

LeftoverLocals (CVE-2023-4969): GPU Memory Isolation Audit

Uninitialized Local Memory Leakage Across Multi-Tenant AI Container Infrastructures

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1. Multi-Tenant GPU Virtualization Architecture

Cloud infrastructure providers maximize accelerator return-on-investment by packing multiple isolated tenant containers onto single physical GPUs using technologies such as Nvidia MPS, Run:ai, or Slurm time-slicing.

While operating systems strictly isolate virtual memory addresses, the internal GPU microarchitecture contains low-level hardware structures—specifically Streaming Multiprocessor Local Memory (L1 cache / shared memory scratchpads)—that operate outside OS MMU boundaries.

CRITICAL: LeftoverLocals exposes the physical reality that multiple GPU vendors do not zeroize on-chip threadgroup shared memory during container context switches.

2. Exploit Mechanics and Data Reconstruction

An attacker running a low-privileged compute kernel allocates a large uninitialized threadgroup memory array immediately after a victim's LLM inference job completes.

Because registers and shared memory retain their electrical charges across context switches, the attacker directly reads raw FP16/BF16 floating-point values from the preceding tenant.

Empirical reconstruction proves that sensitive LLM key-value attention vectors and intermediate hidden states can be reassembled with over 90% accuracy, extracting proprietary model weights and user prompt tokens.

3. Hardening and Isolation Recommendations

Hardware vendors must implement hardware-enforced zero-fill routines in GPU microcode. Where microcode patches incur performance overhead, cloud platforms must enforce physical GPU isolation (one tenant per physical PCIe card) or apply driver-level scrub passes.

Empirical Laboratory & Architectural Telemetry

Metric / Target	Vulnerable Baseline	Mitigated / Zero-Filled
Memory Dump Recovery	Up to 5.5 MB per switch	0 KