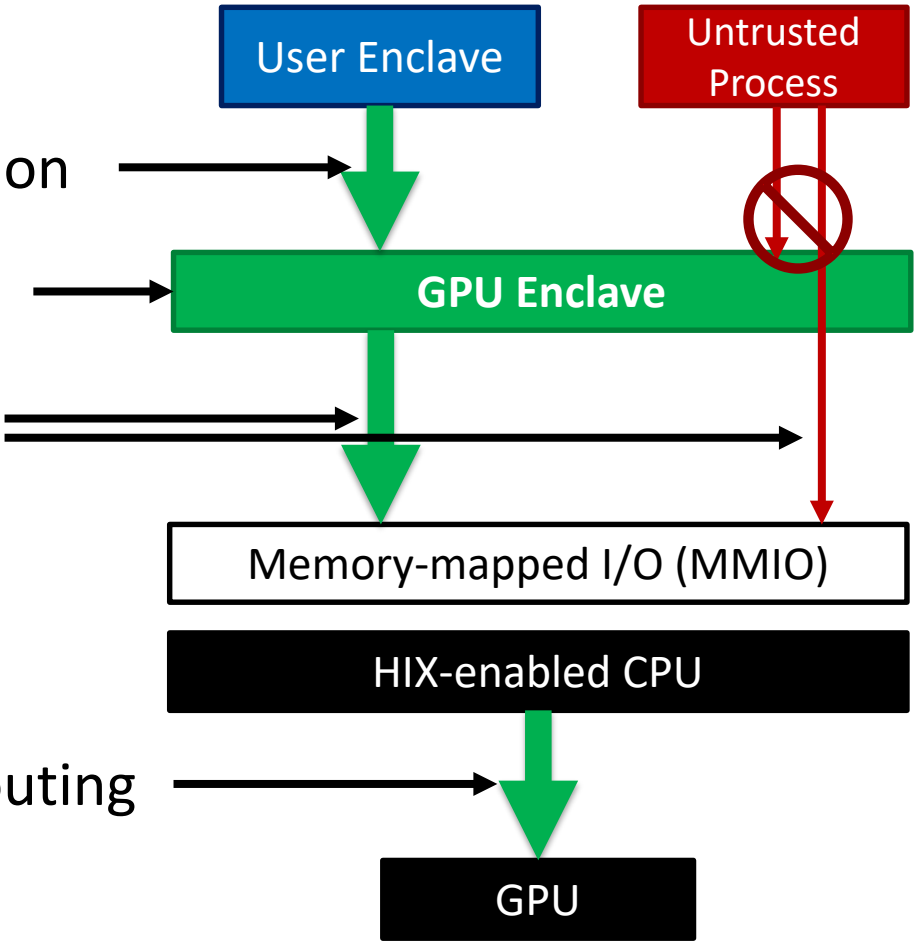

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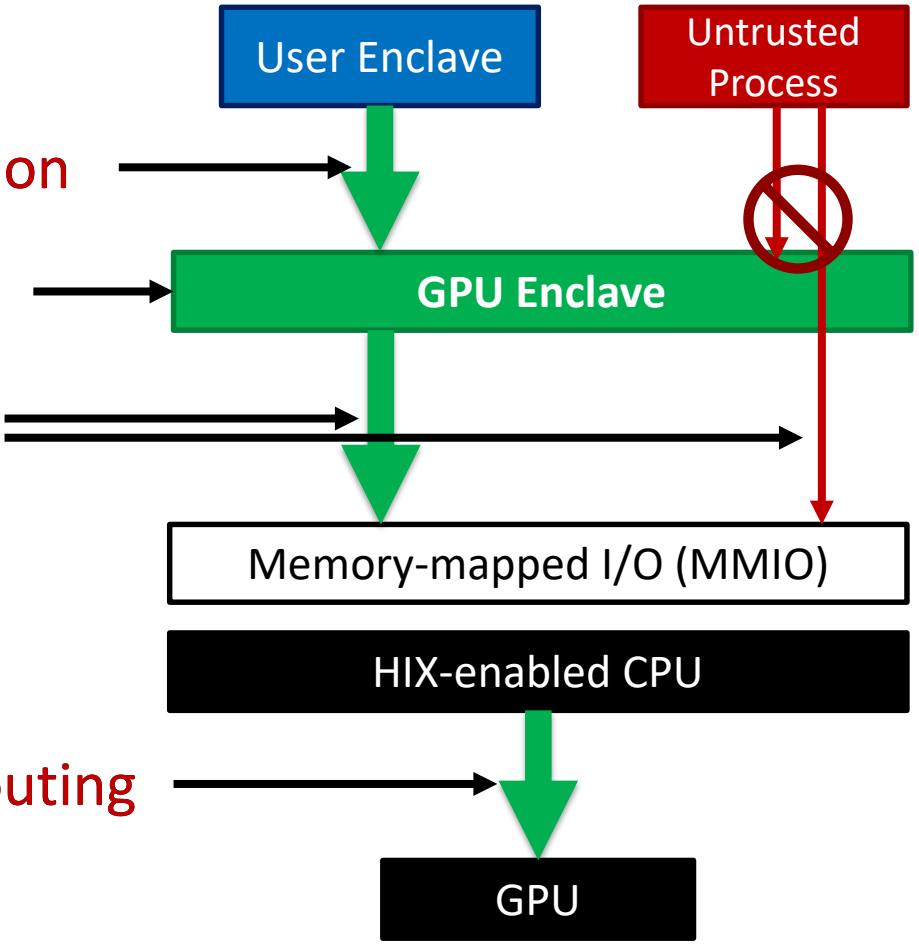

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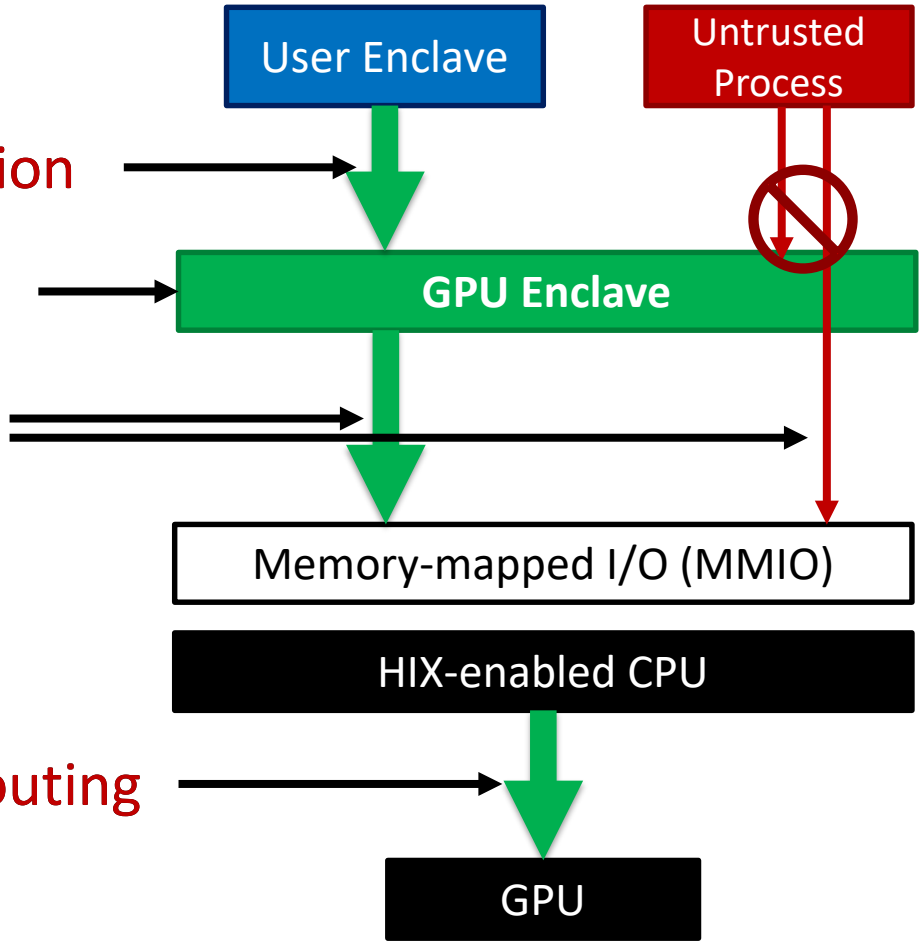

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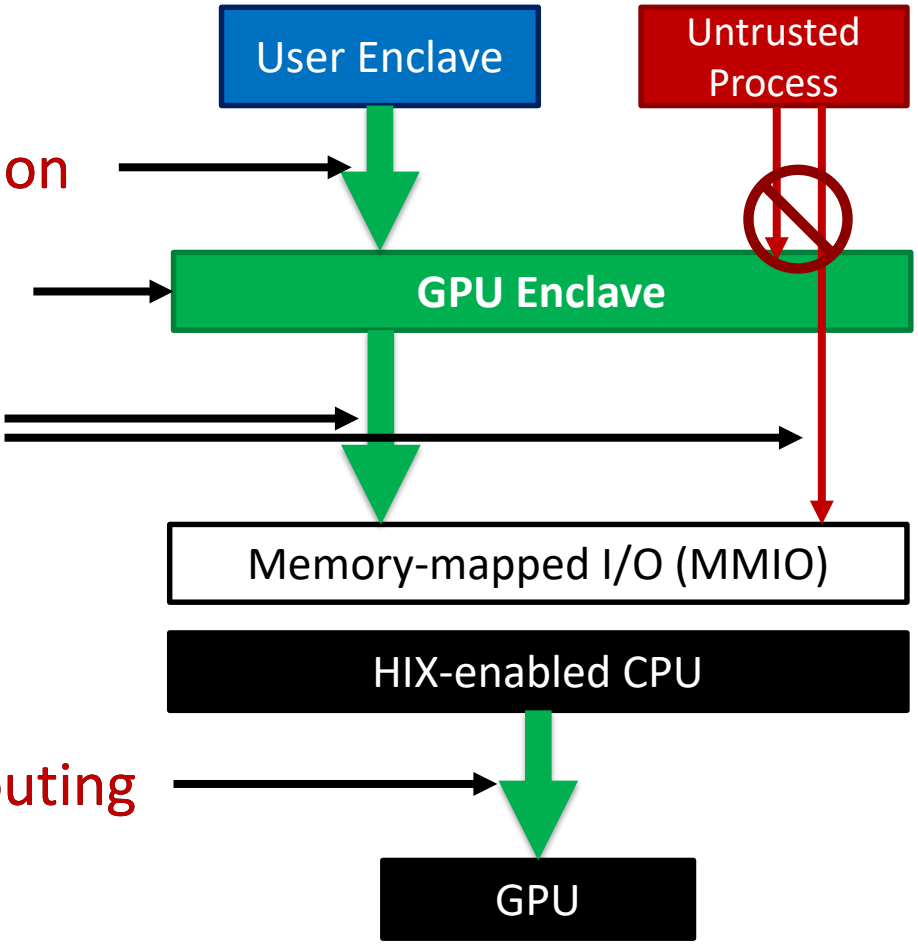

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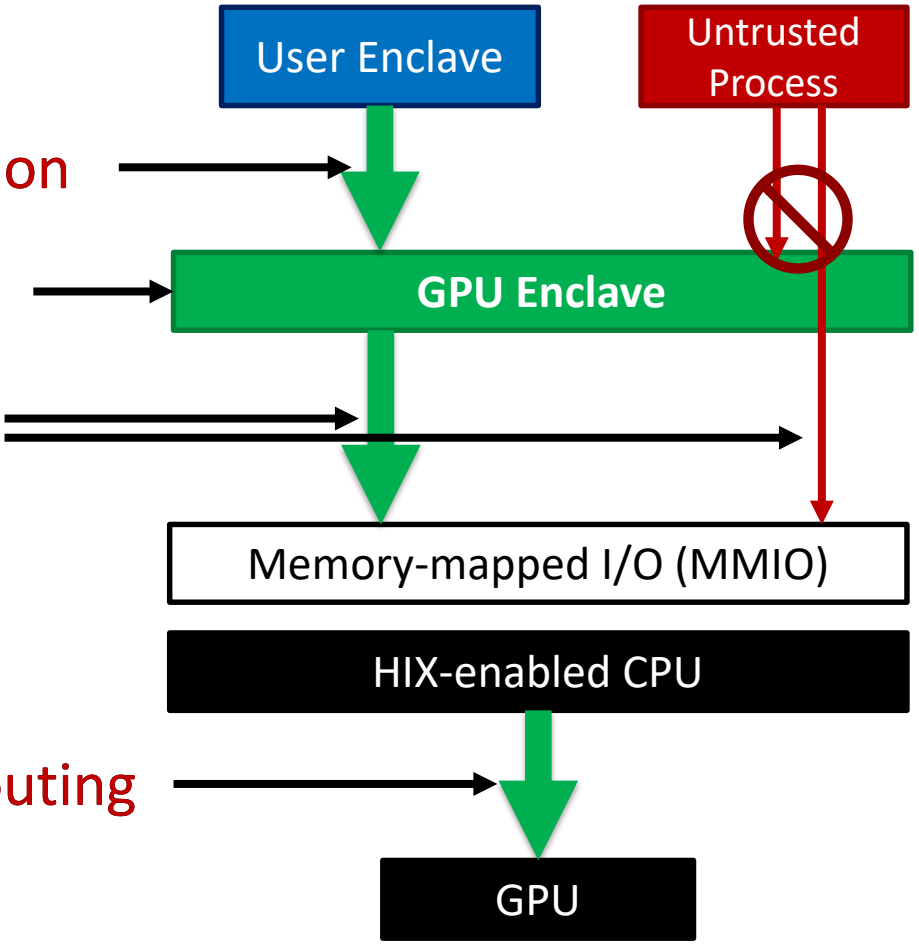
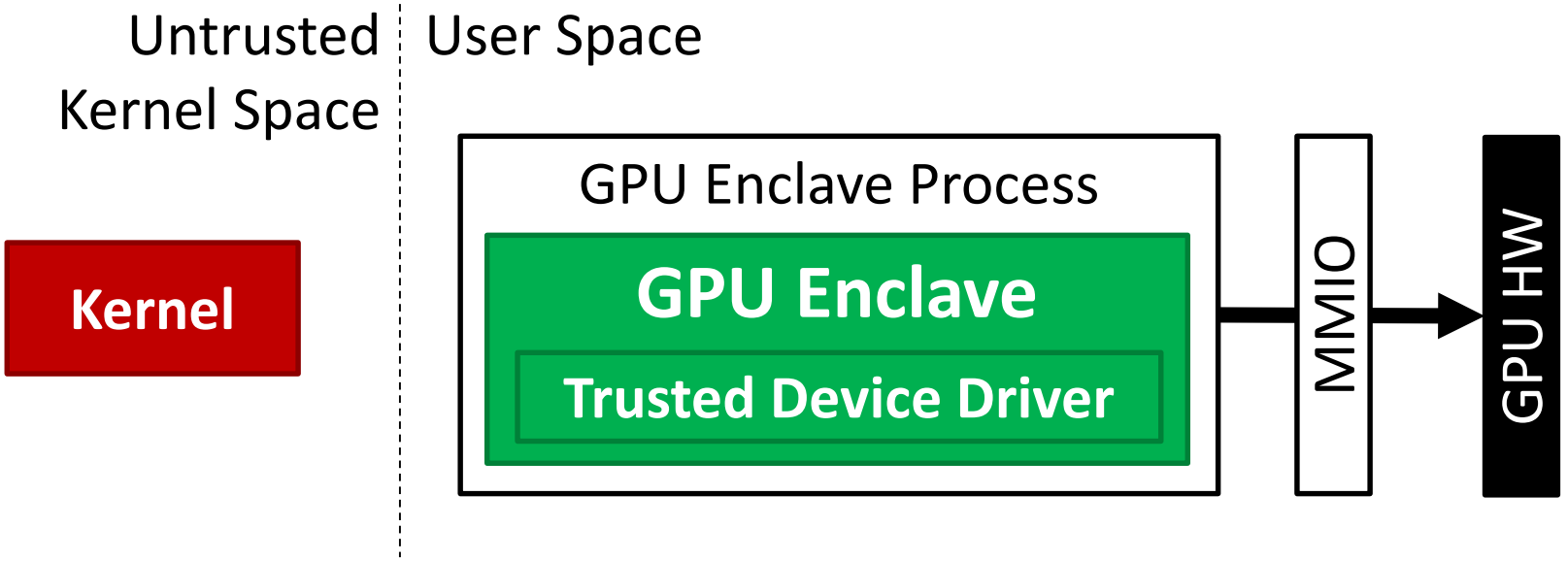


GPU Enclave: Trusted Device Driver

- Move device driver from untrusted kernel space to trusted enclave
- Extended SGX enclave that owns and controls GPU in TEE



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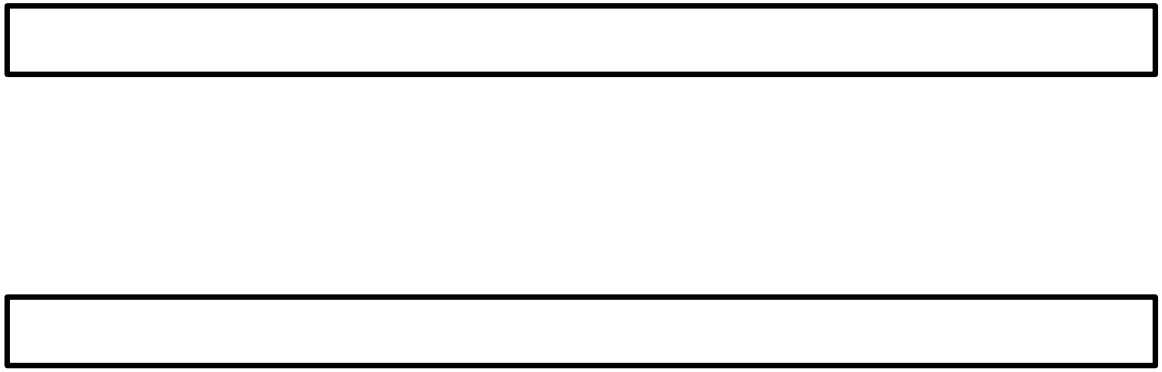

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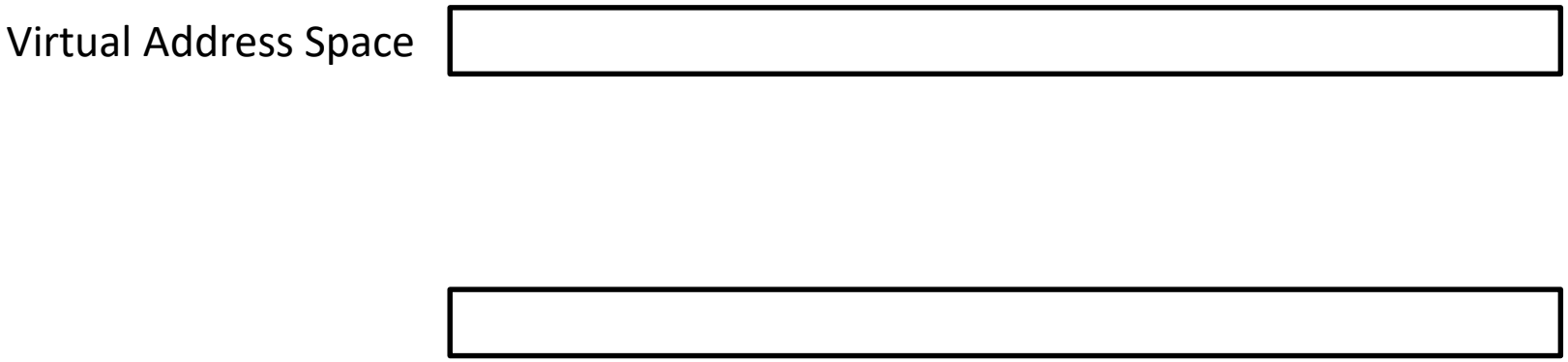

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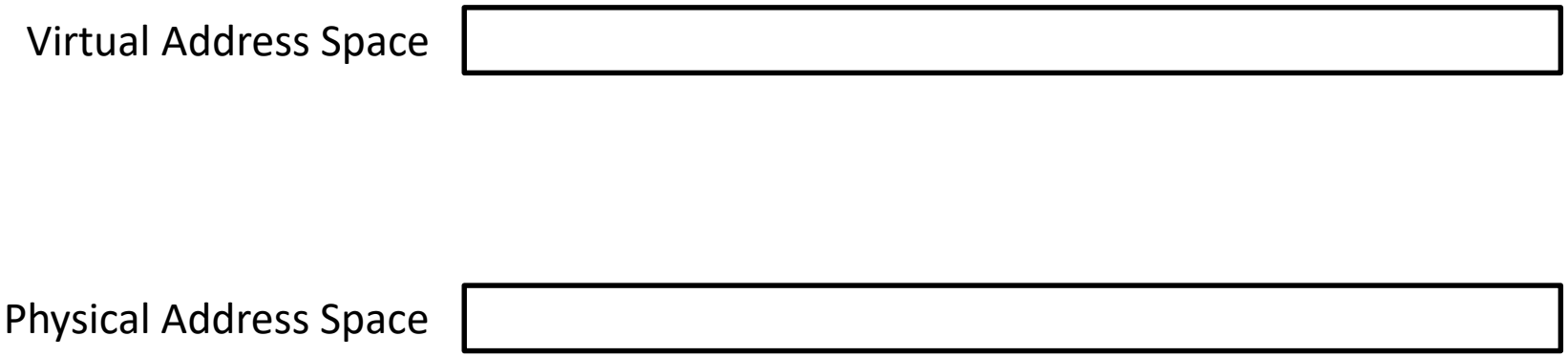

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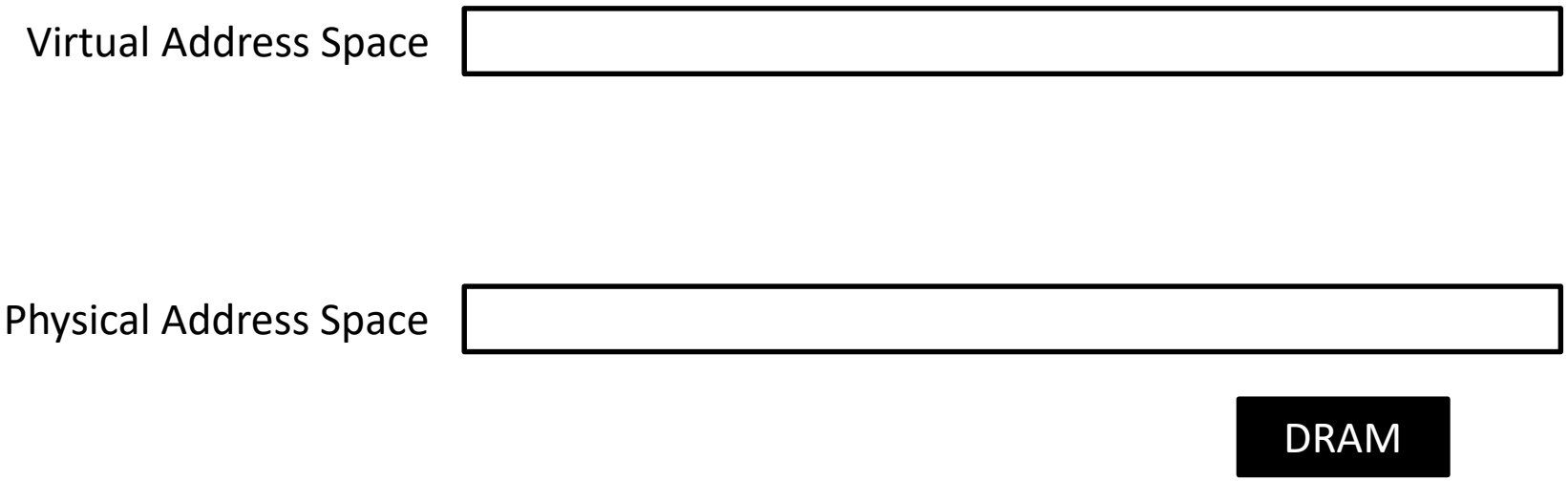

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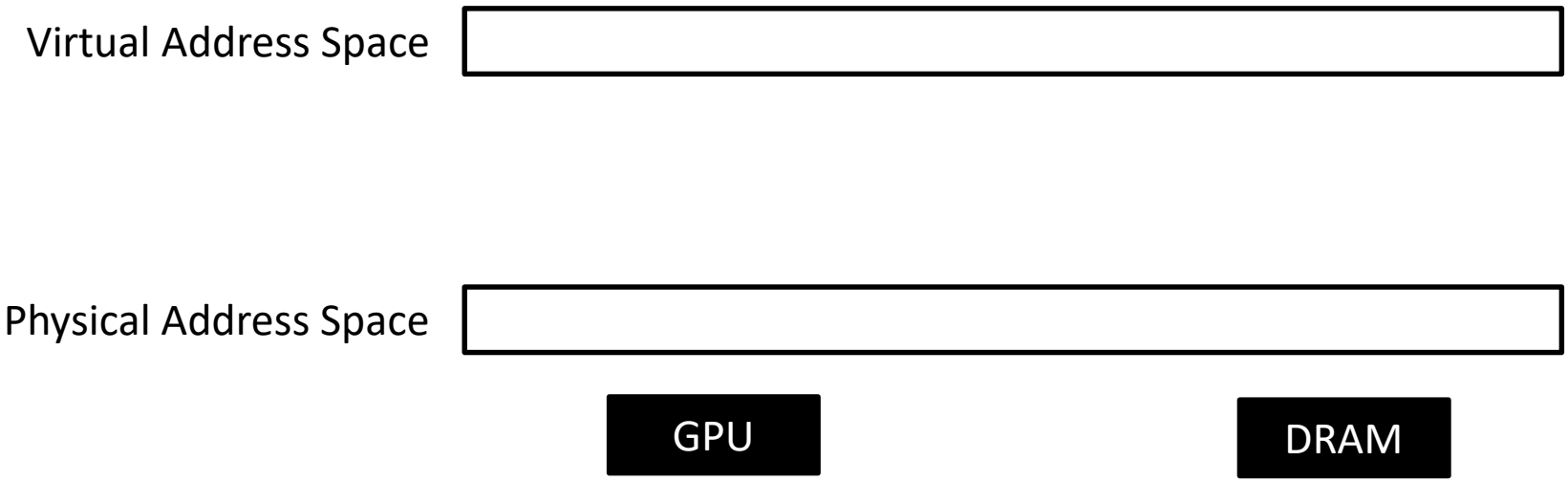

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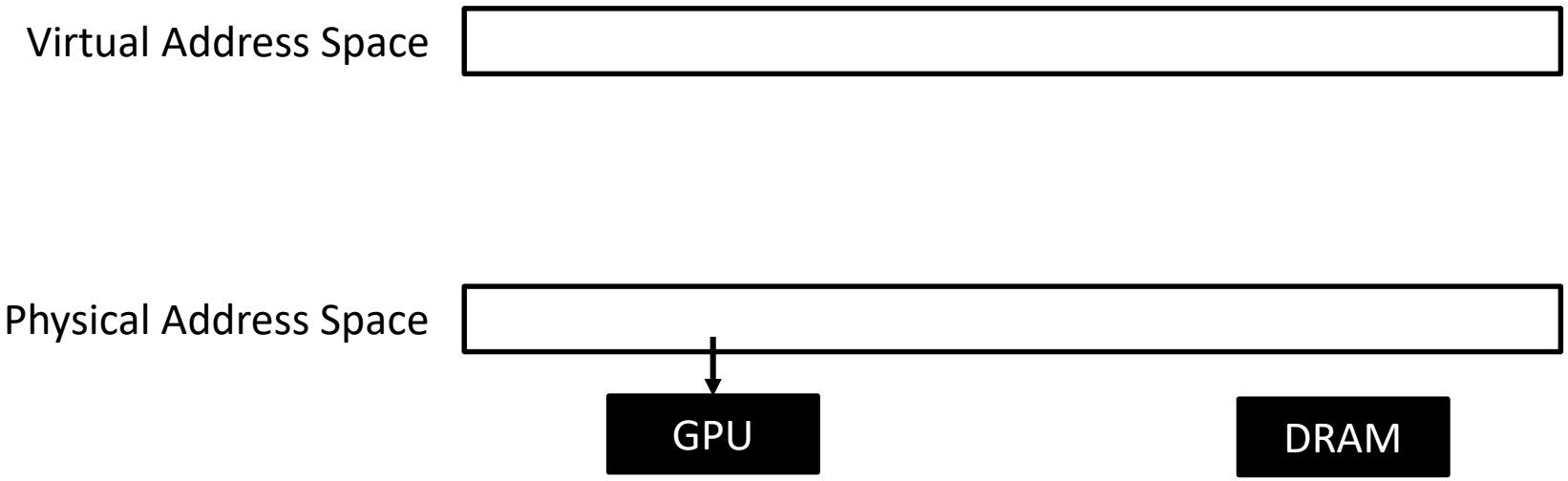

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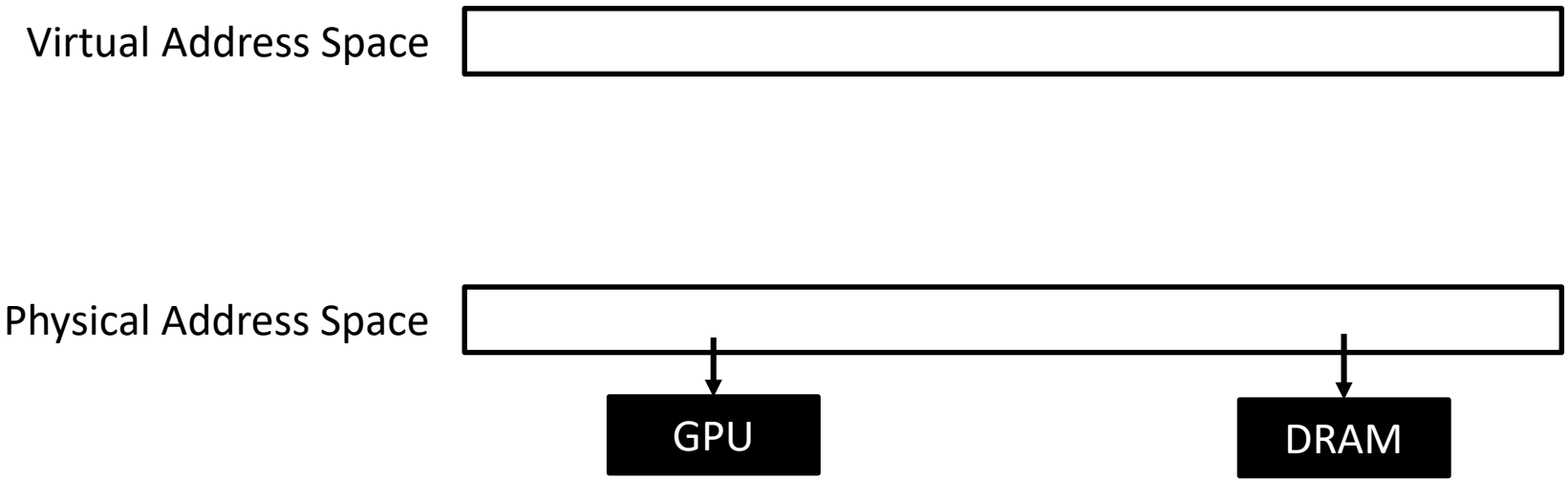

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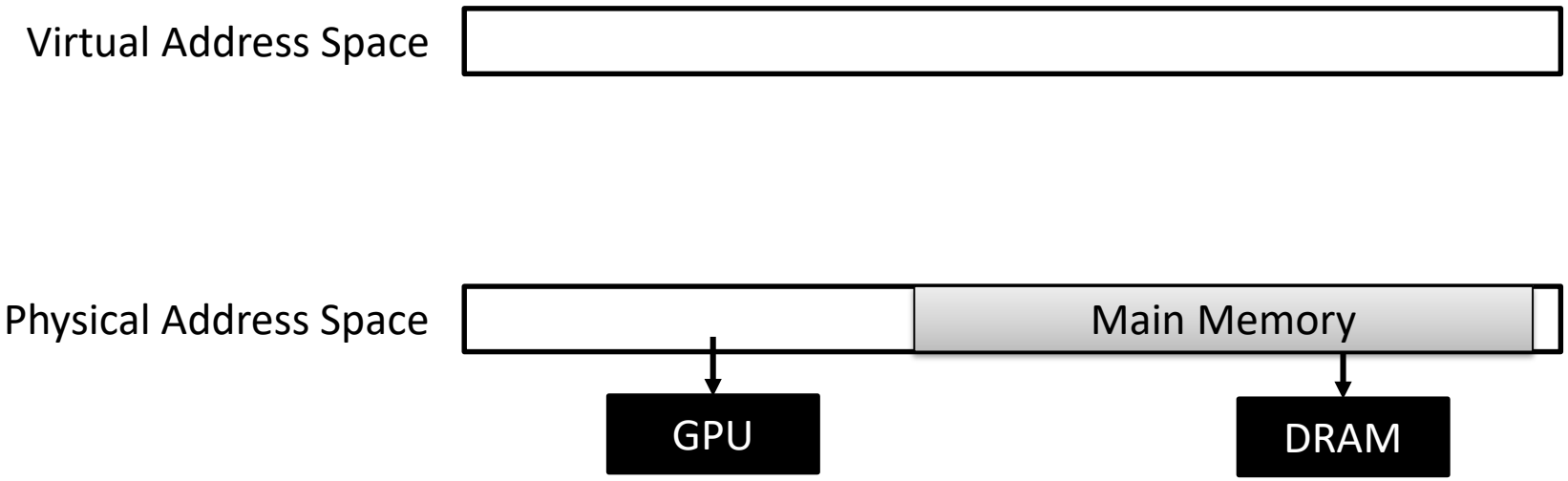

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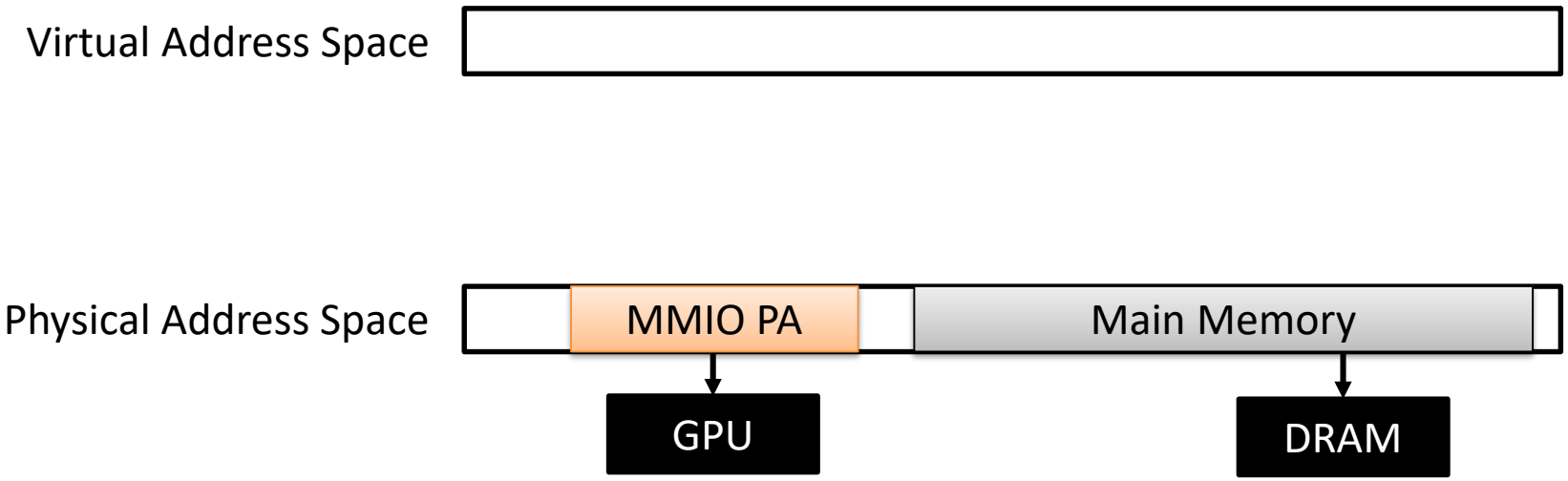

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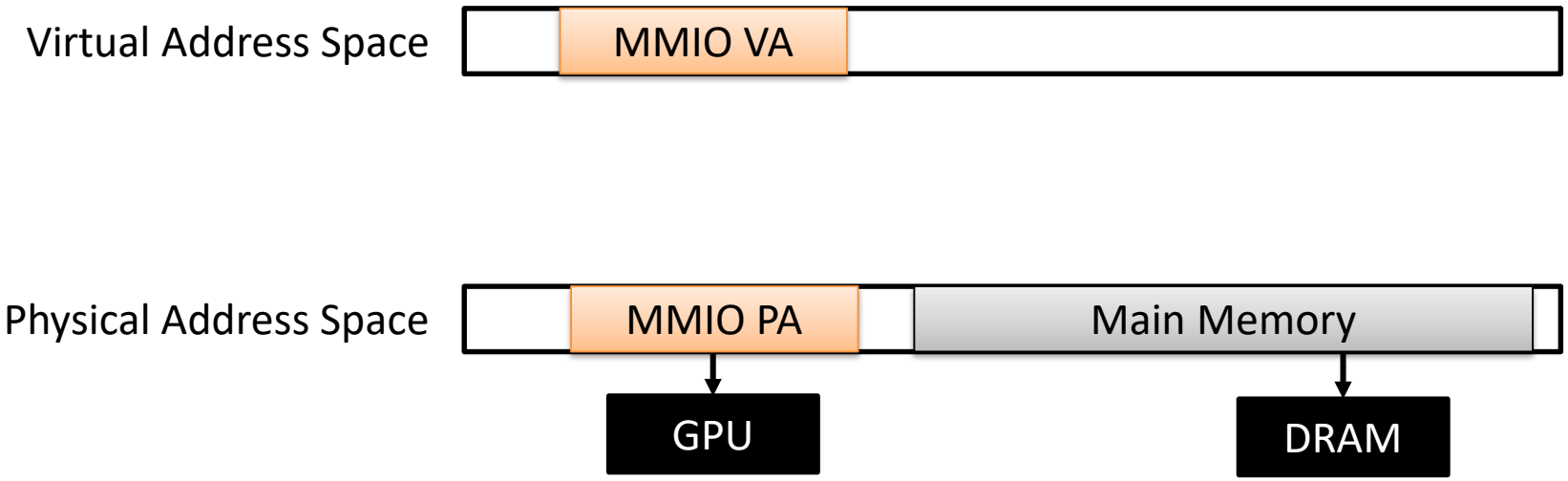

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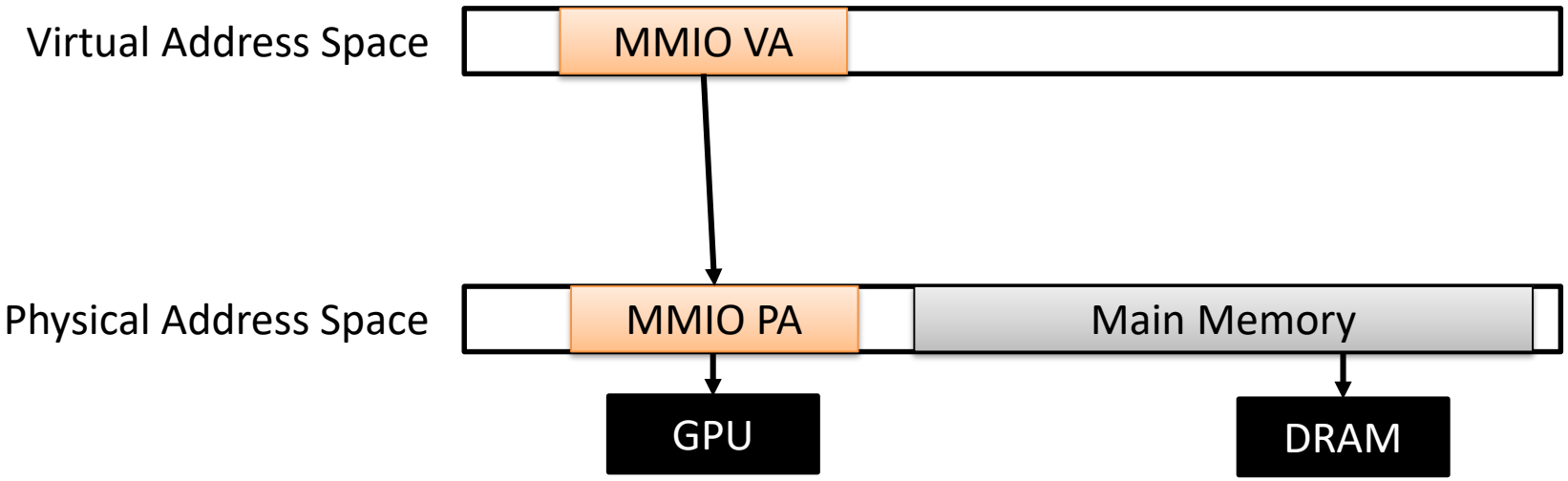

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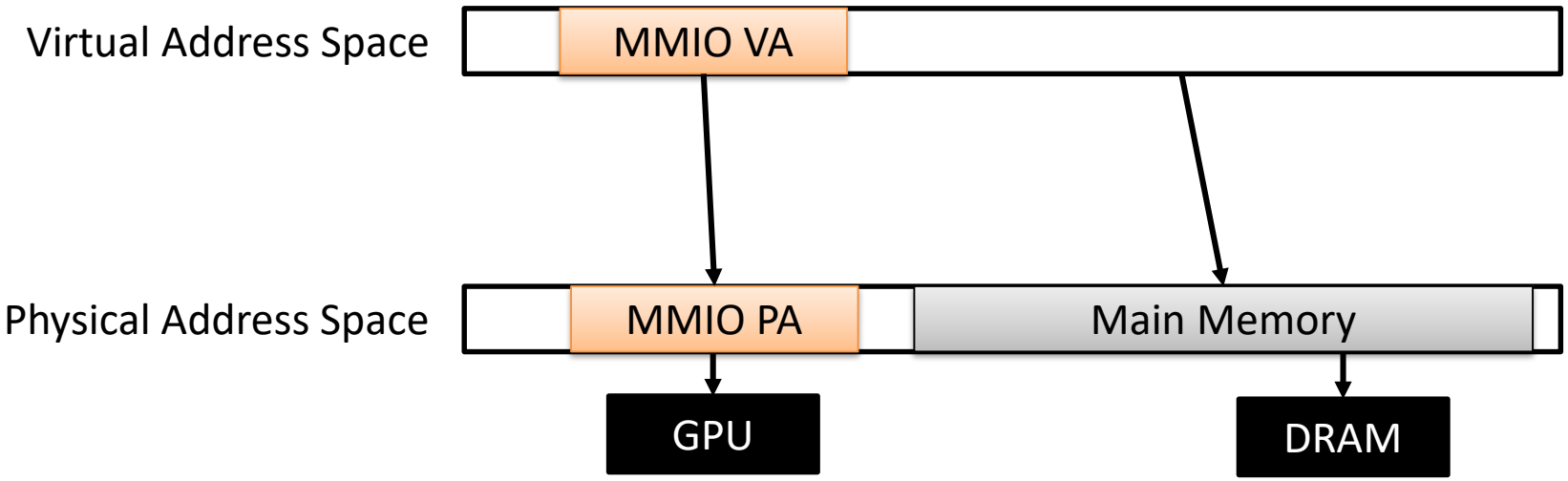

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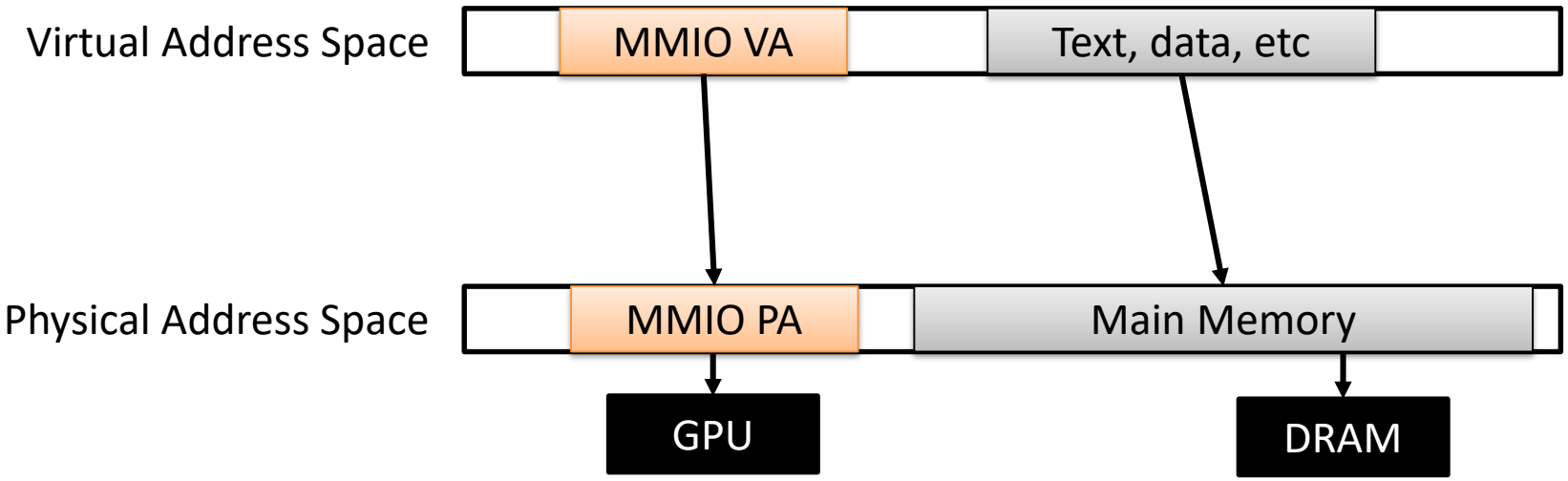

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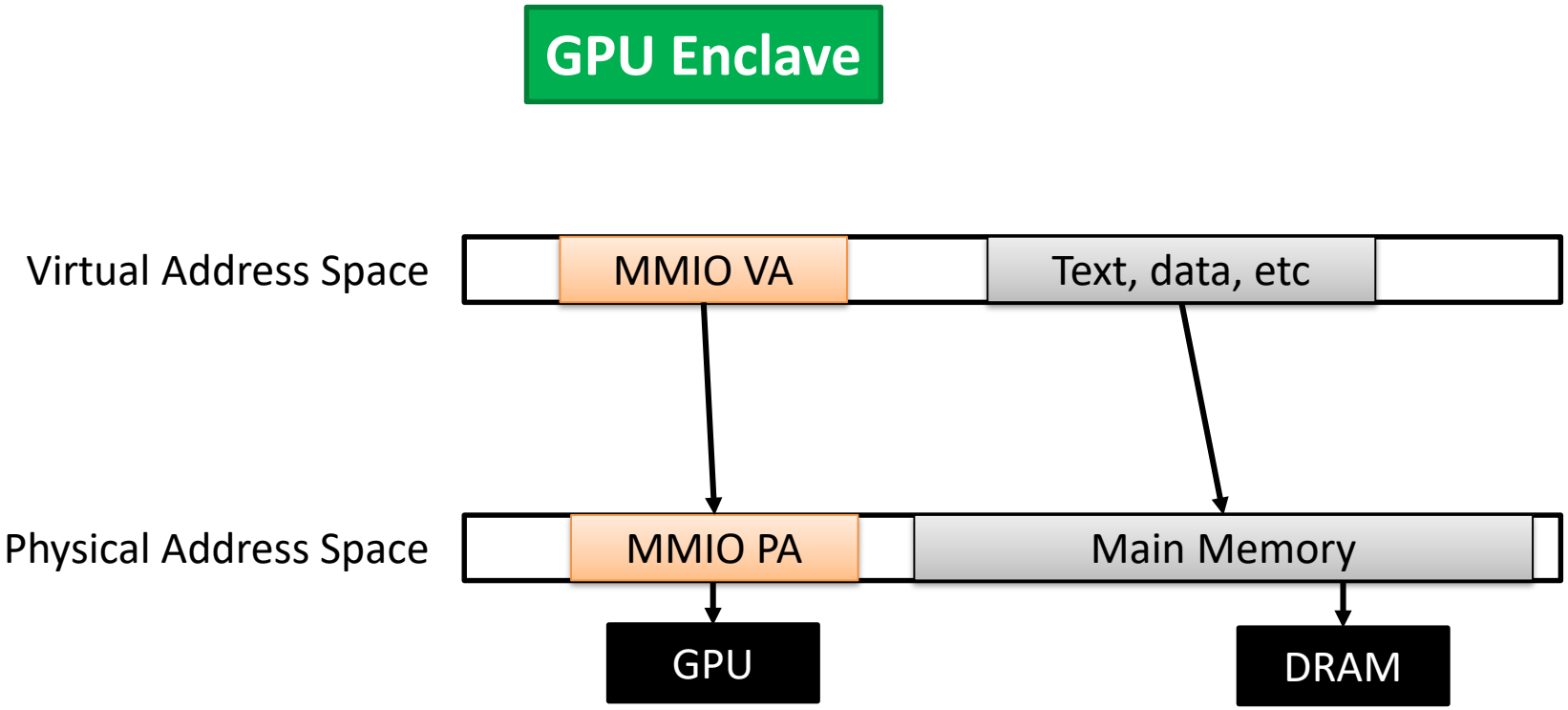

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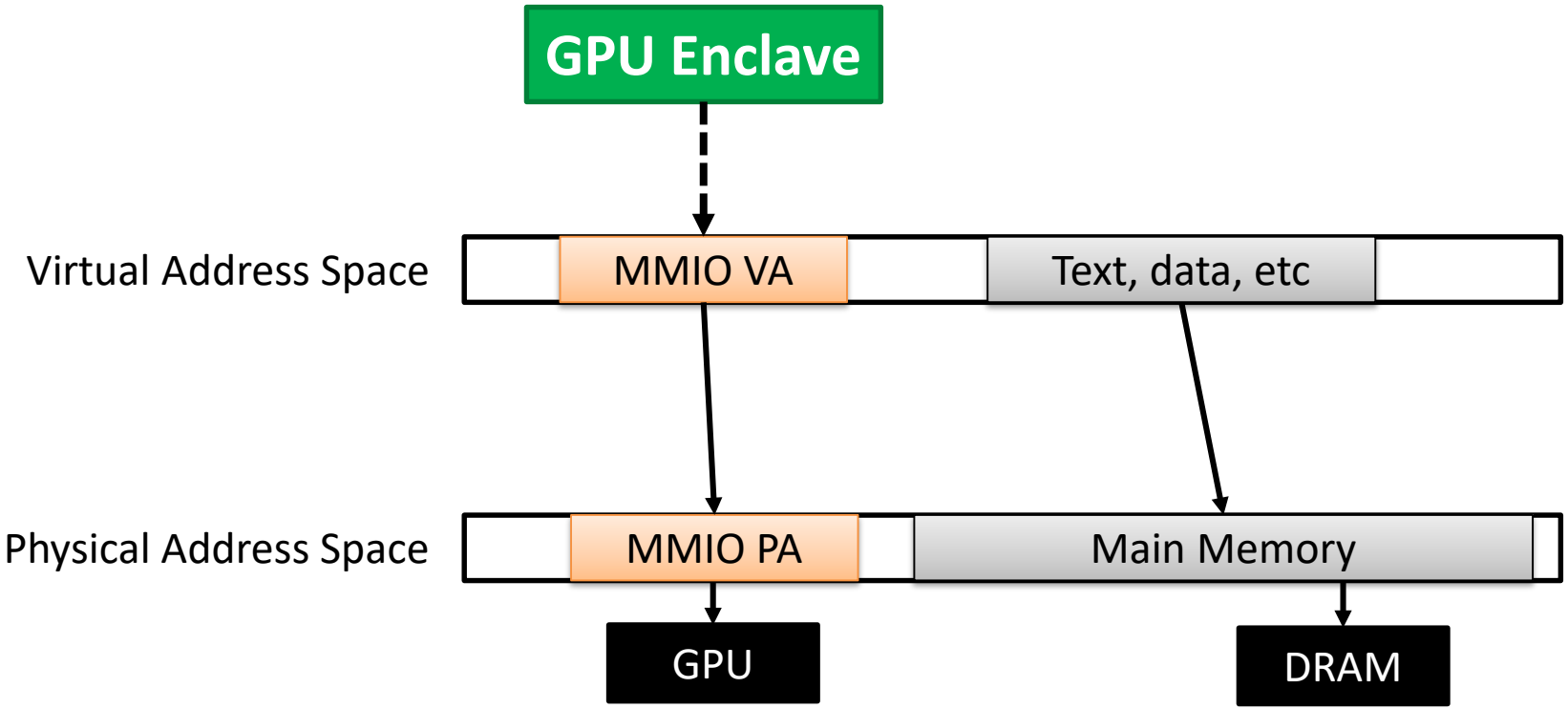

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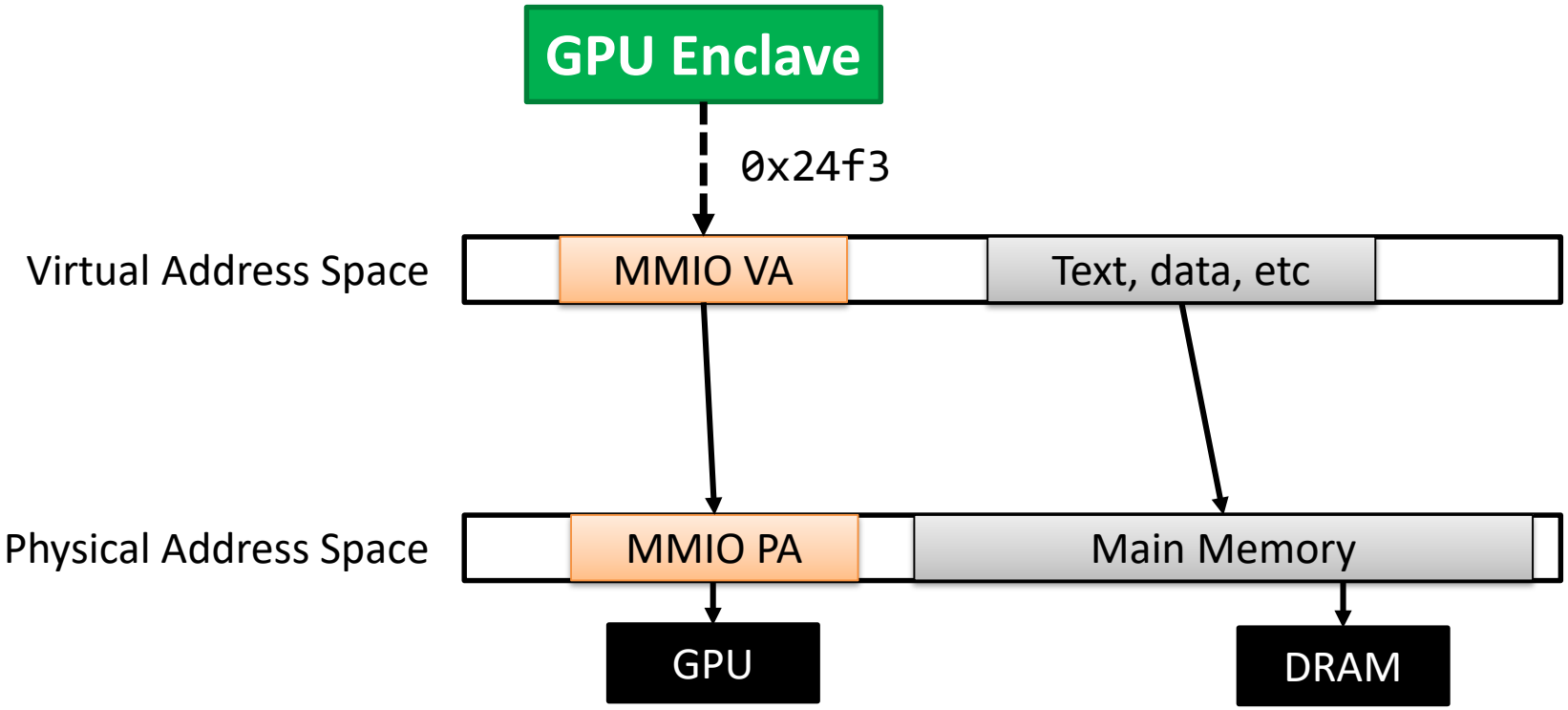

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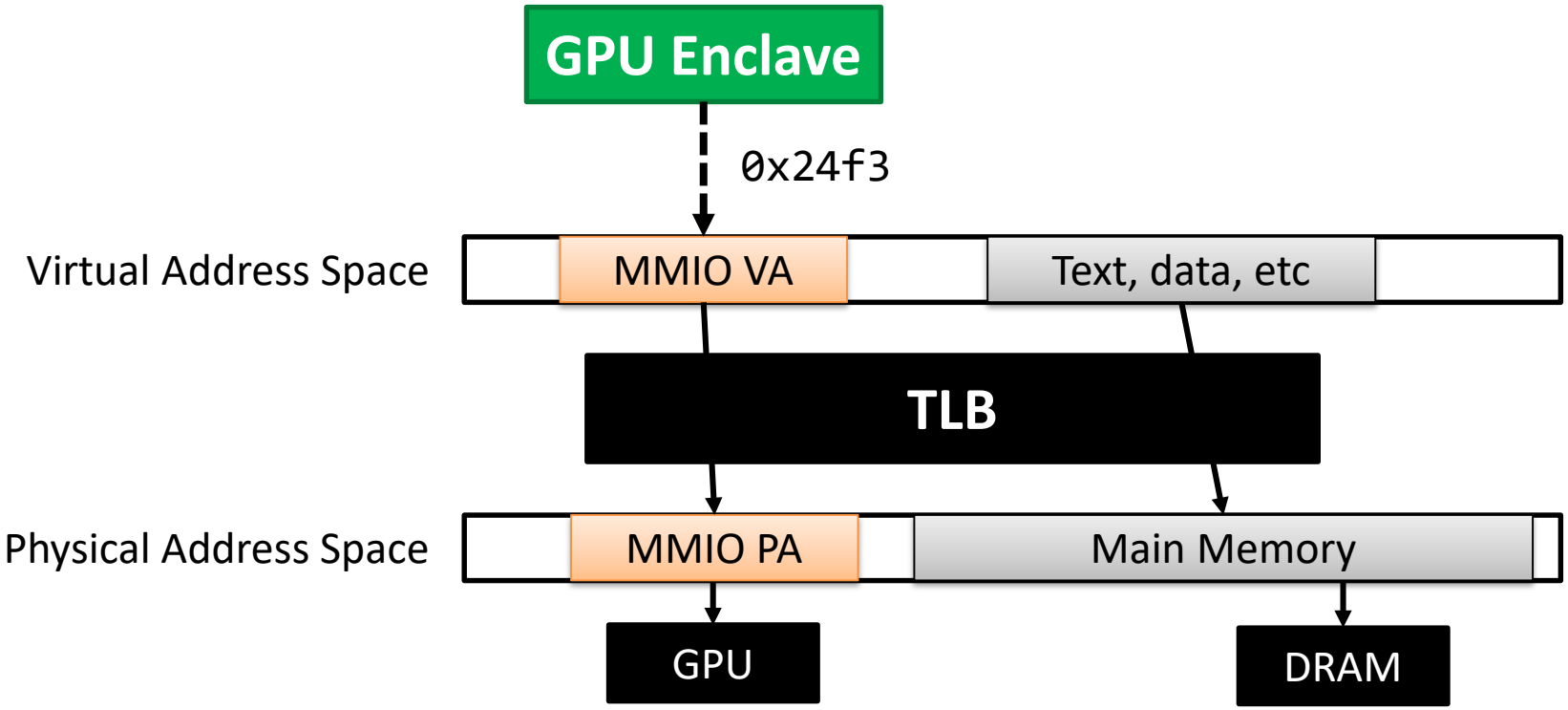

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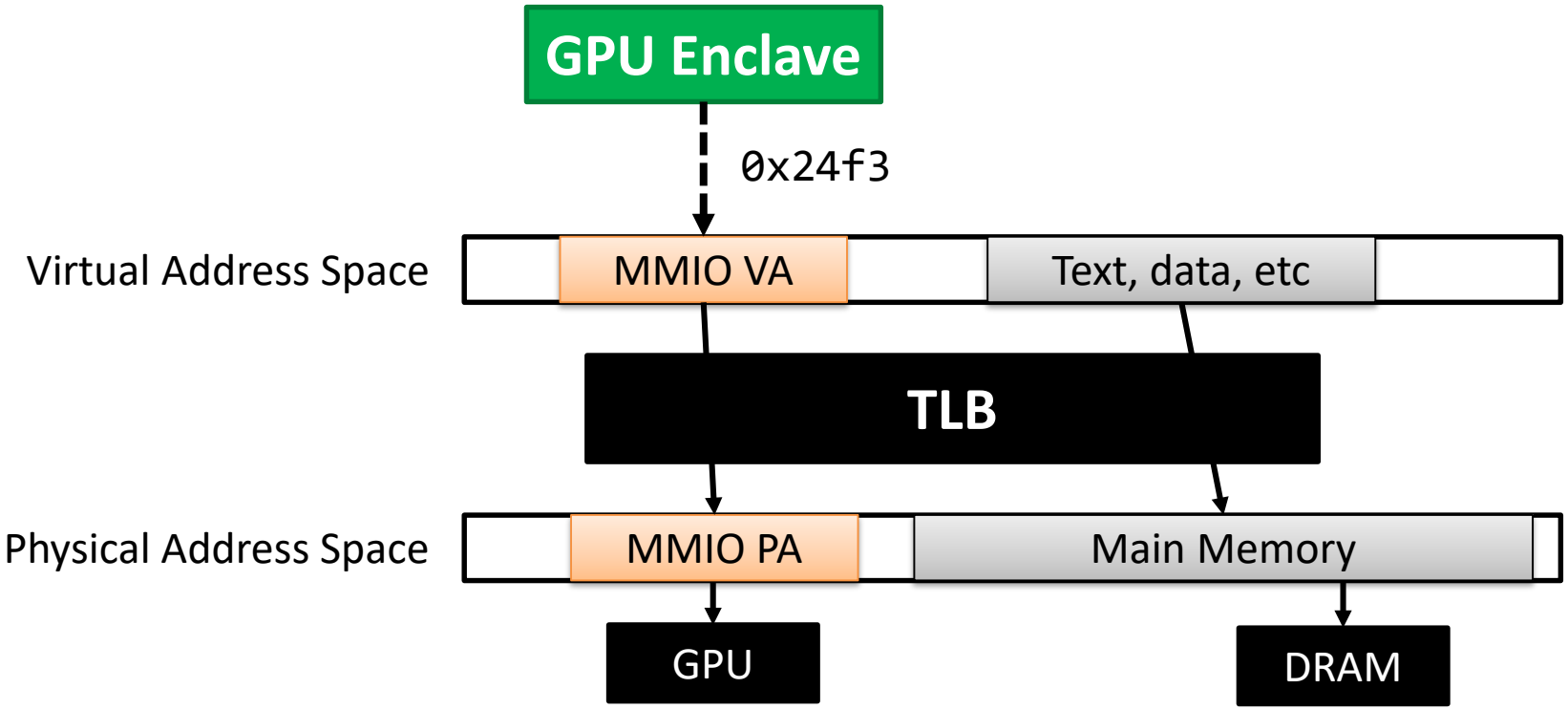

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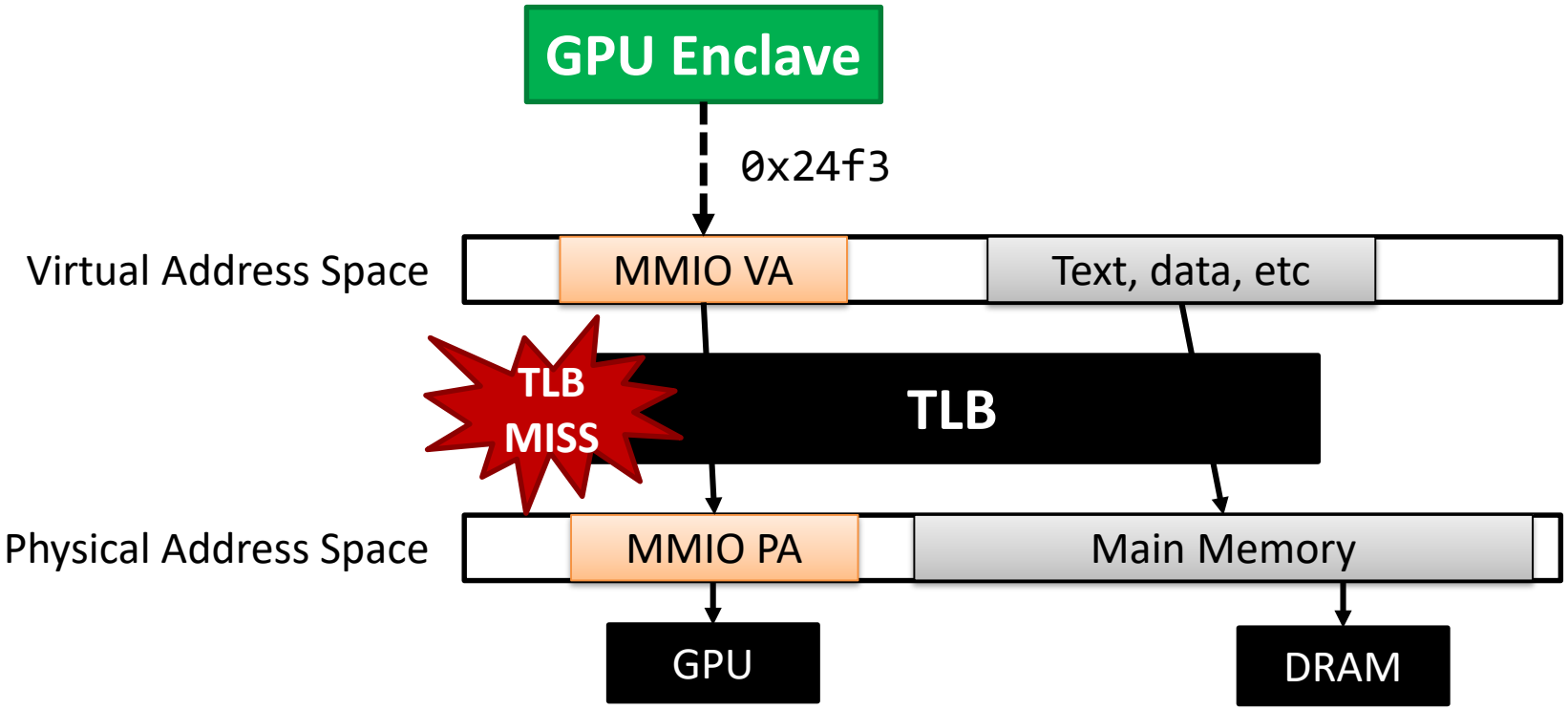

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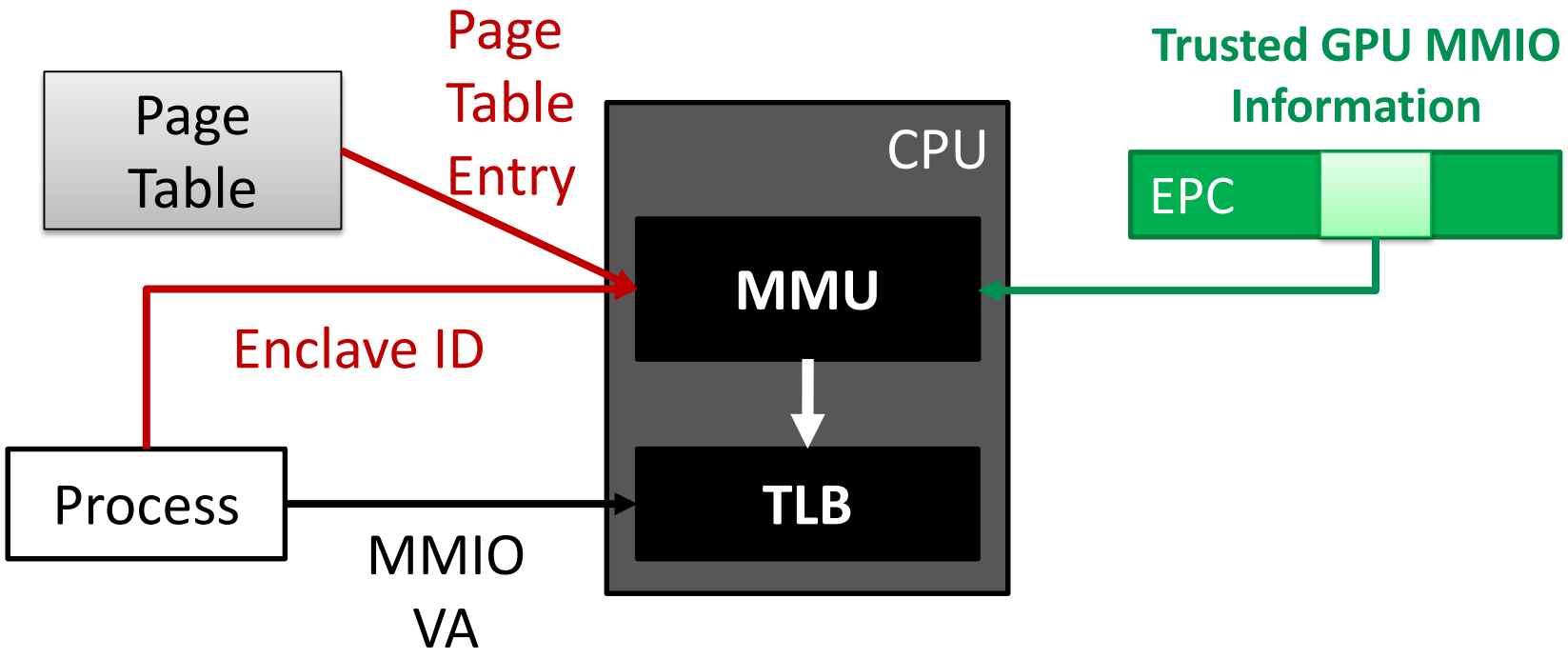

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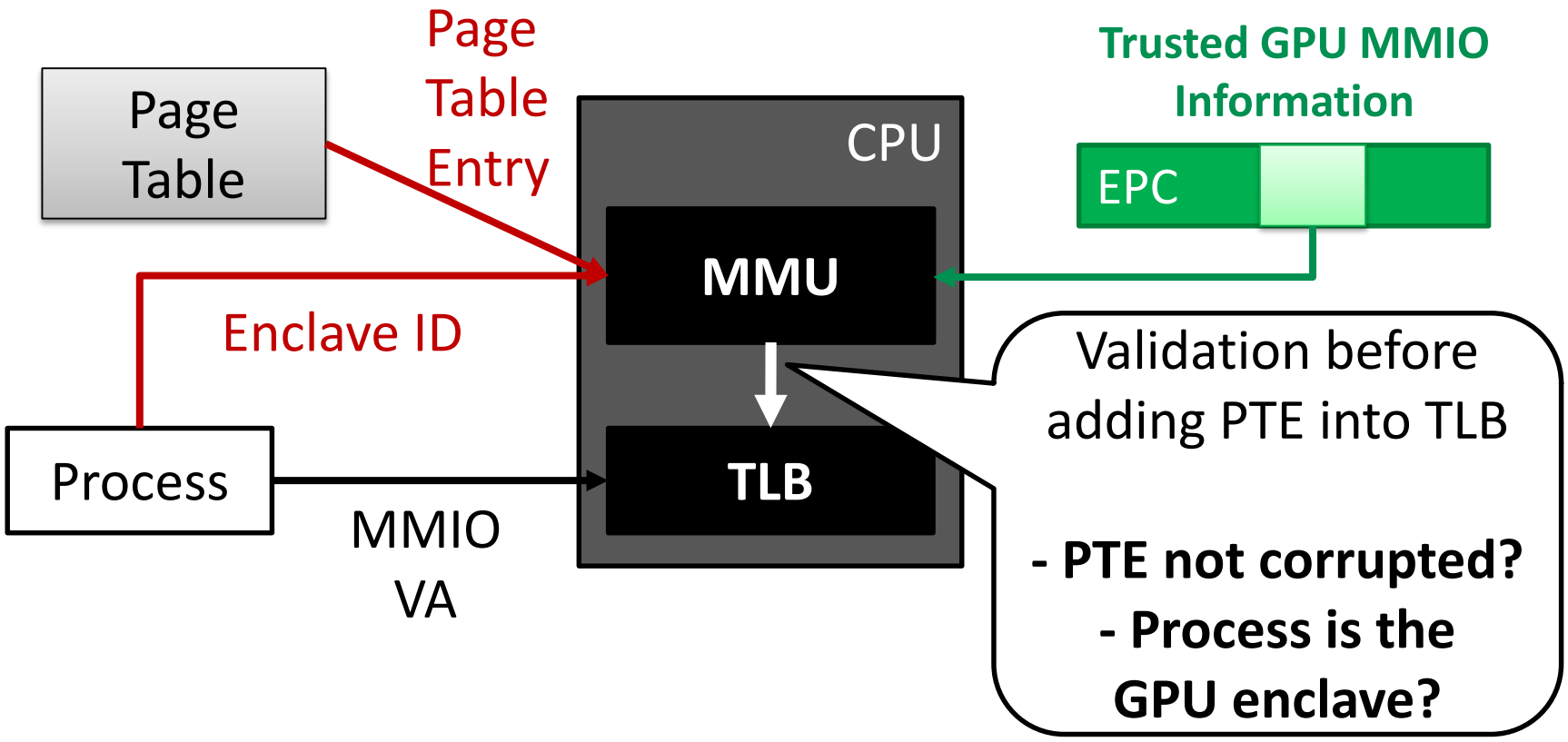
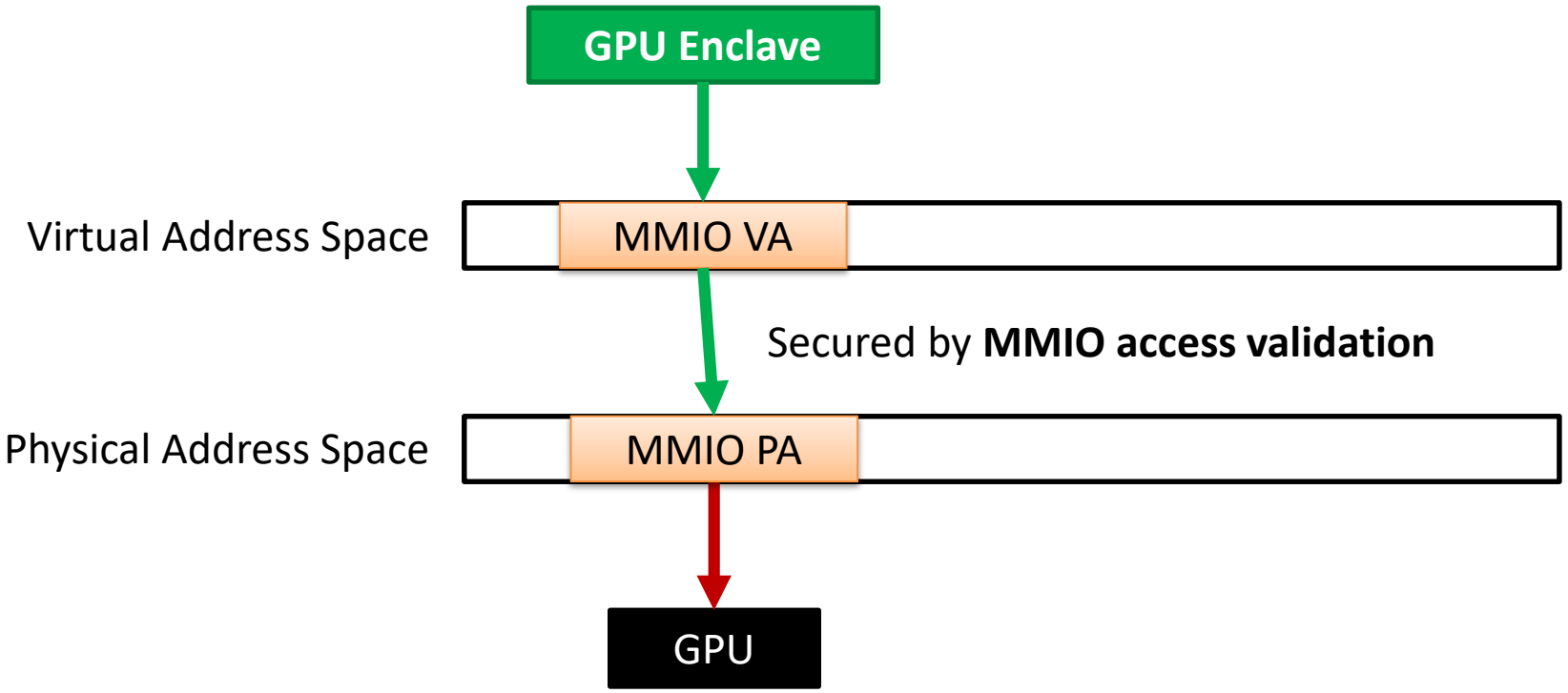


PCIe Packet Routing



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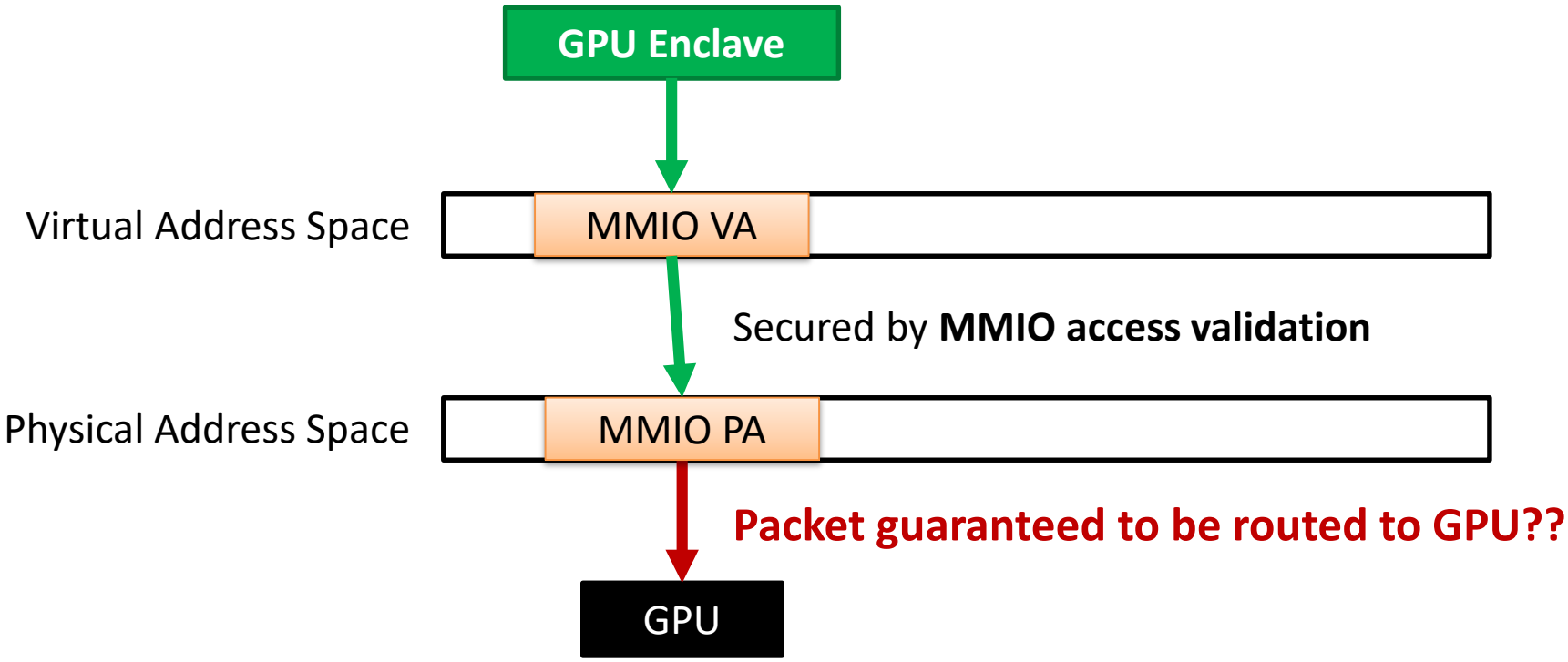

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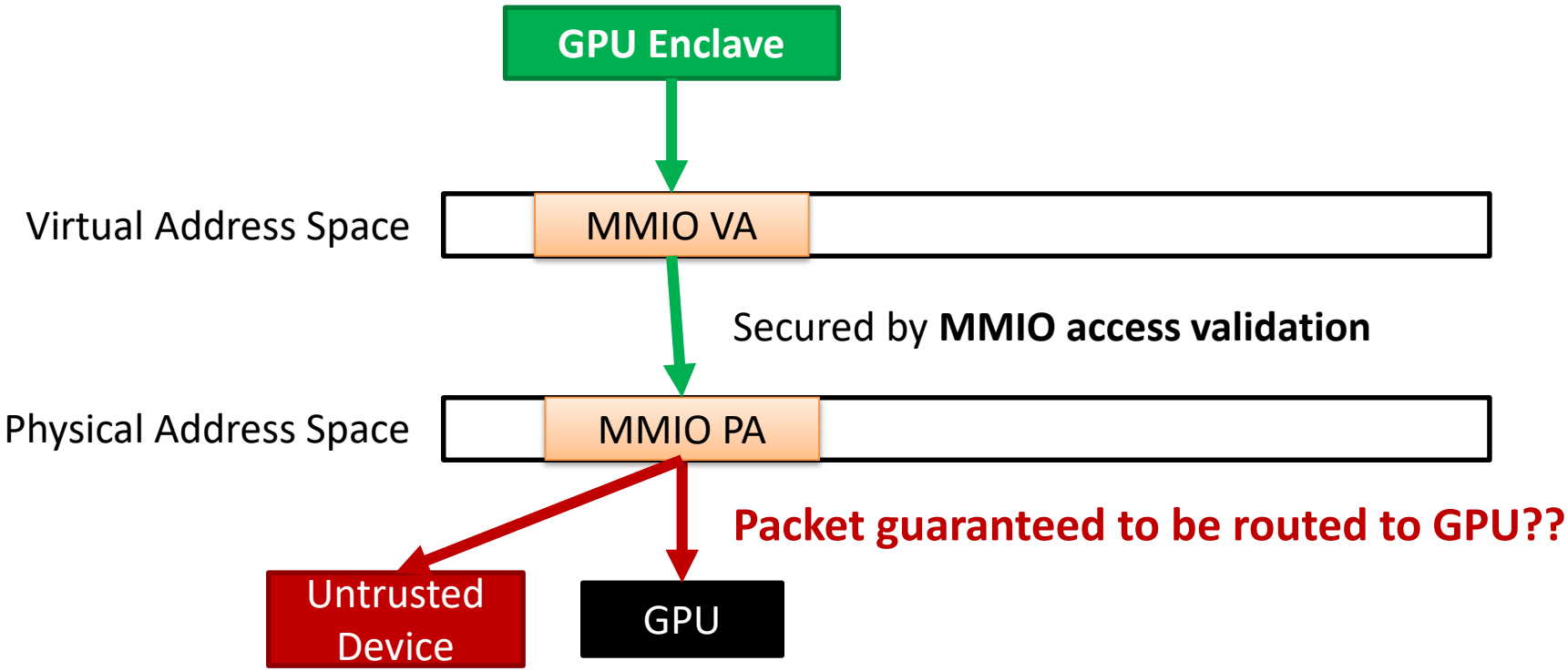

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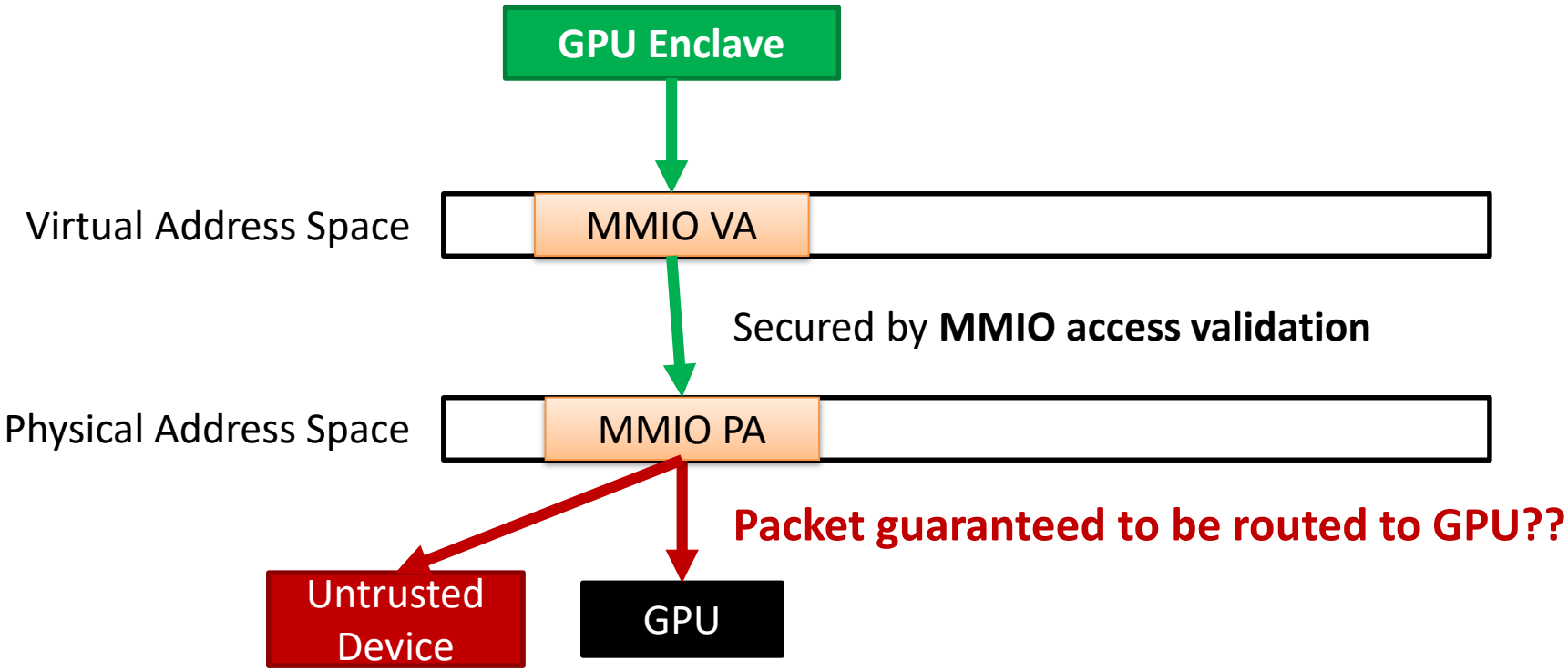

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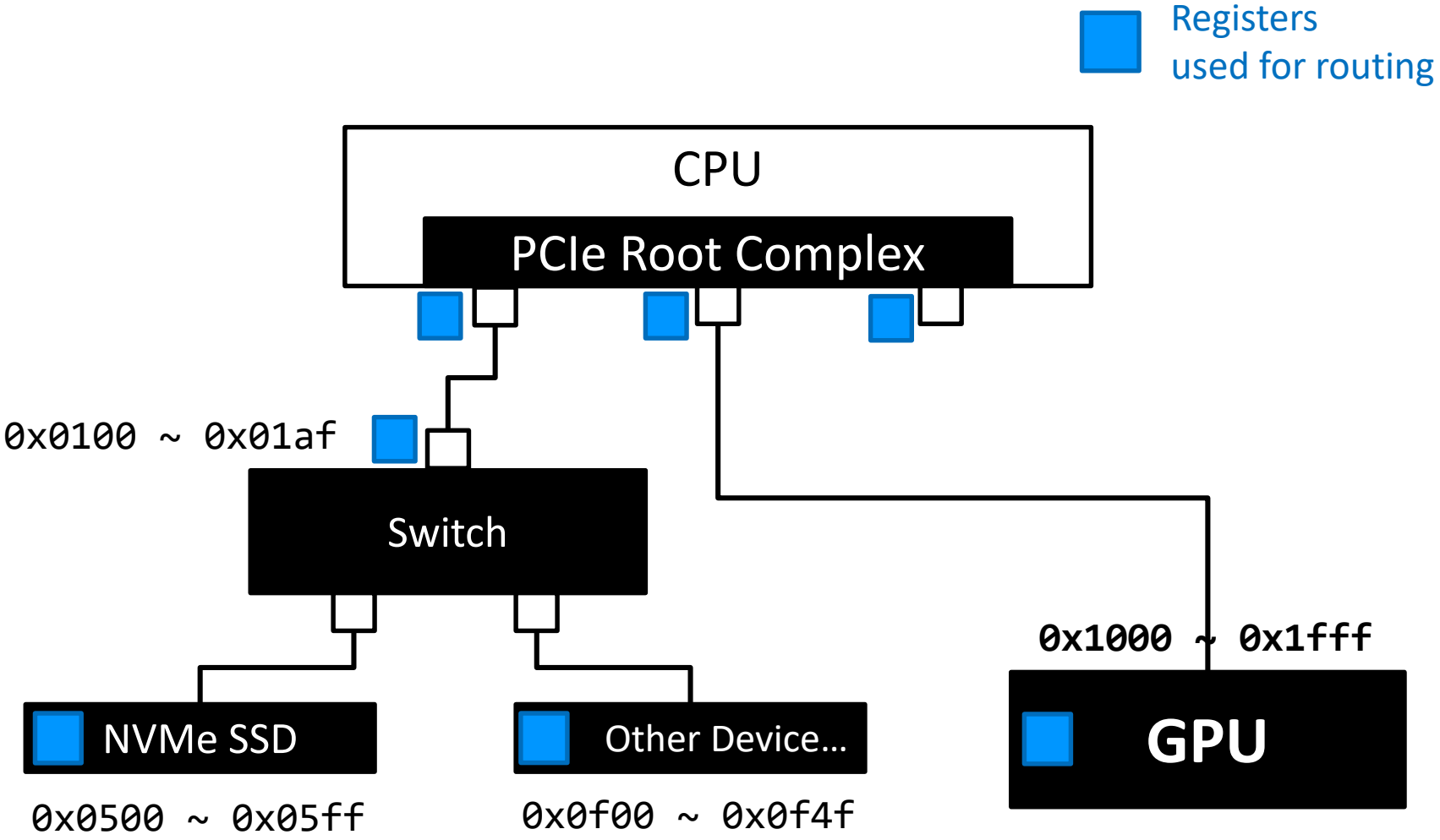
- Use PCIe hardware registers for packet routing (e.g. BARs*)



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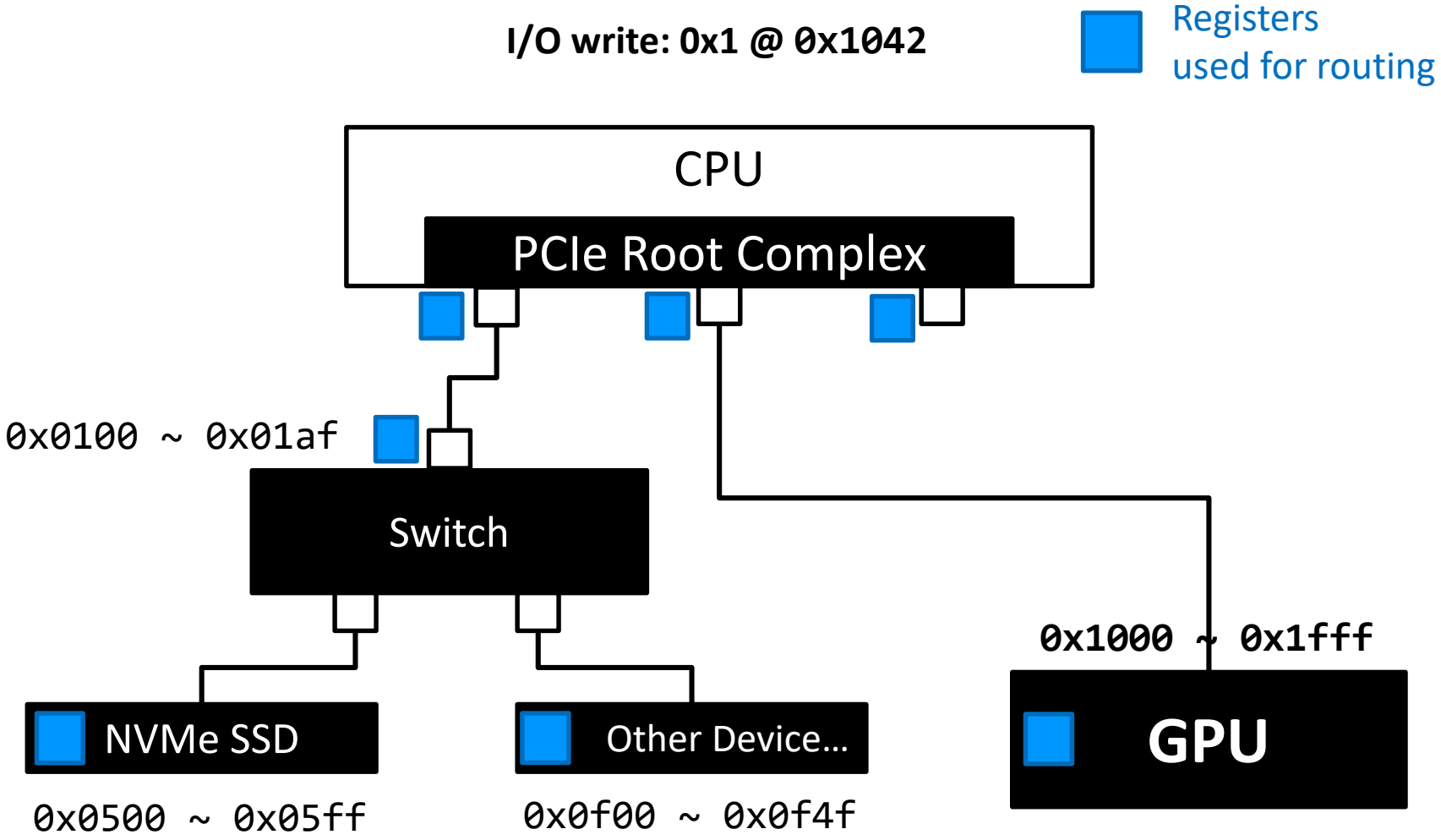

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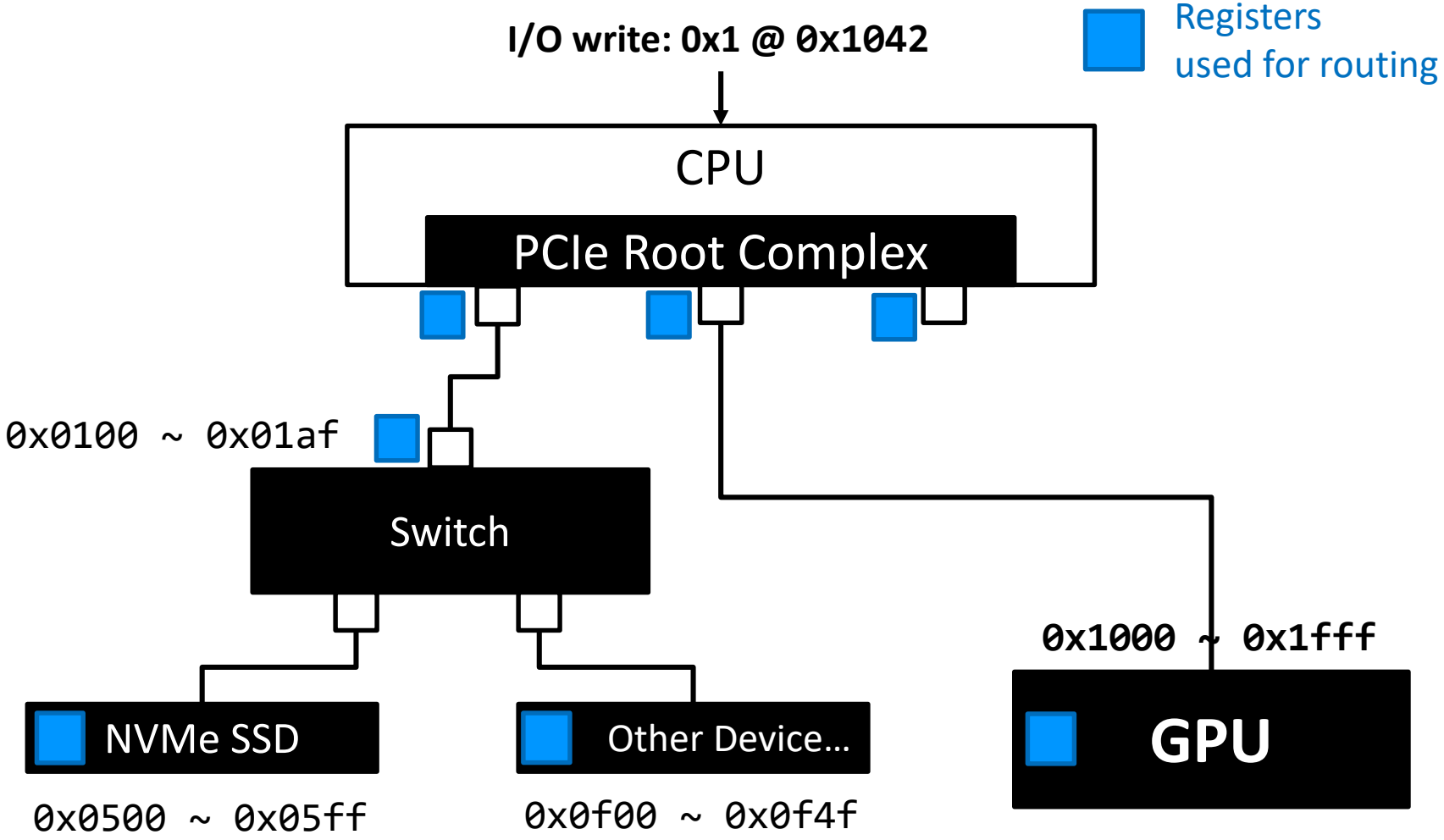

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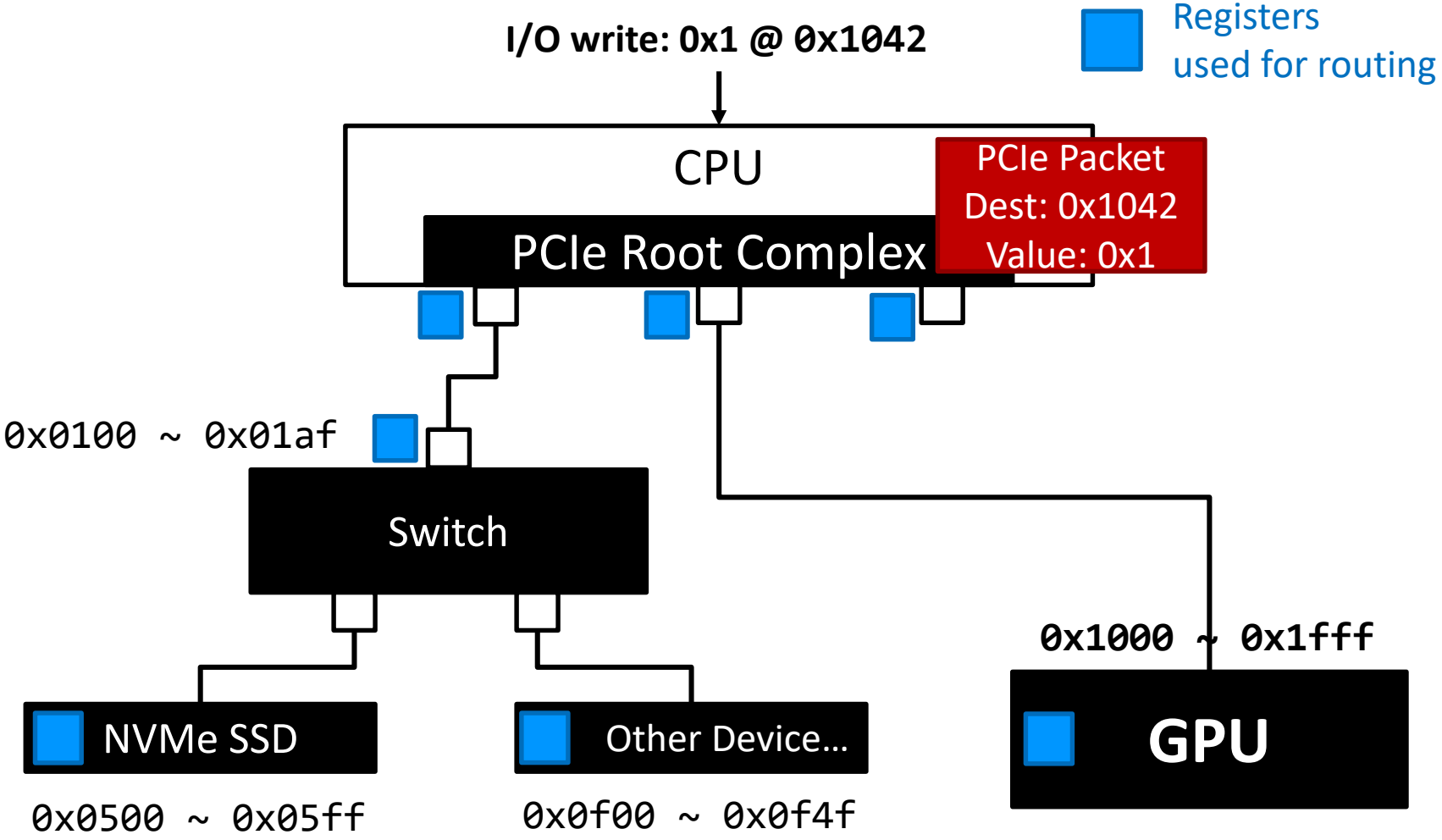

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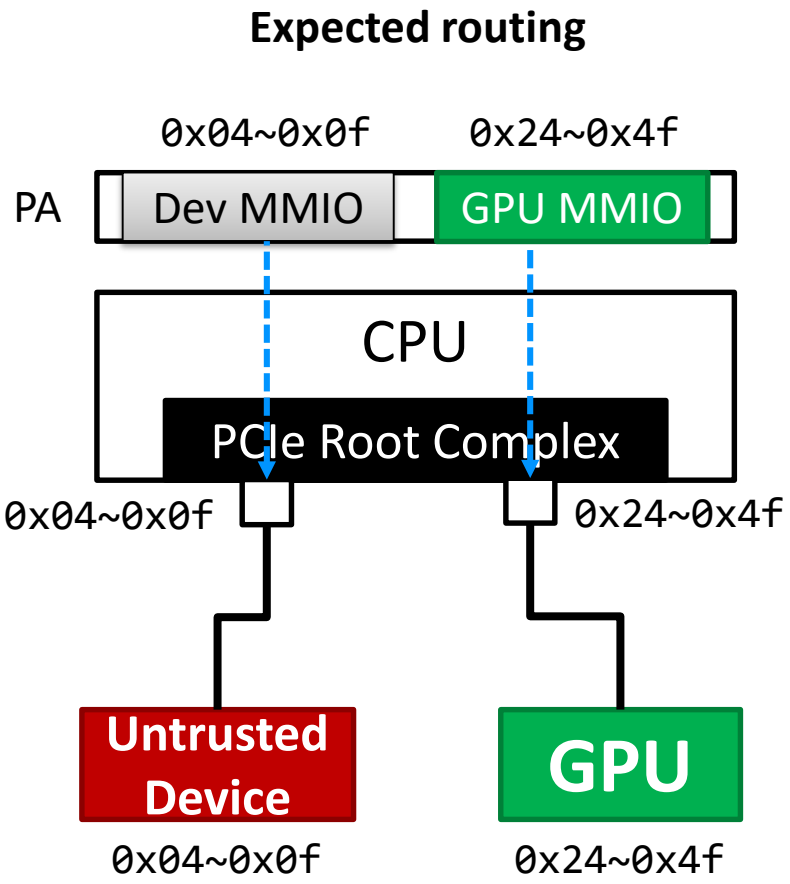

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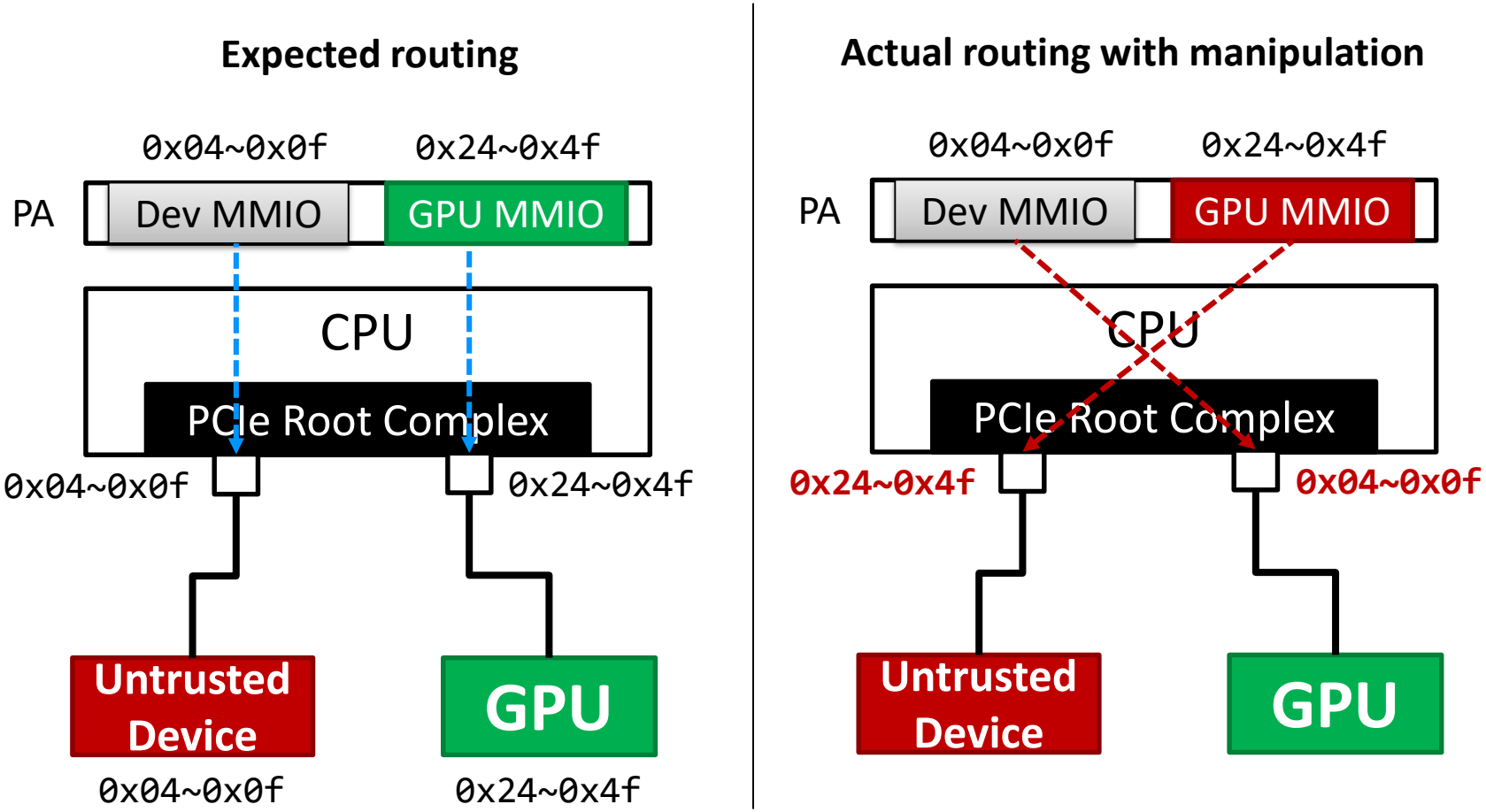

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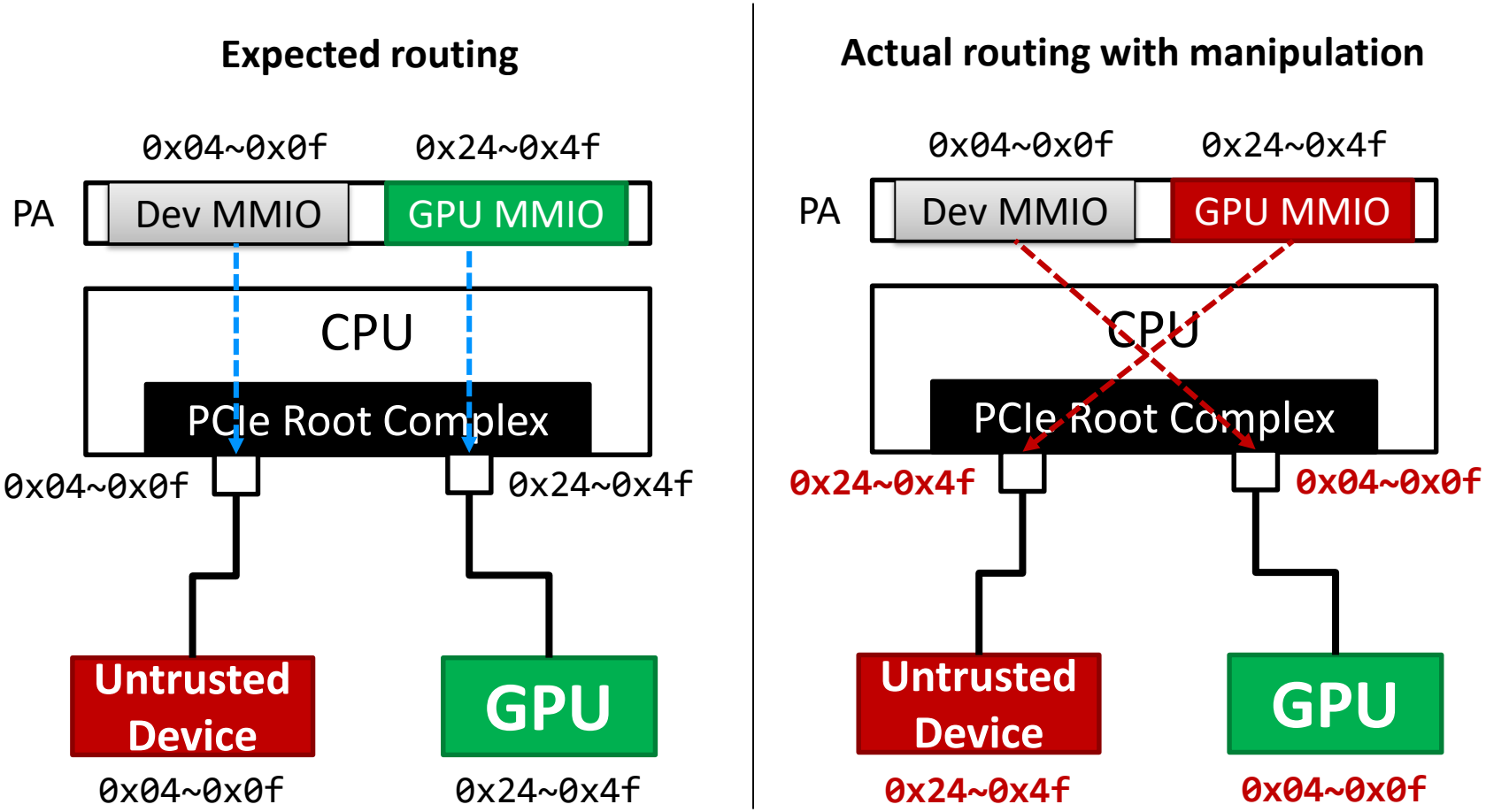

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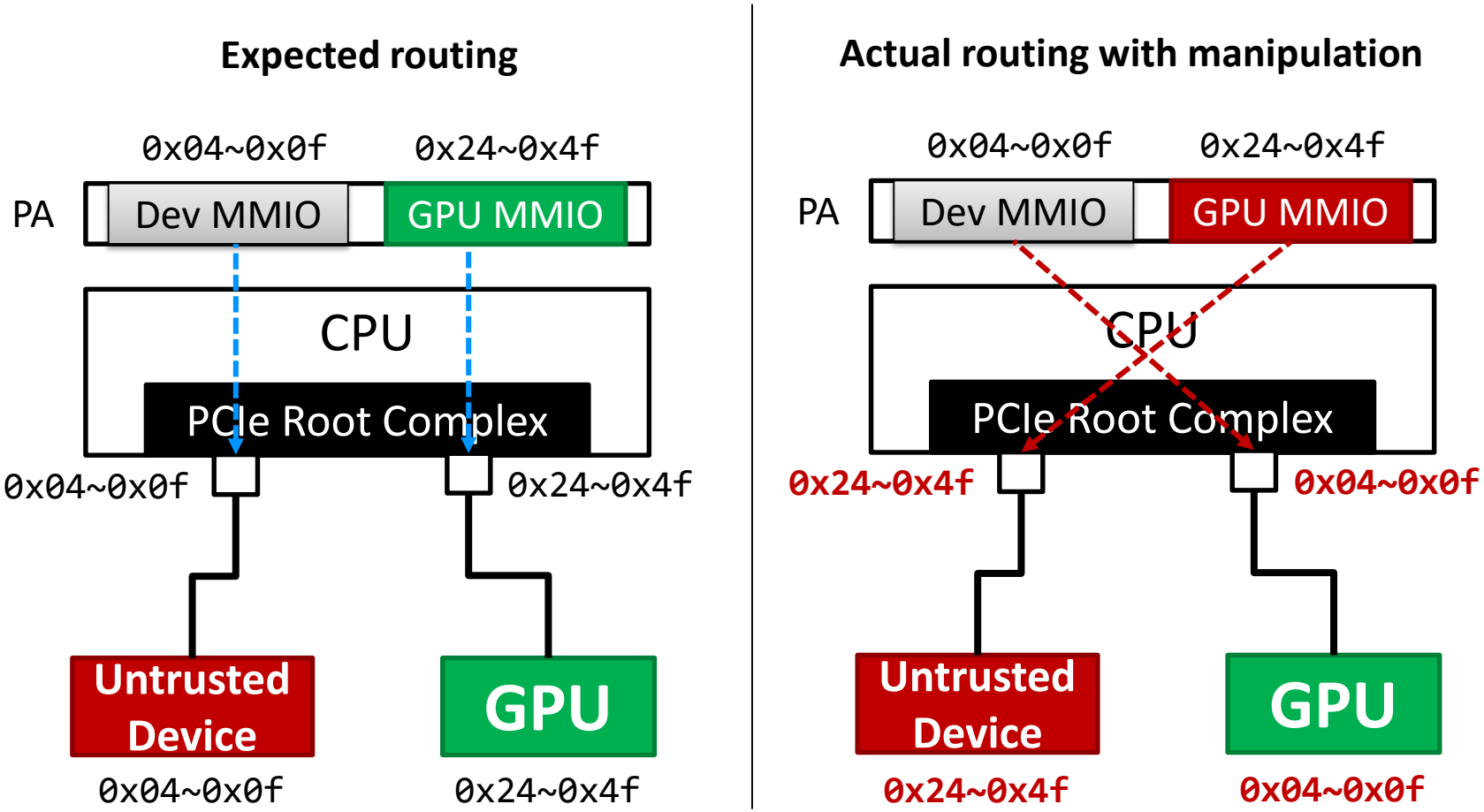

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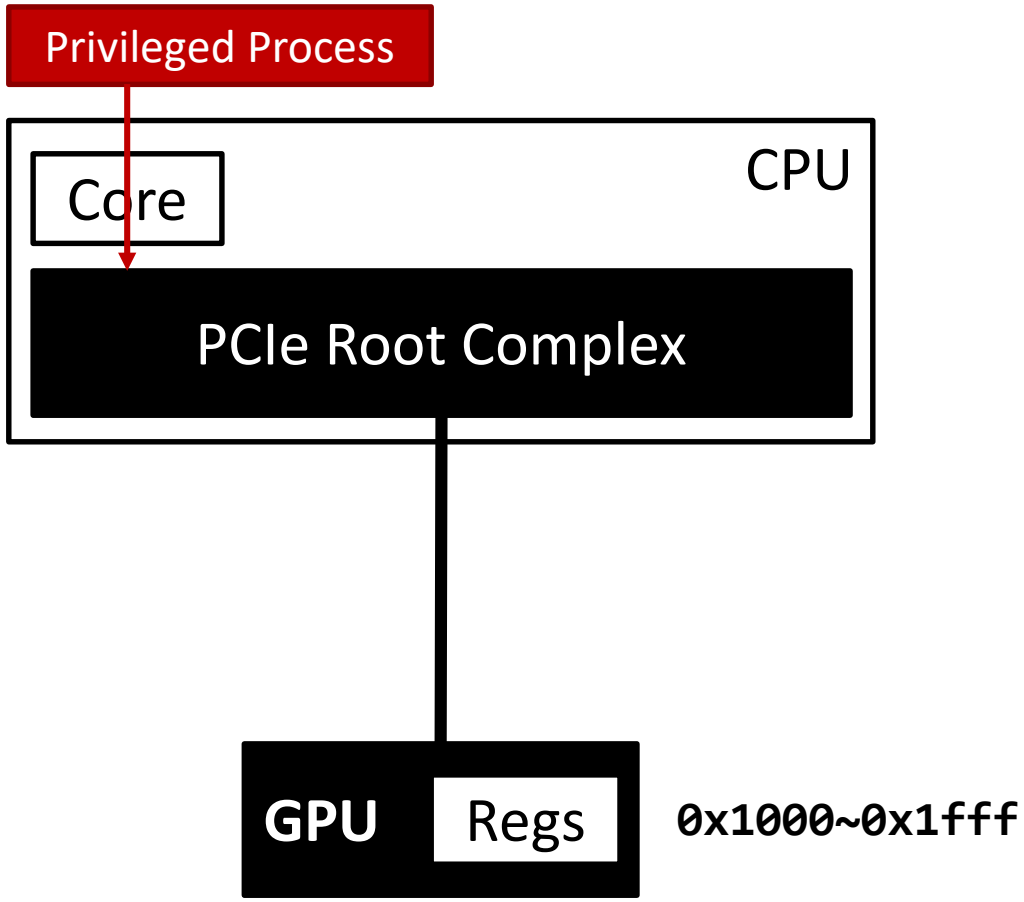
- **Solution:** freeze MMIO routing information (MMIO lockdown)



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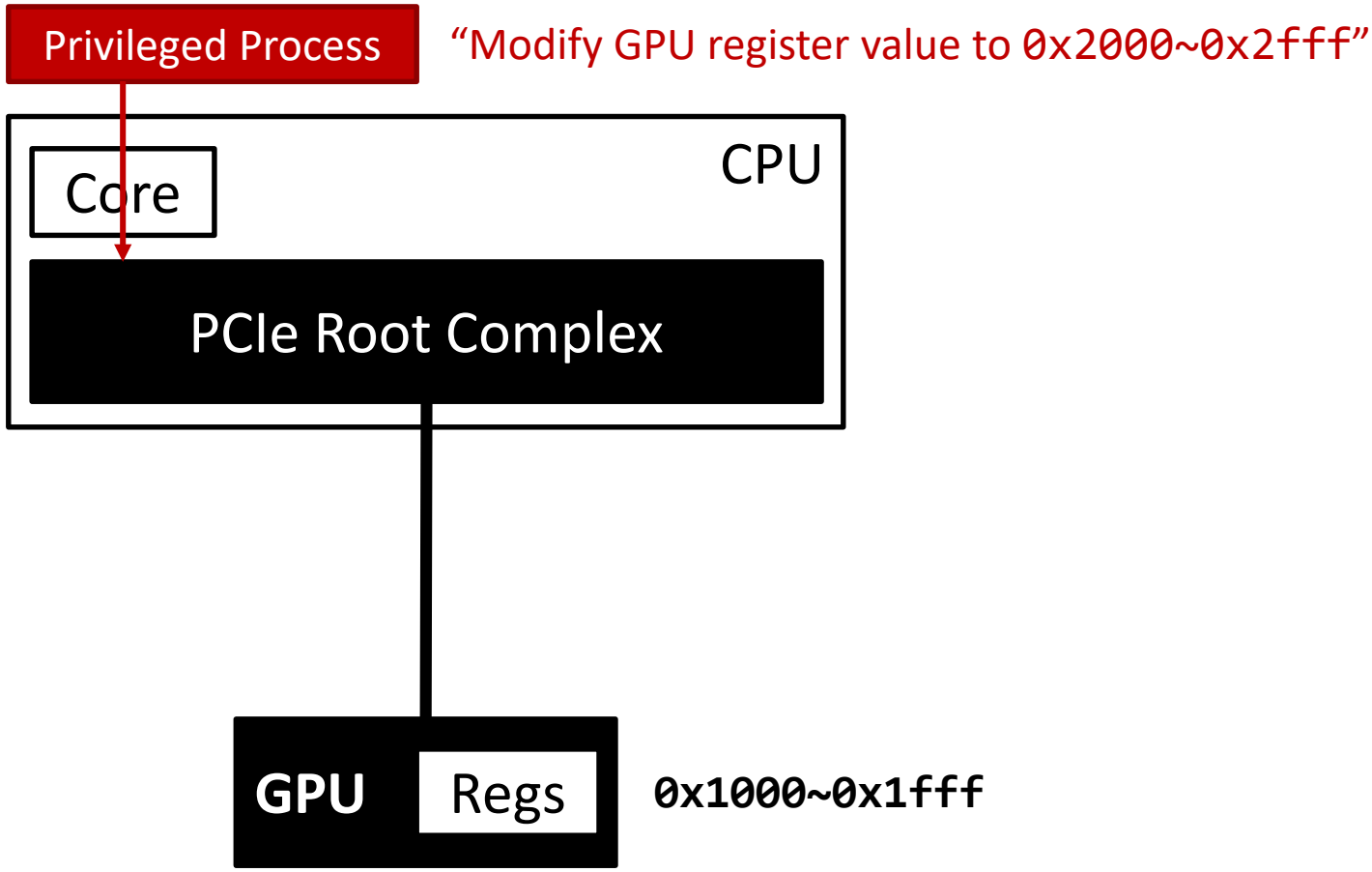

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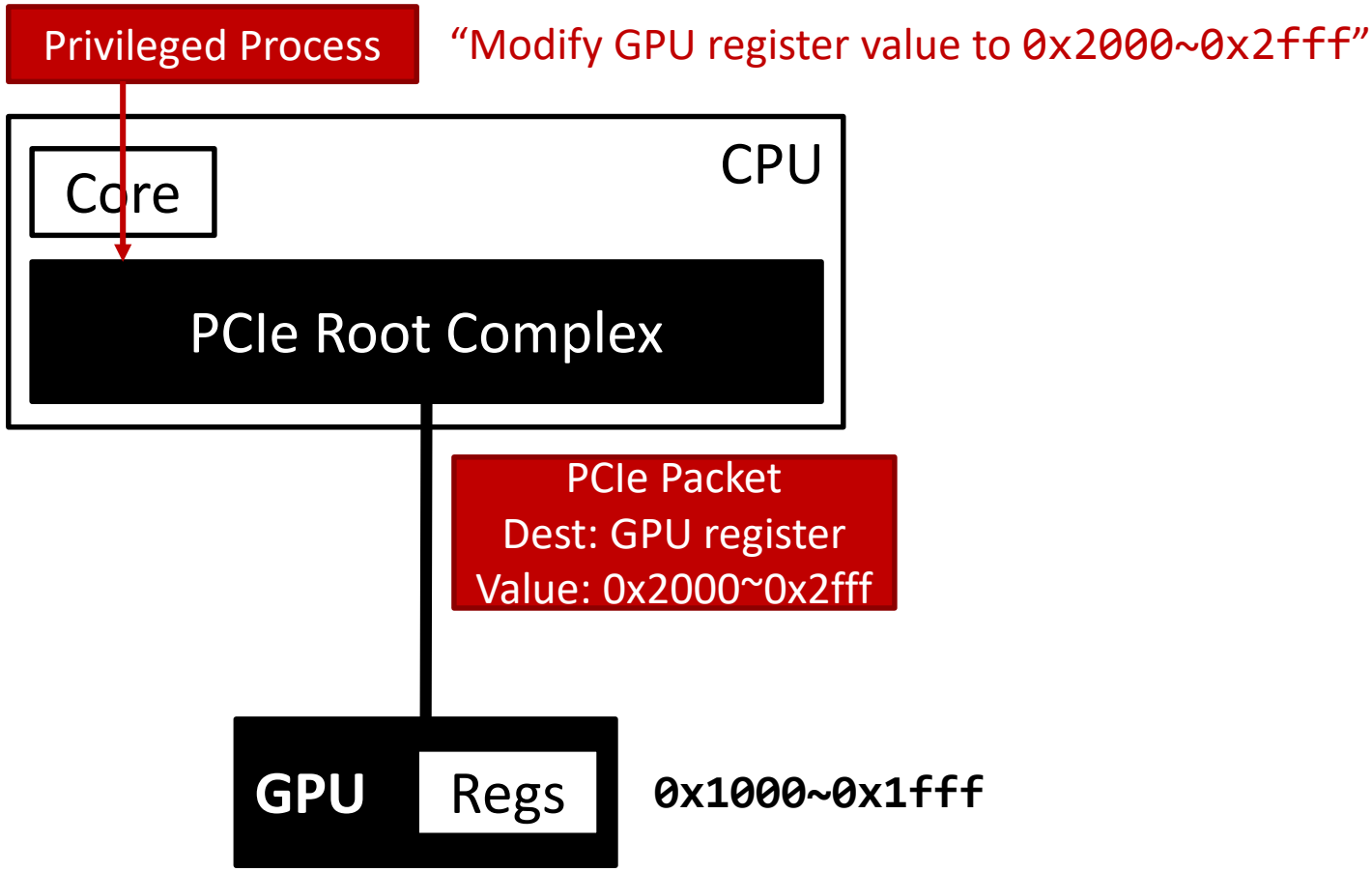

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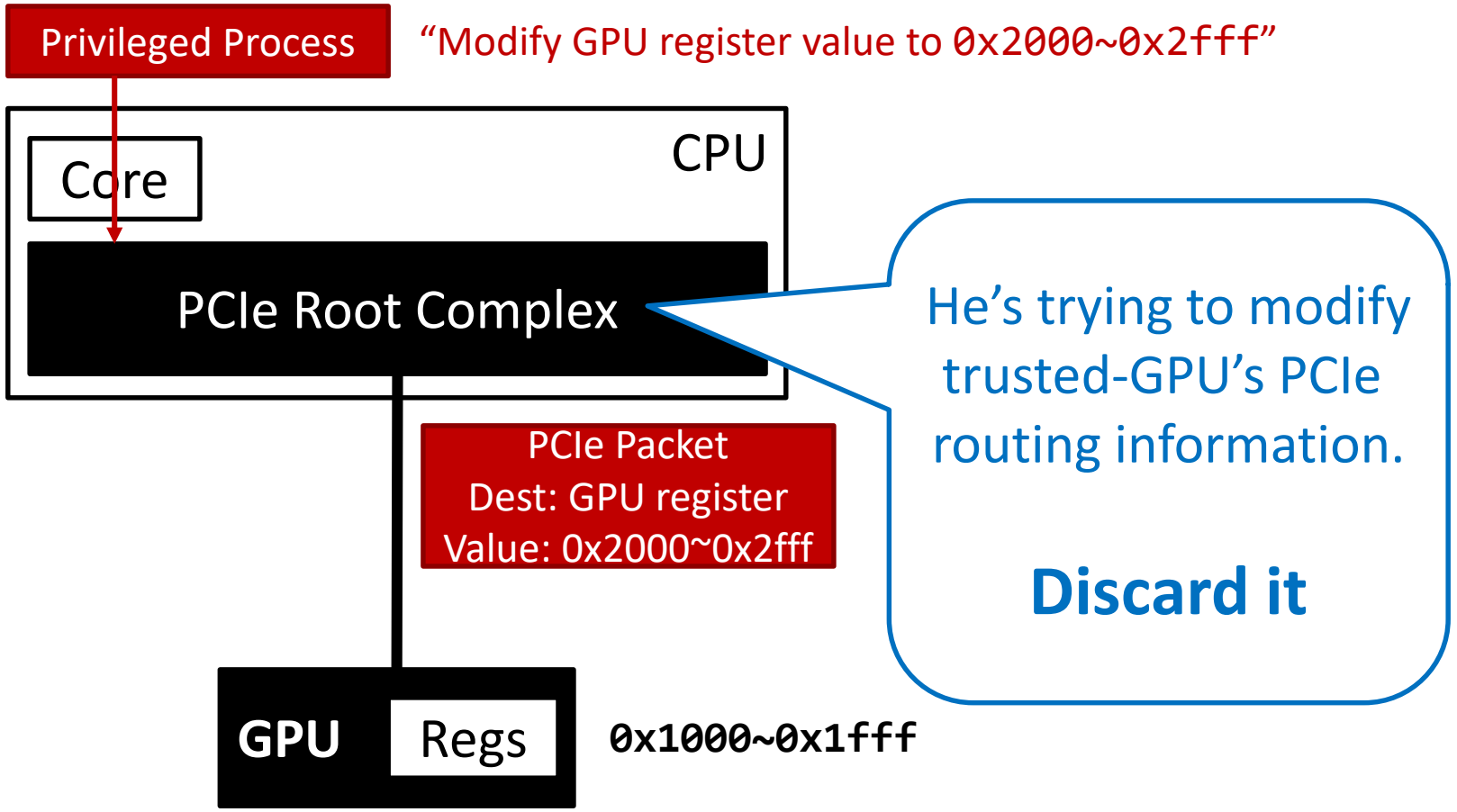

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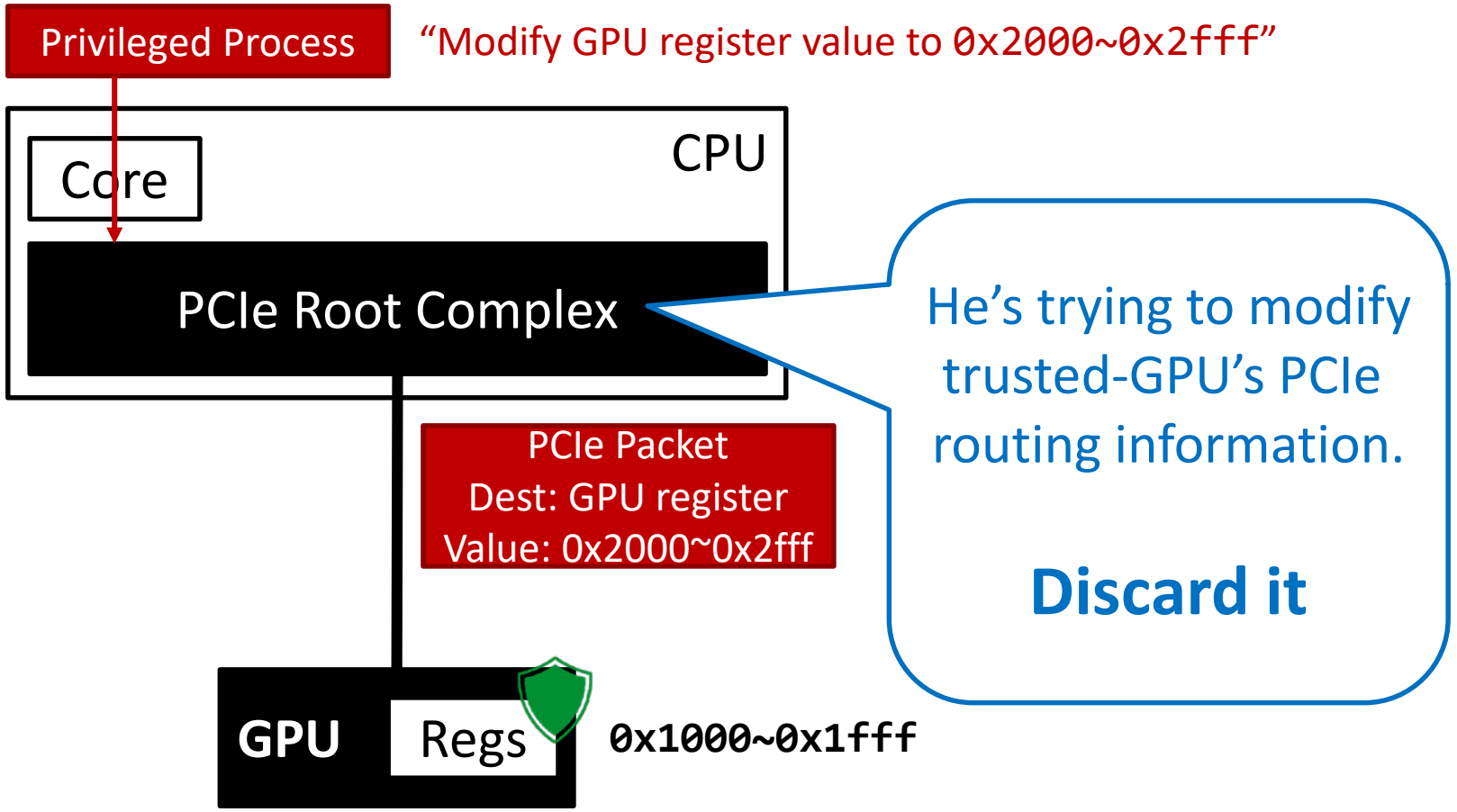
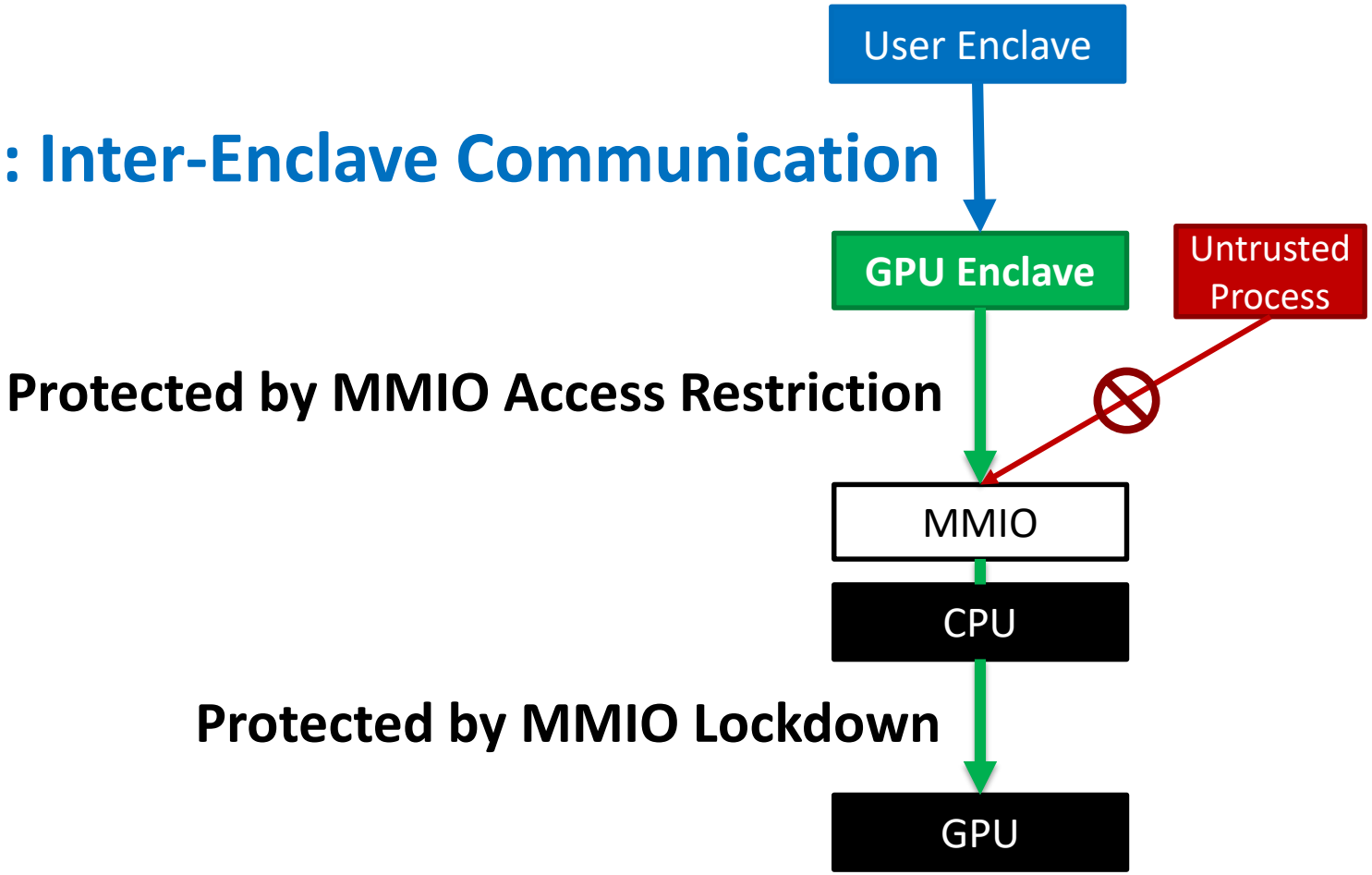


Architecture Review

Next: Inter-Enclave Communication



Inter-Enclave Communication

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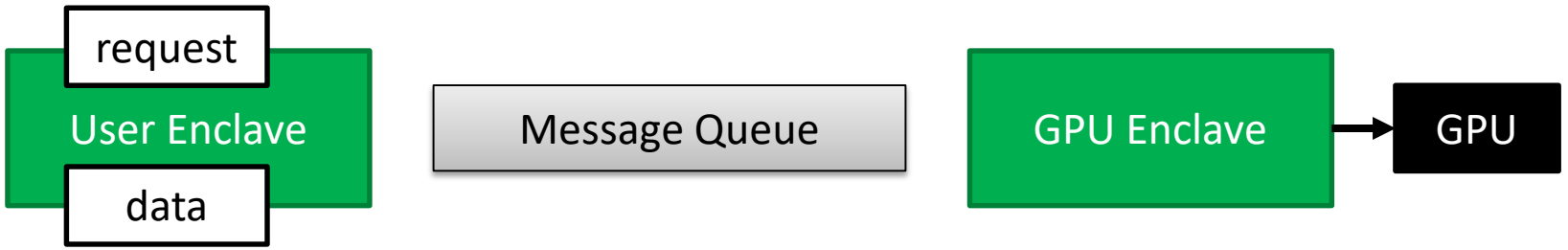

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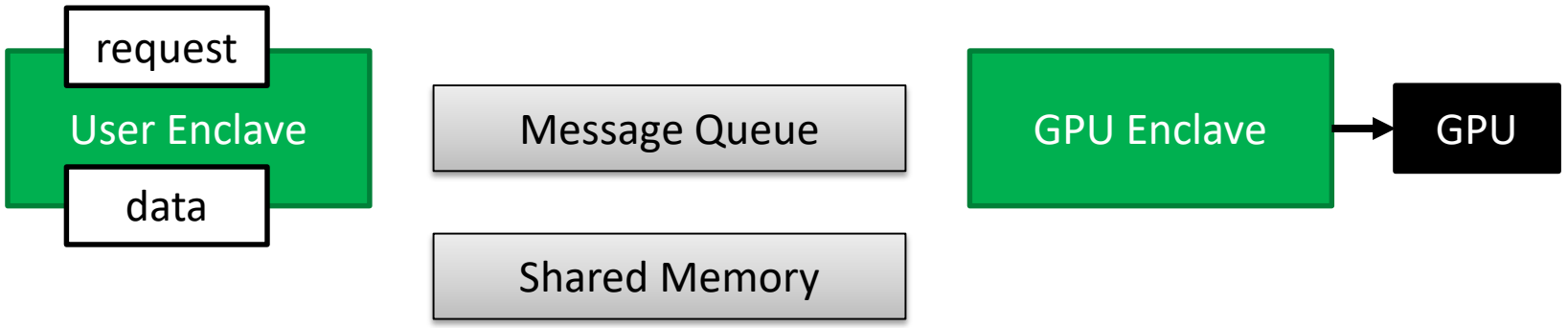

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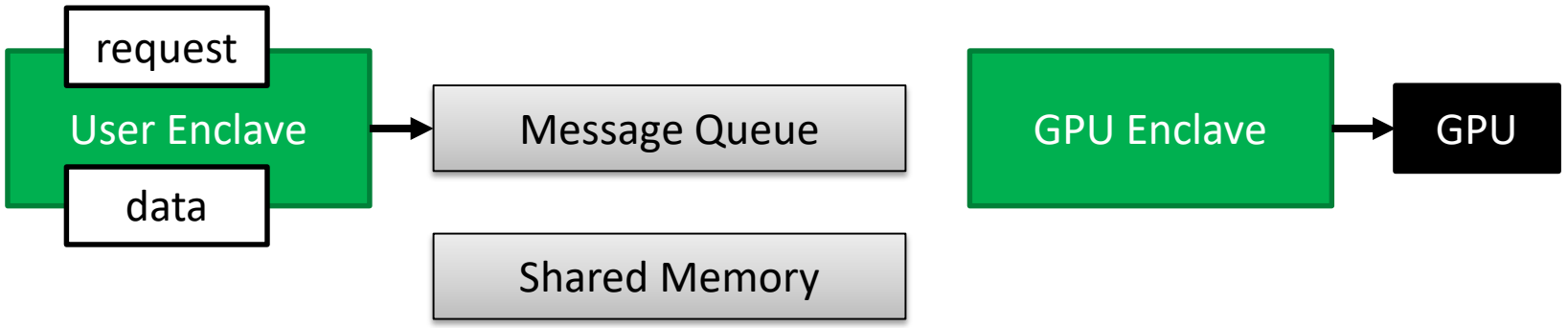

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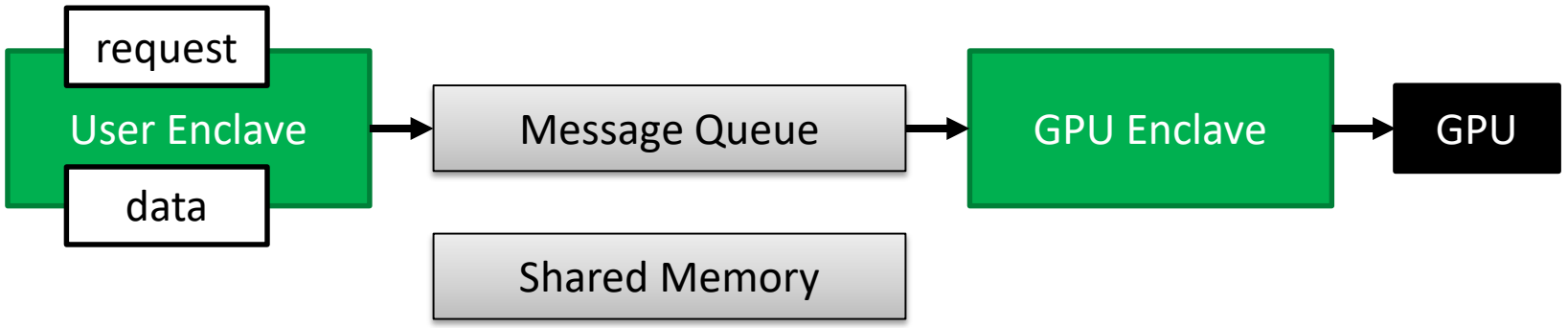

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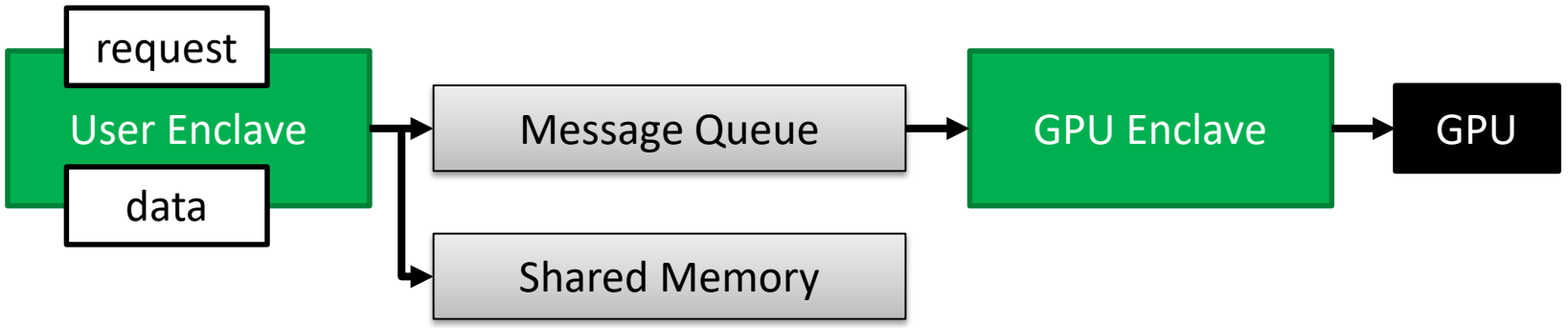

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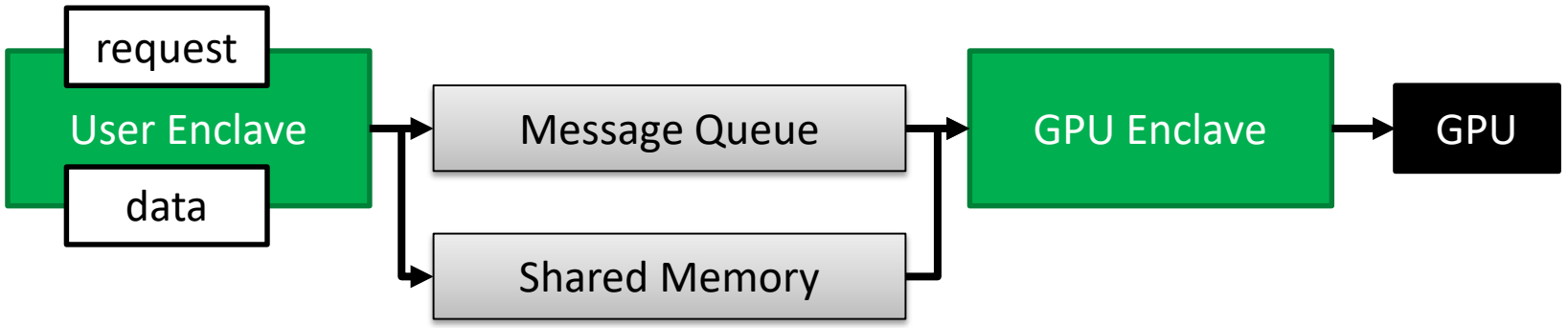
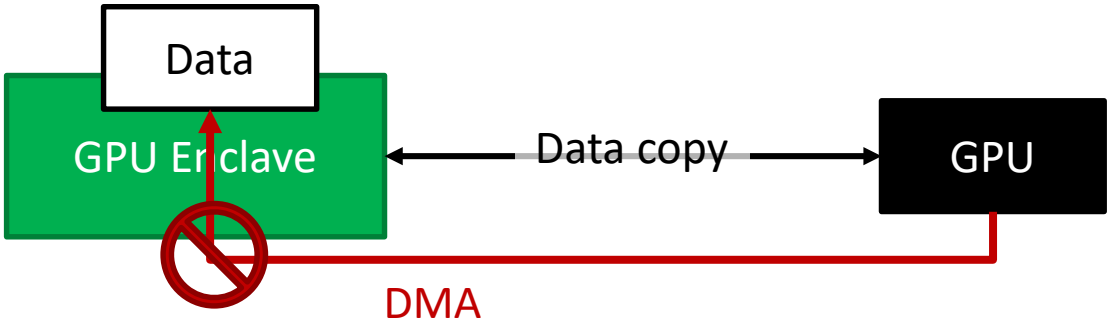


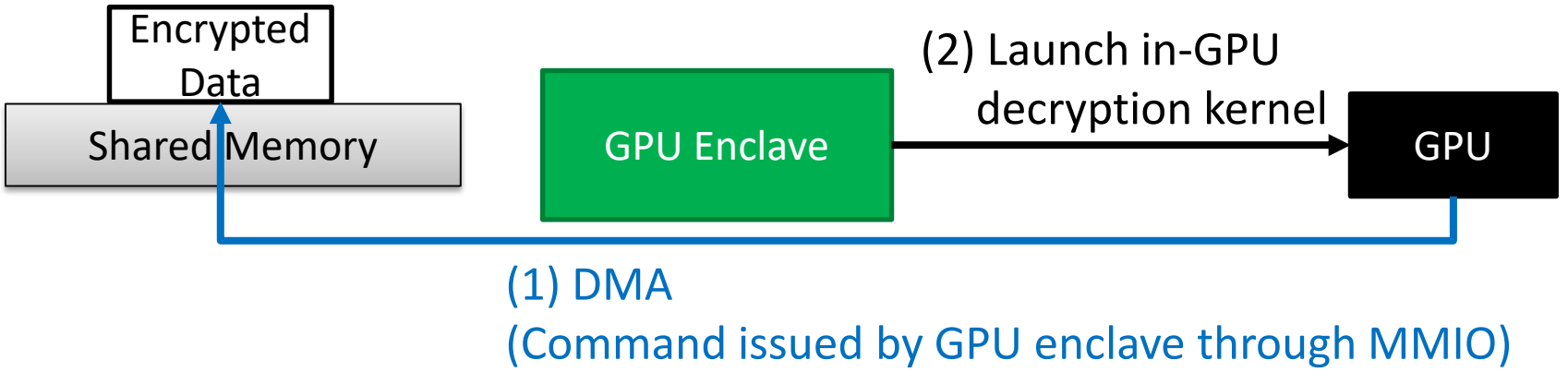
Communication Challenge: DMA

- **Challenge**
  - DMA from device to enclaves not allowed by SGX
  - Data copy can only be done through (slow) MMIO



Trusted DMA Support

- GPU DMAs encrypted data from shared memory to GPU
- GPU enclave launches in-GPU decryption kernel



Evaluation

Evaluation

- Prototype Implementation
  - Hardware changes are emulated in a KVM/QEMU virtual machine
  - GPU enclave implementation is based on Gdev [Kato, ATC'12]

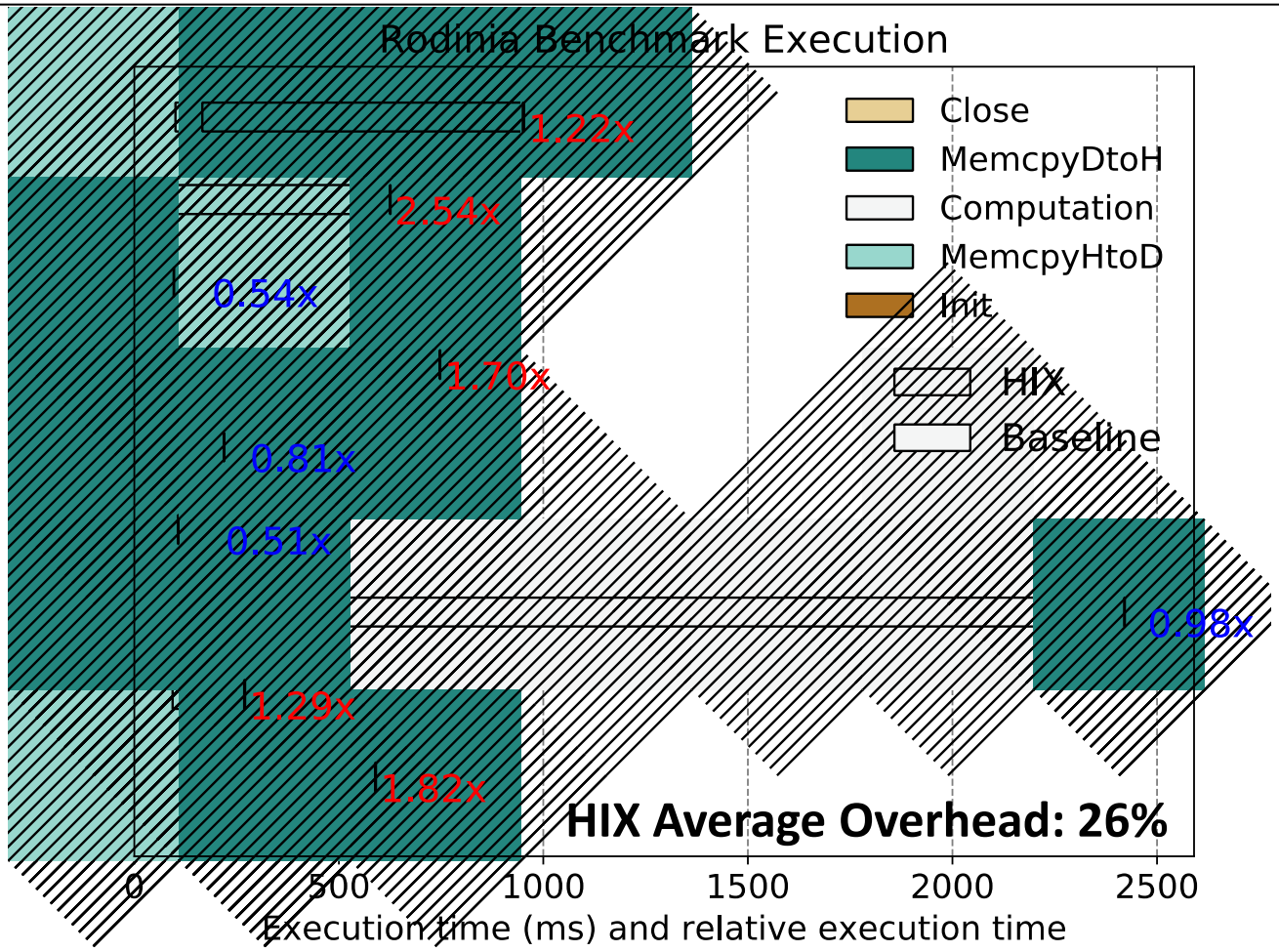
- Performance analysis: Rodinia GPU microbenchmark
  - Measure overheads due to cryptography, etc.
  - Baseline: unmodified Gdev NVIDIA GPU driver

	Baseline	HIX
Trusted Execution	No	Yes
Encryption	N/A	AES-OCB [Rogaway '14]
GPU	NVIDIA Geforce GTX 580*	

** Newer devices are not supported by Gdev*

Performance Result: Rodinia

App Name	SRAD	PF	NN	NW	LUD	HS	GS	BFS	BP
Memcpy	48.4MB	256.0MB	501.2KB	192.1MB	32.0MB	12.0MB	64.0MB	46.9MB	159.8MB



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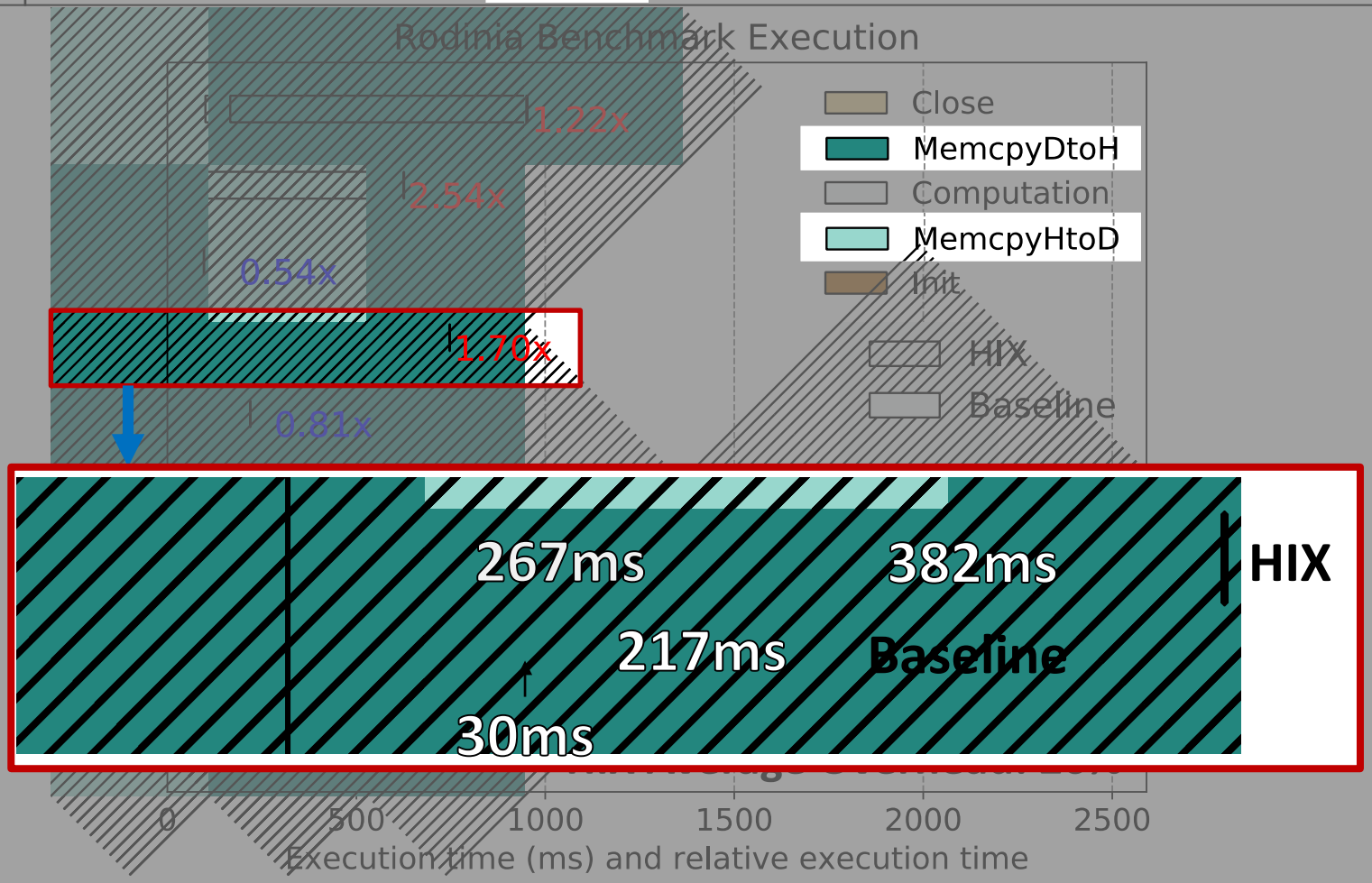

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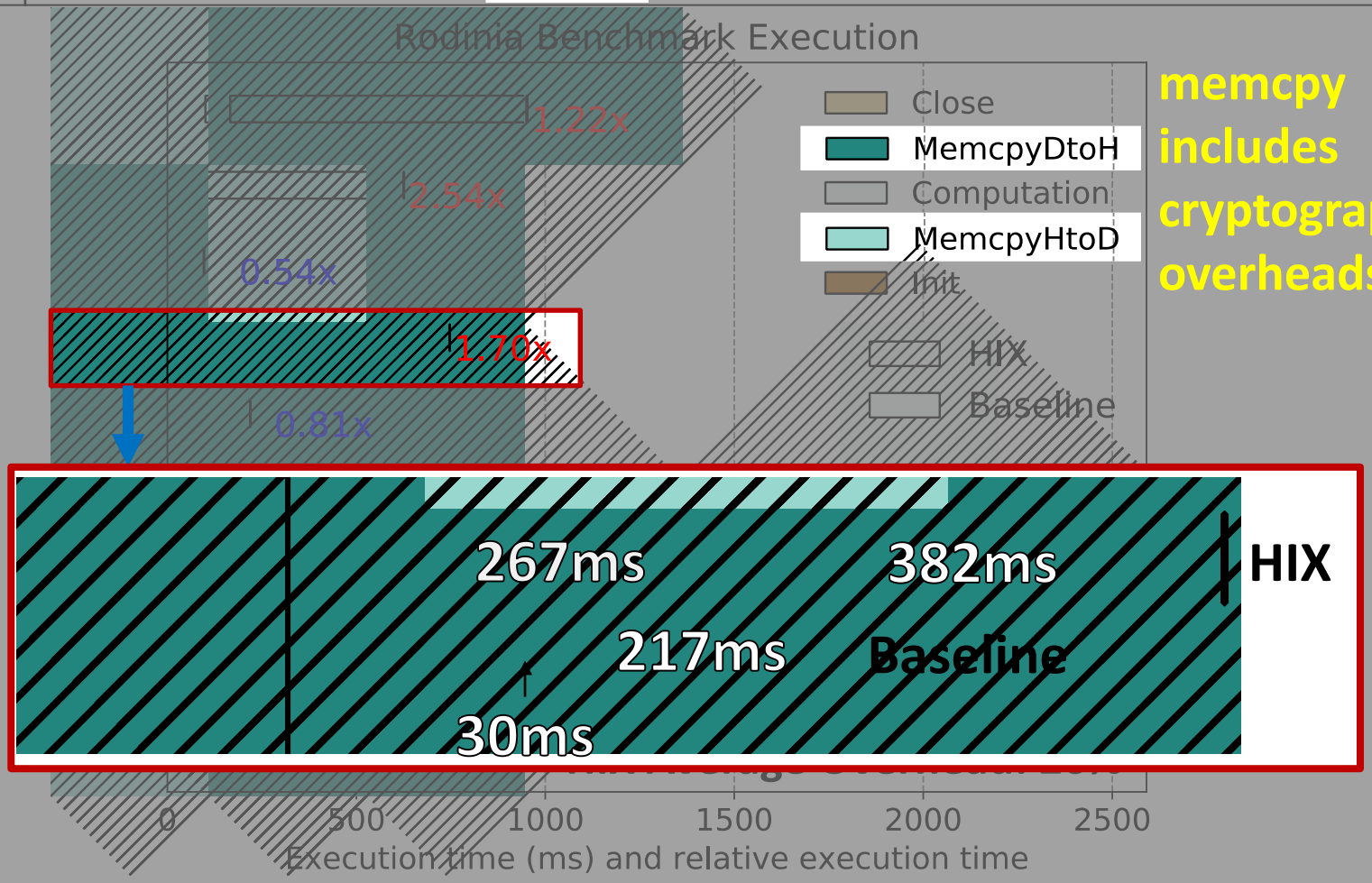

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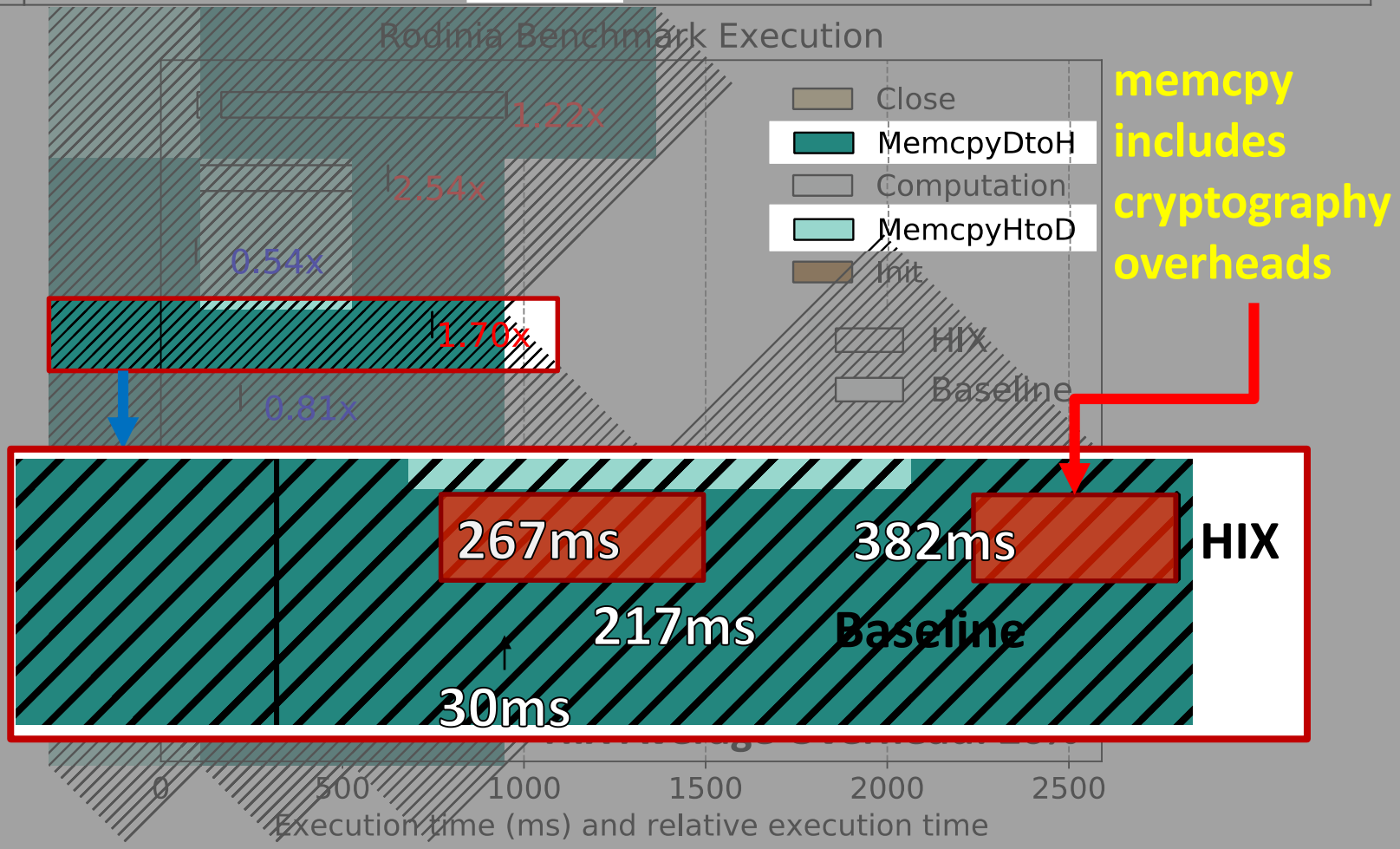

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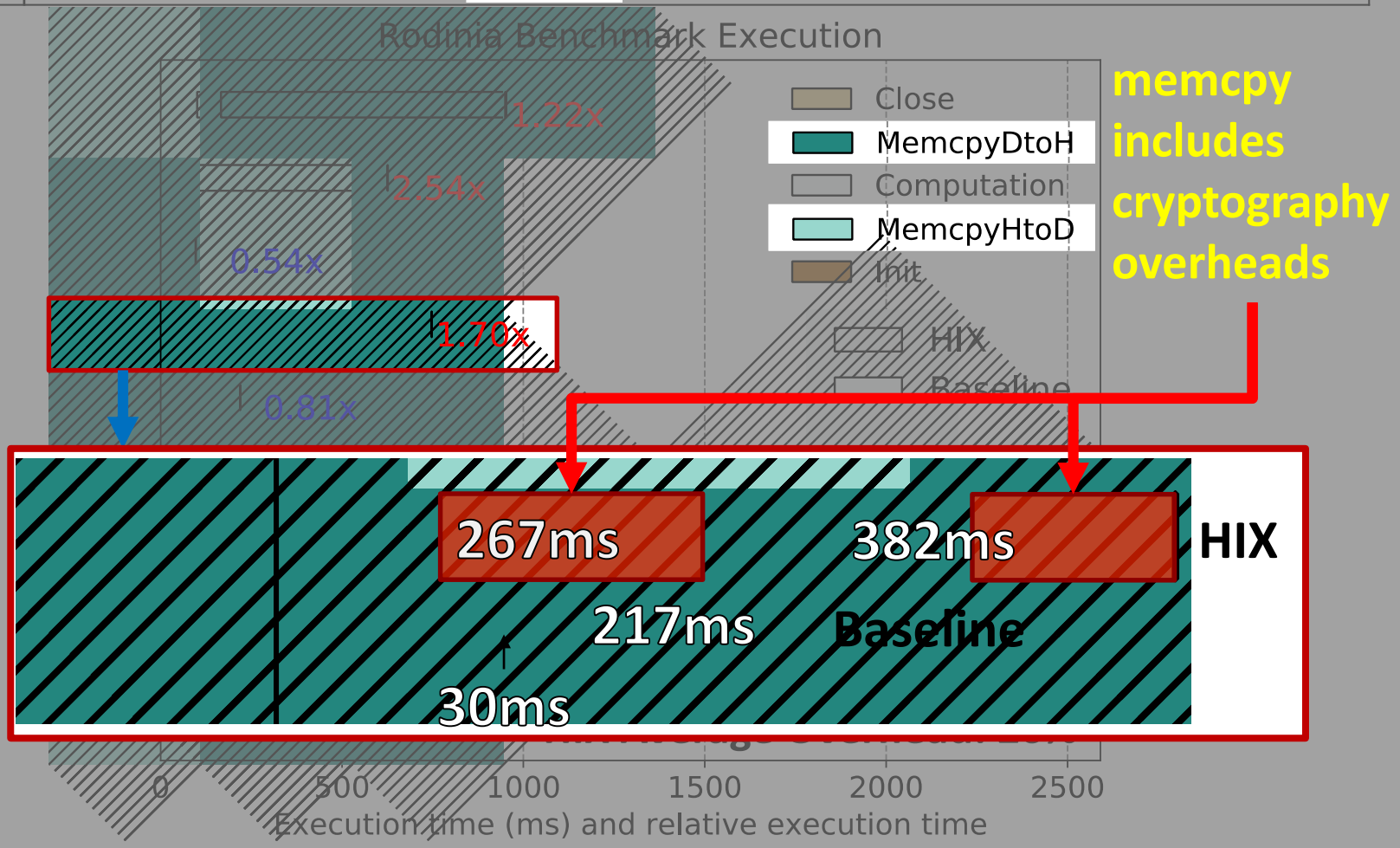

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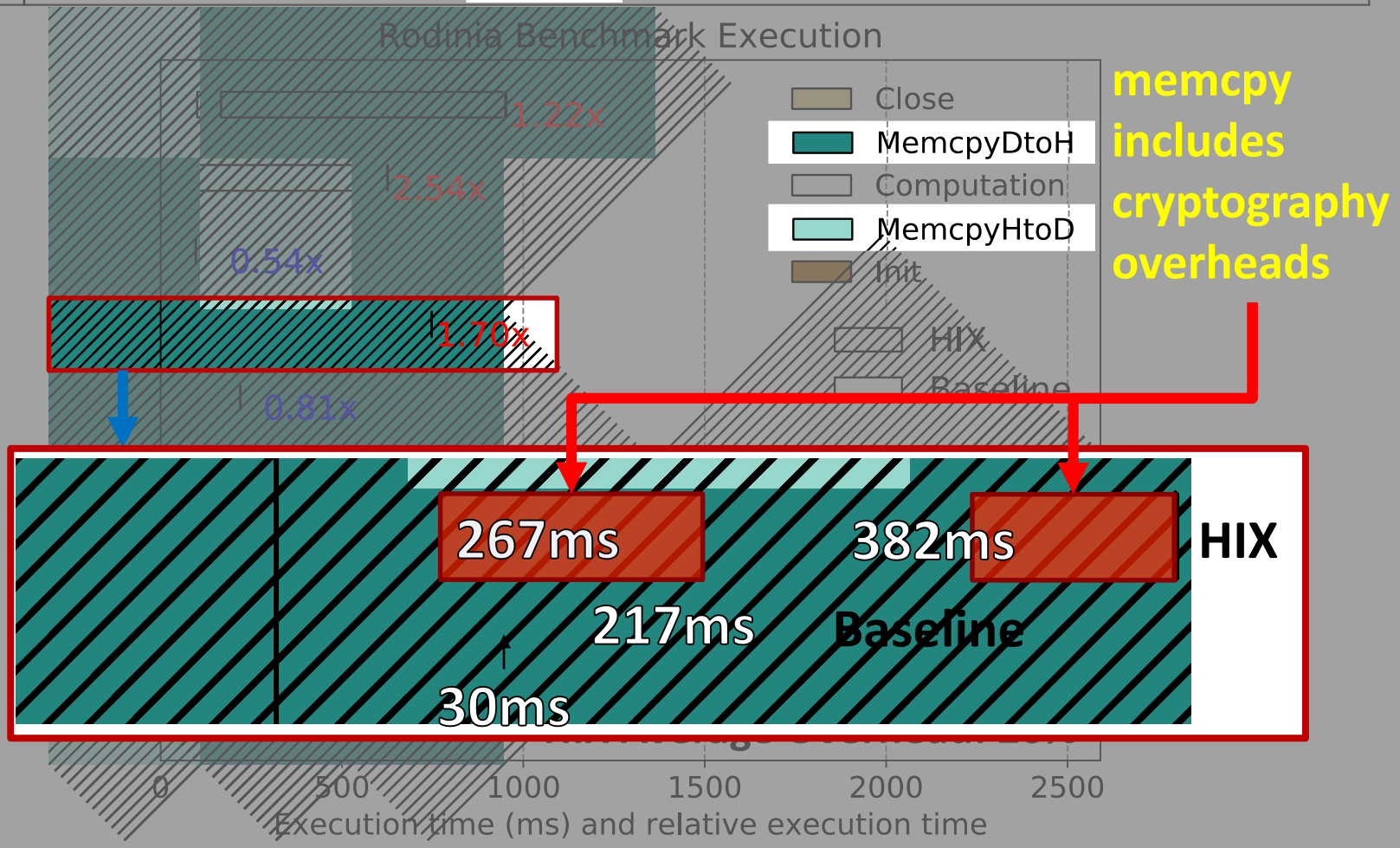

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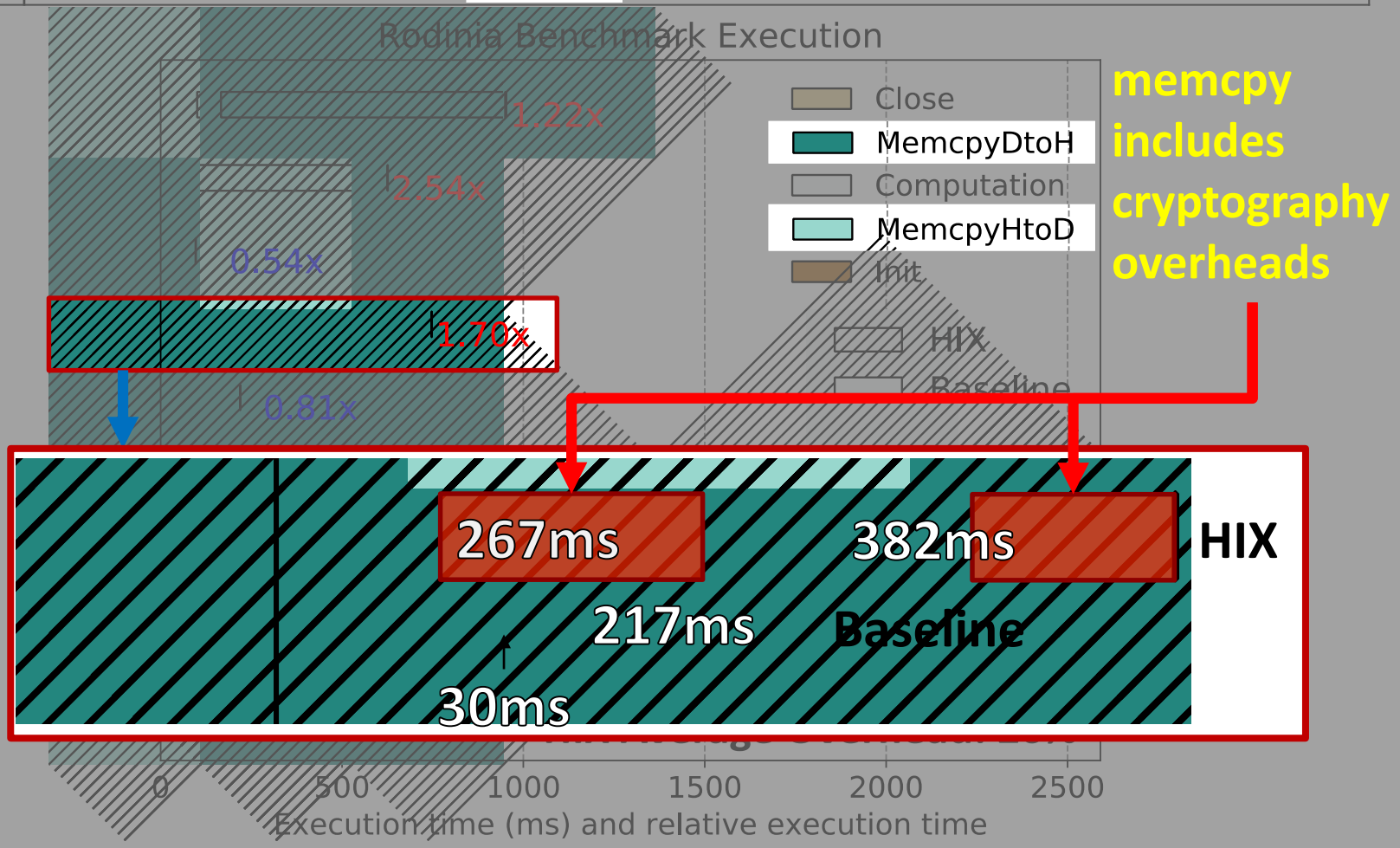

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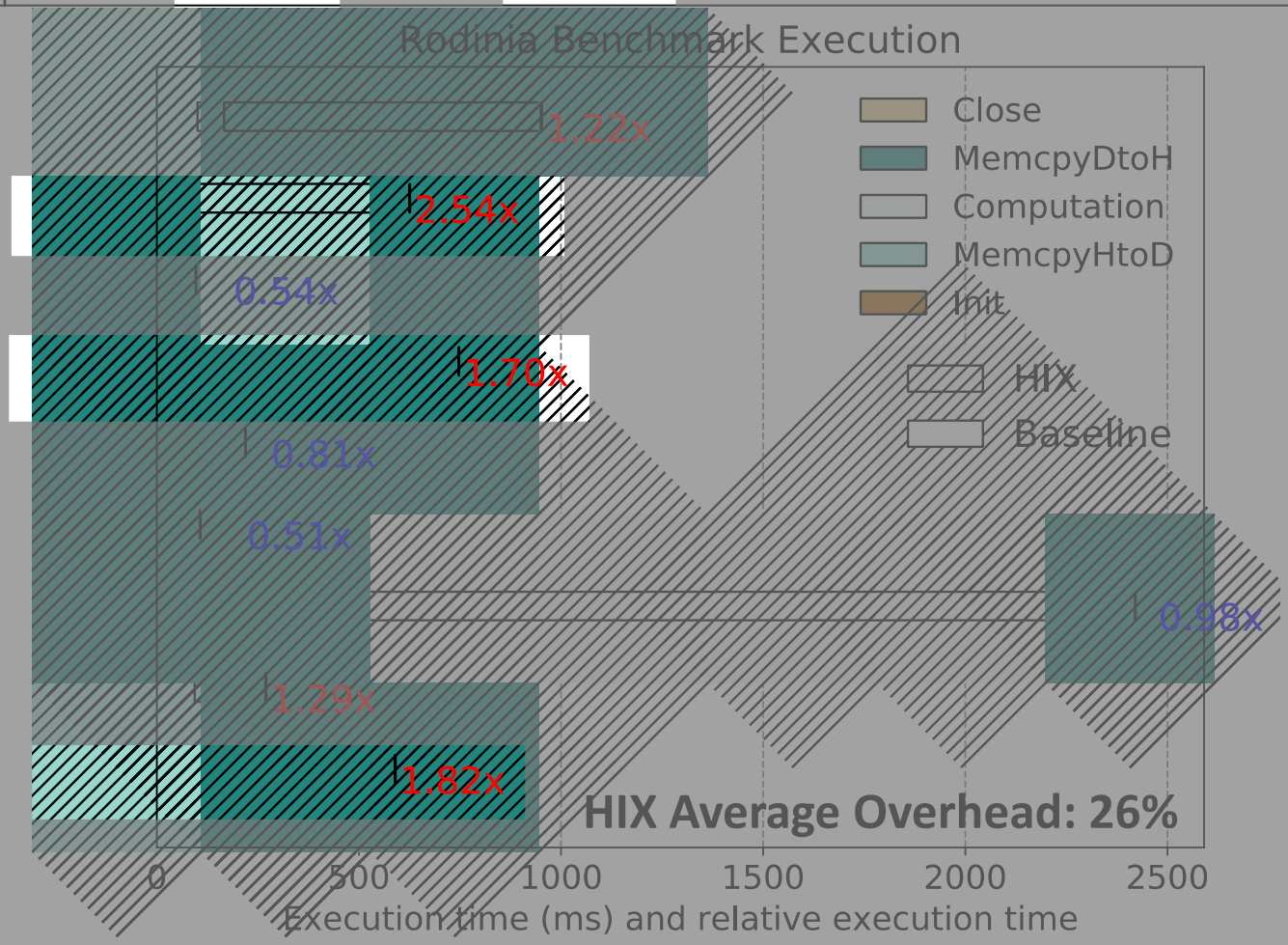

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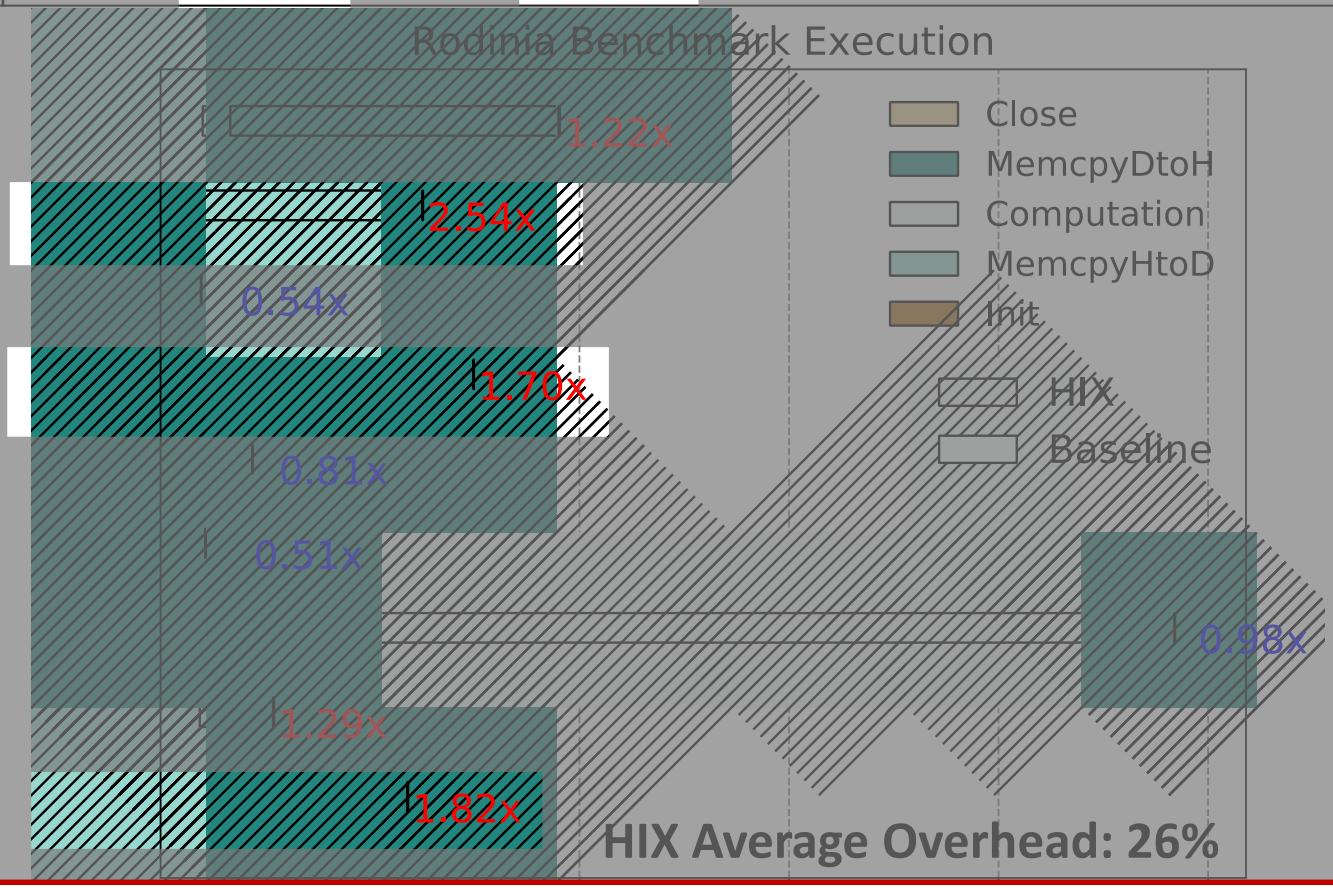

Large Amount of Data → High Cryptography Overheads

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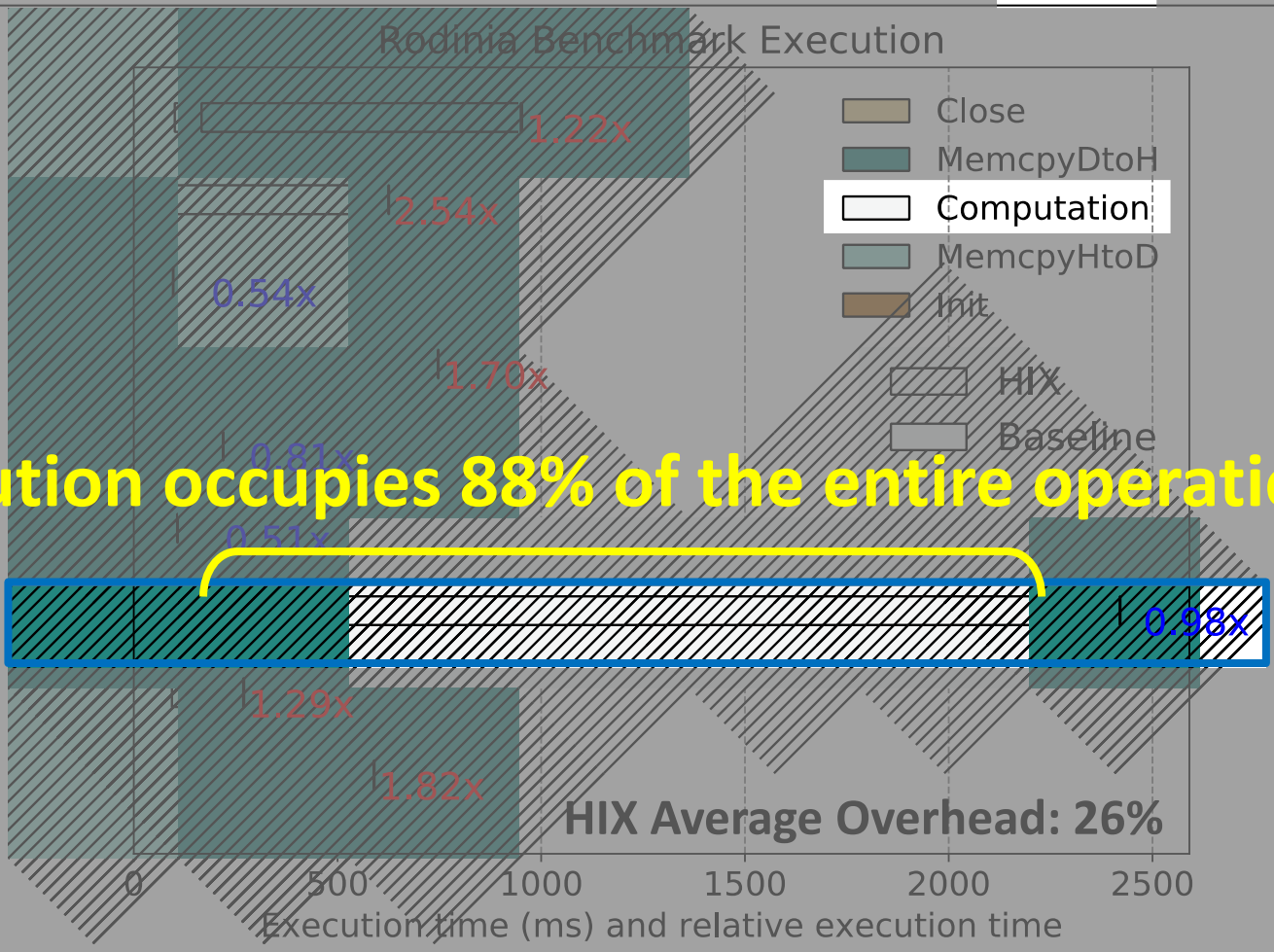

Execution occupies 88% of the entire operation time

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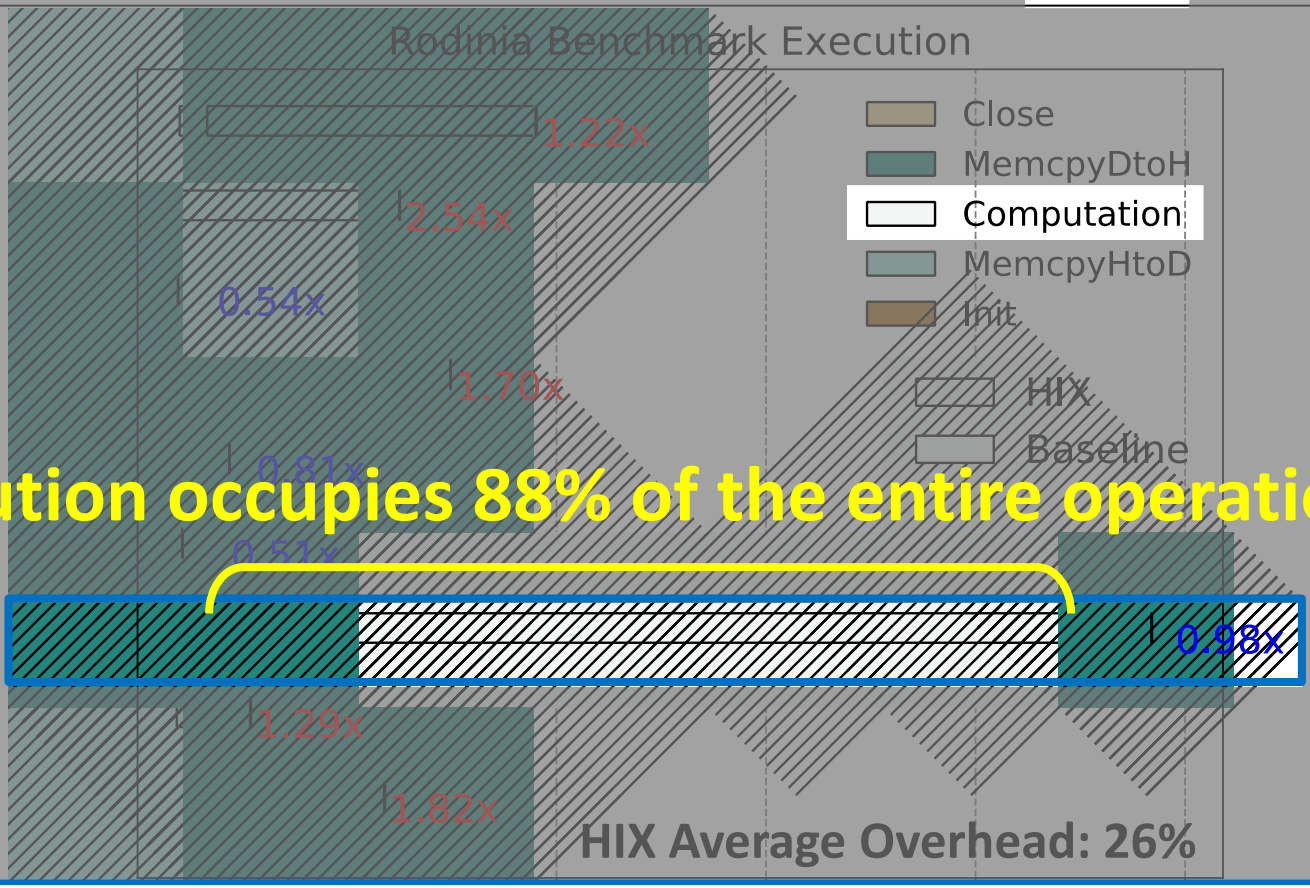

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High Computational Ratio → Cryptography Overhead Ratio Reduced

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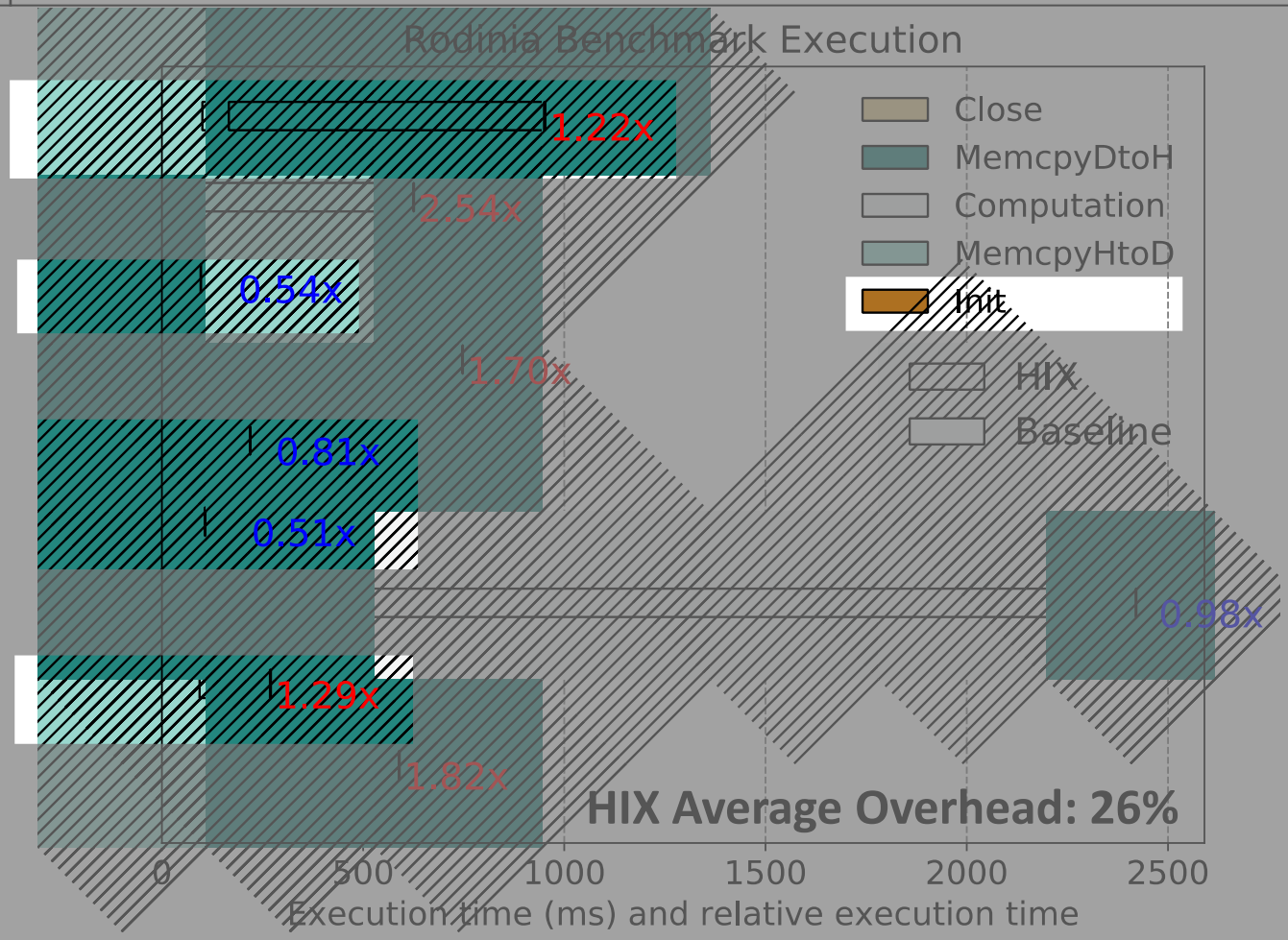

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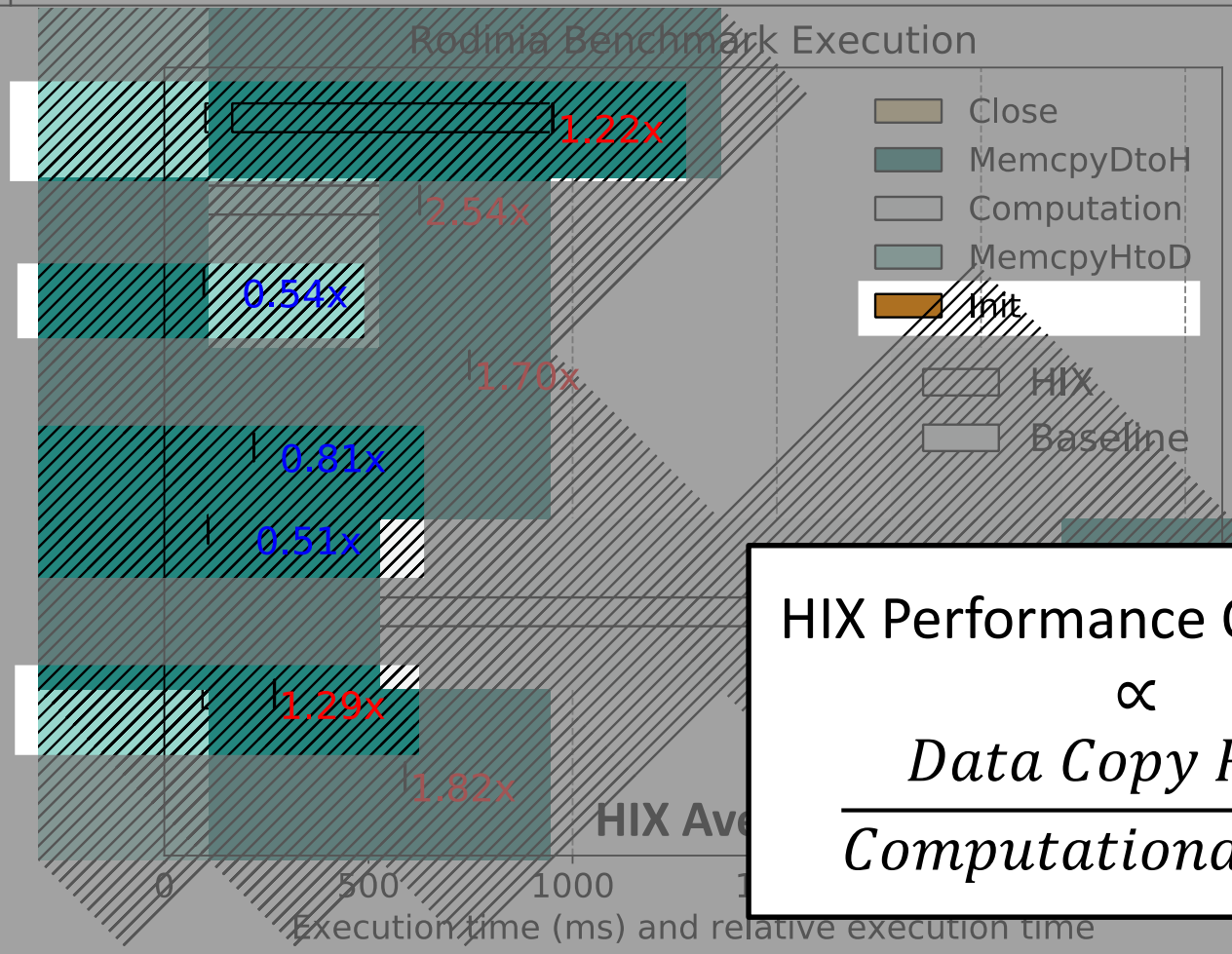
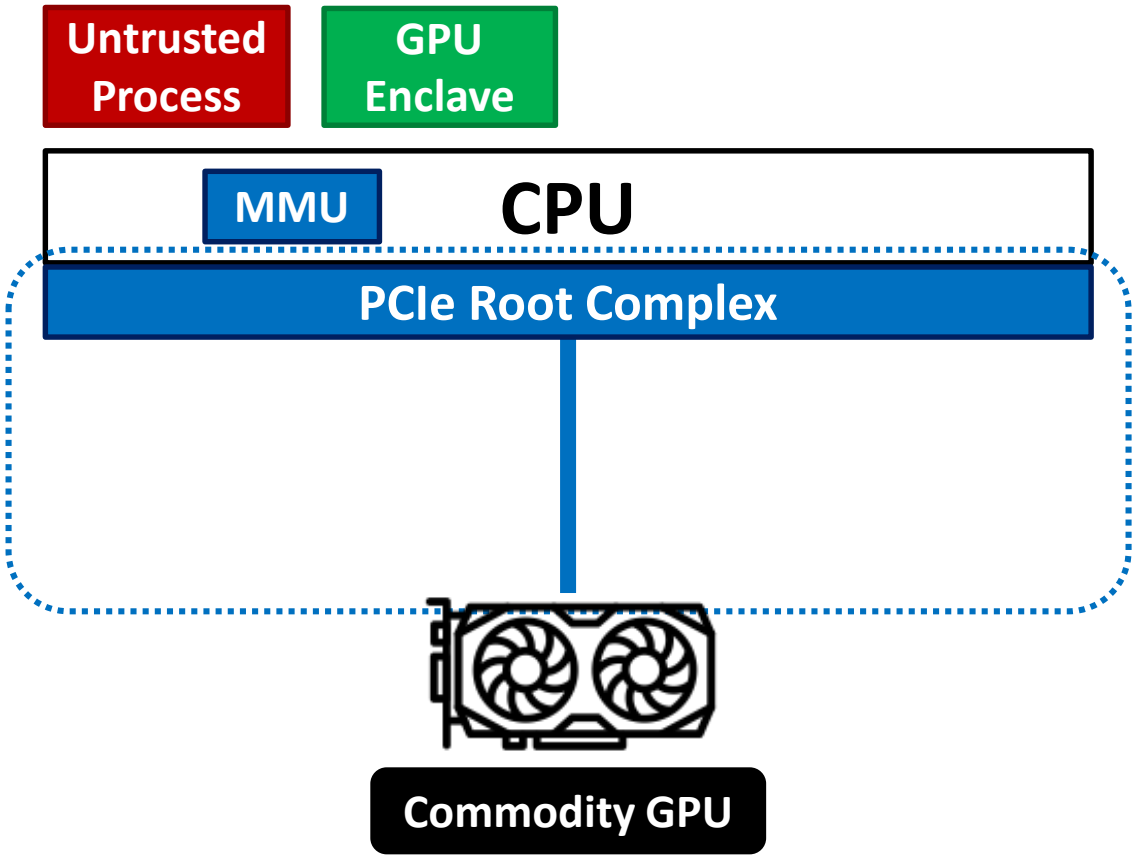


HIX Performance Overheads

$$\propto \frac{Data\ Copy\ Ratio}{Computational\ Ratio}$$

Conclusion

- HIX: Provide trusted execution environment to **commodity GPUs**



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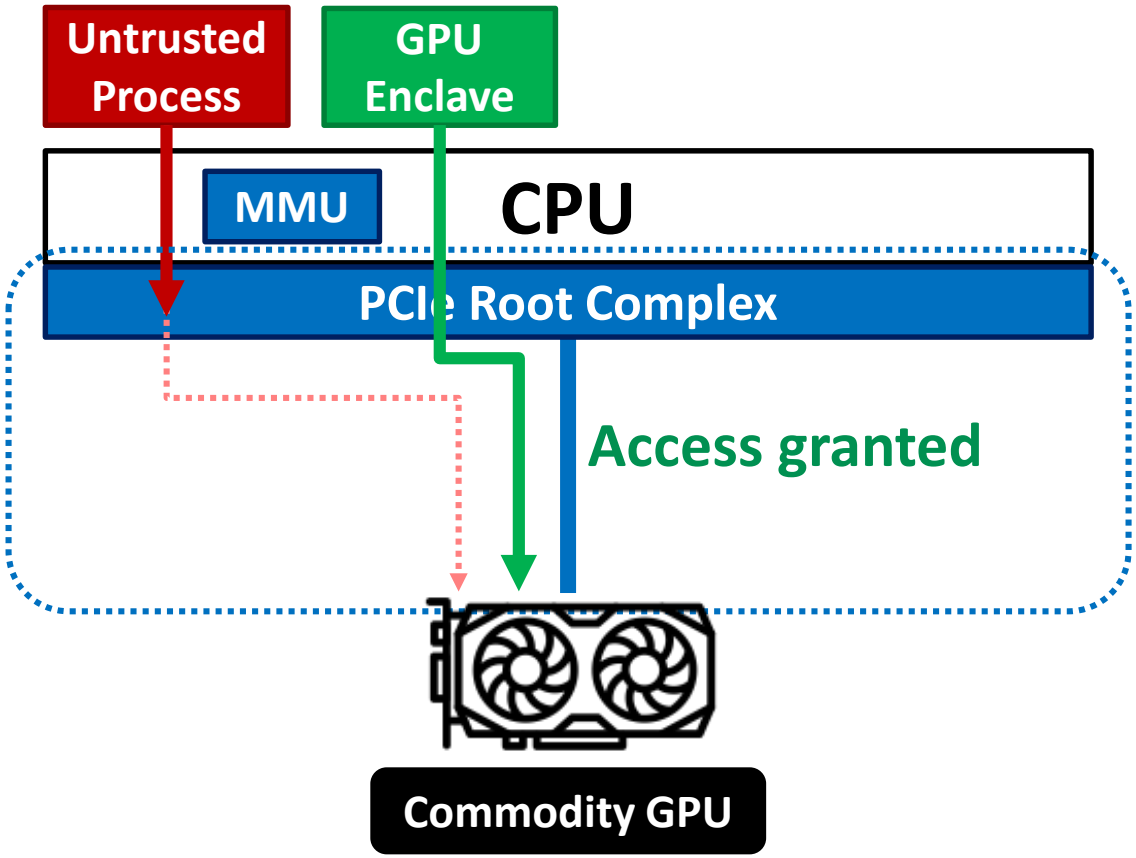

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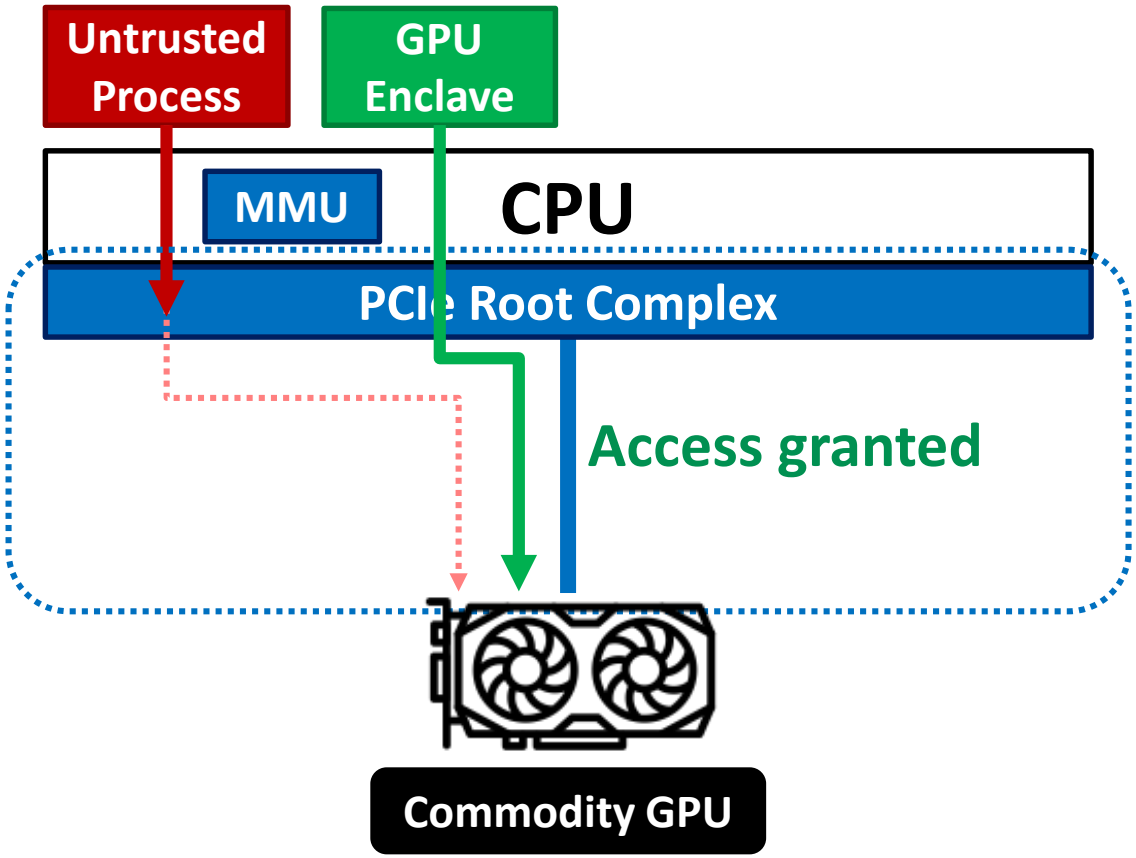

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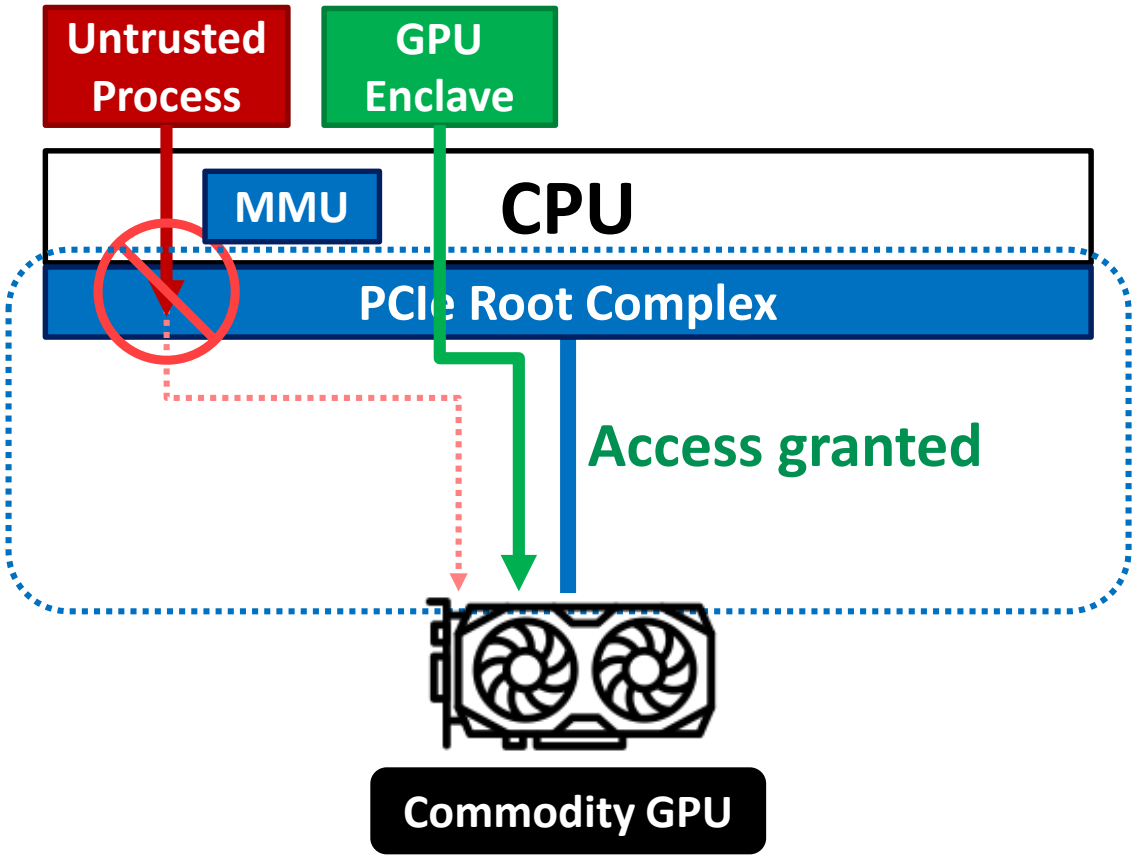

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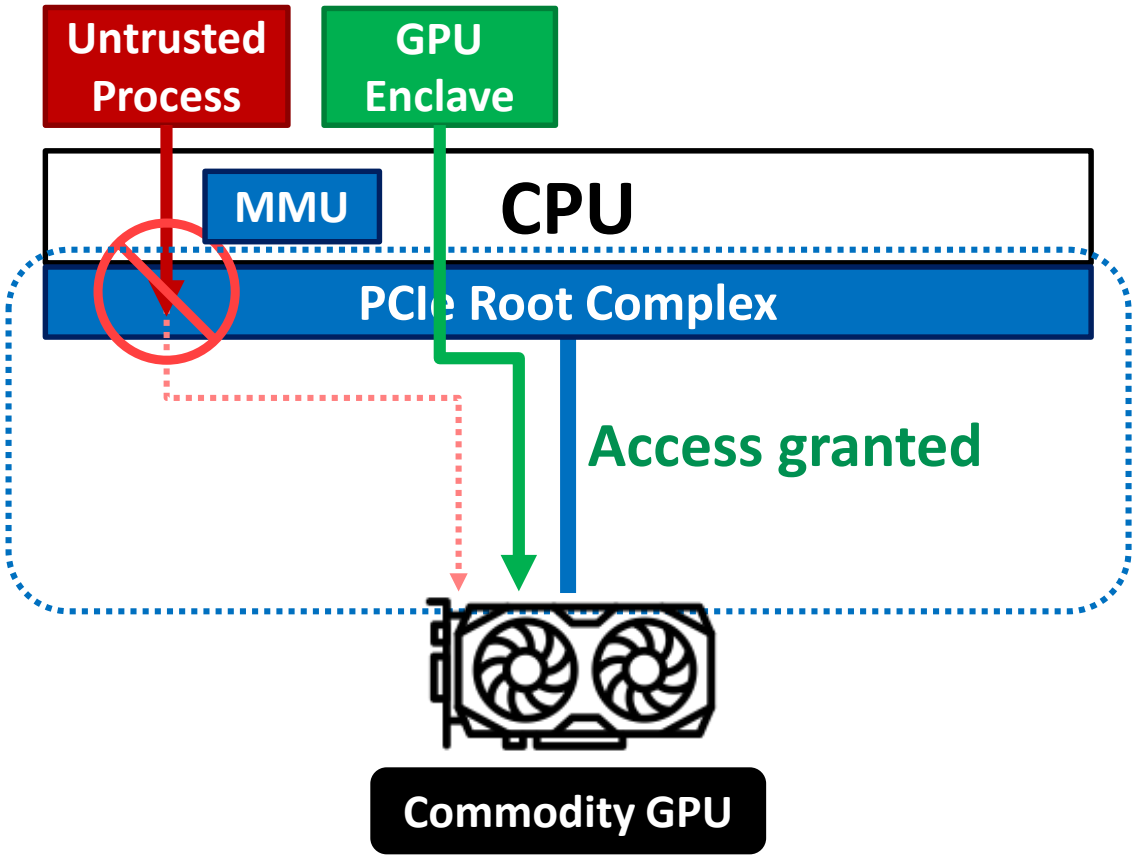

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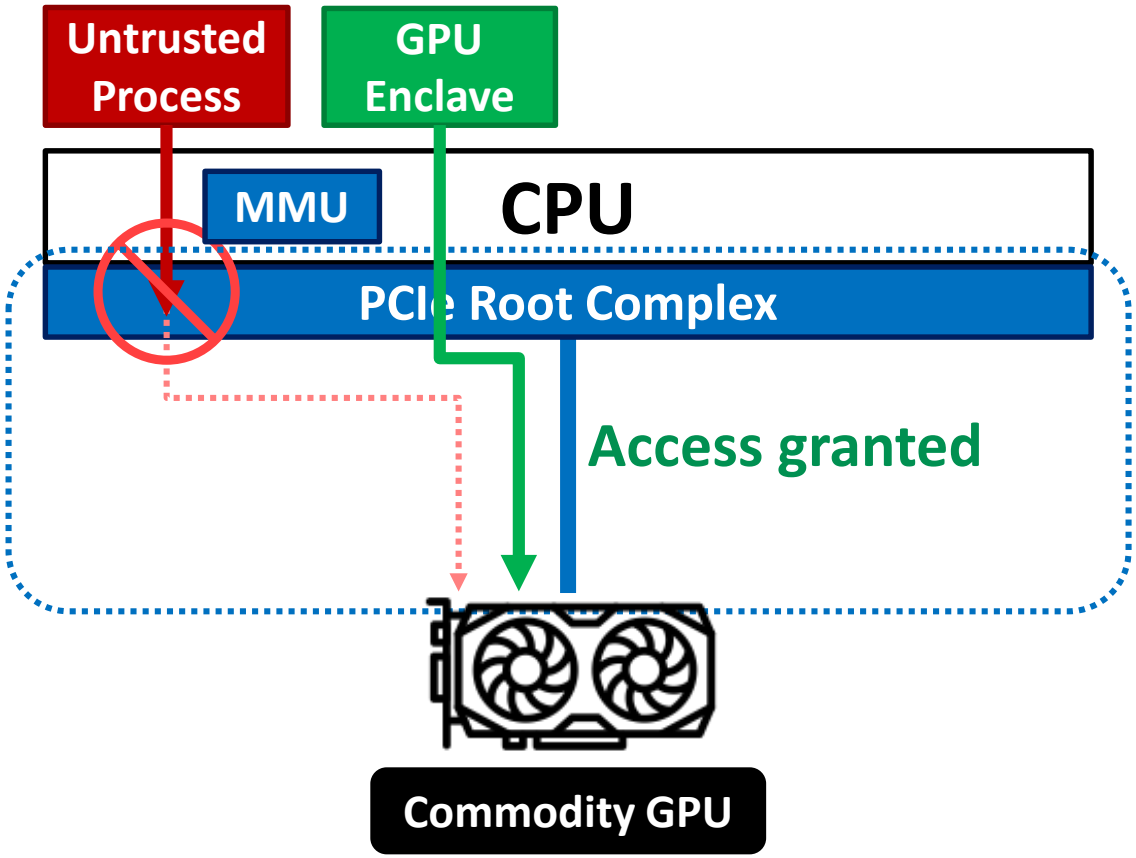

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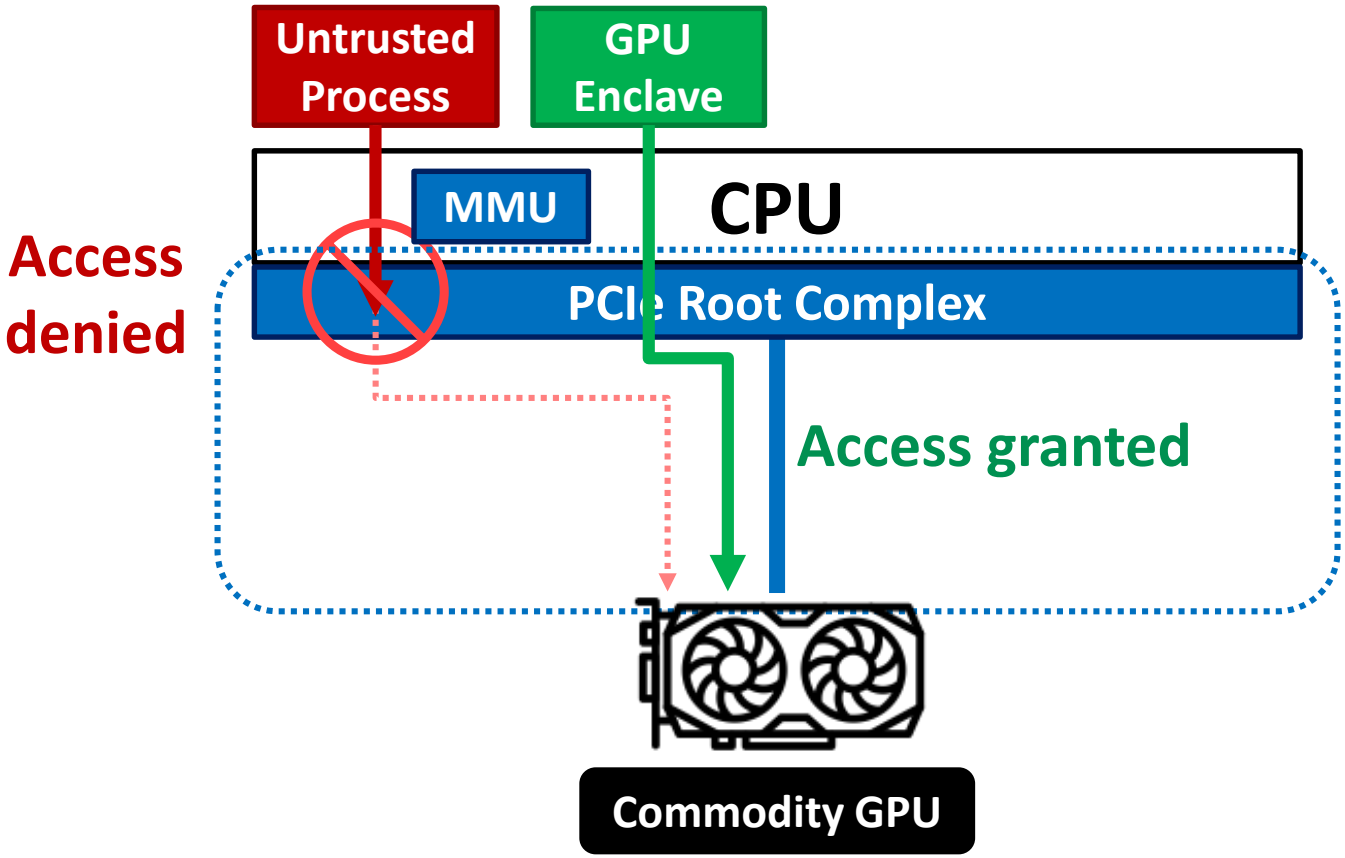

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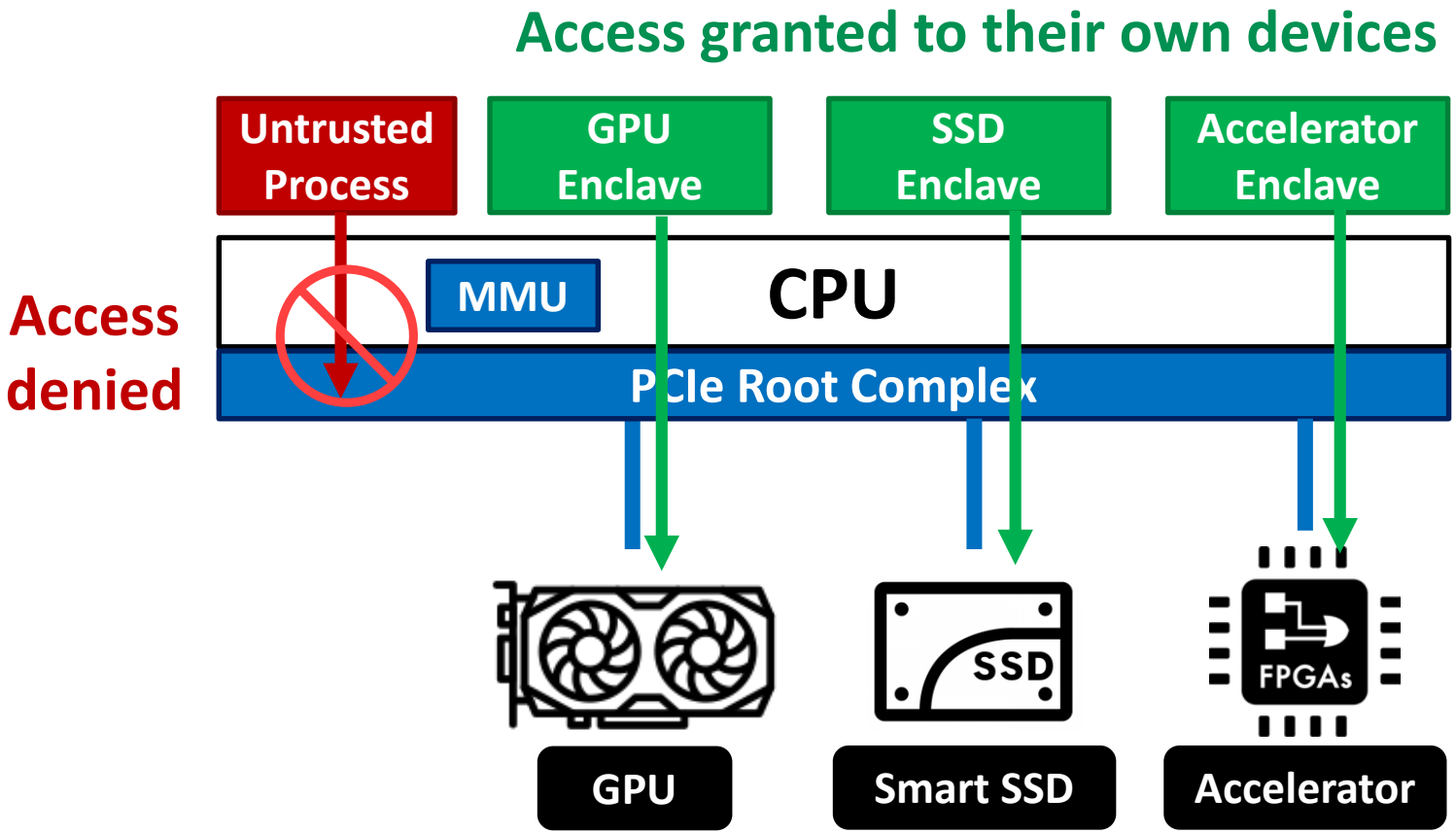

Expandable Device Protection

Heterogeneous Isolated Execution for Commodity GPUs

Thank you for Listening!

Q&A

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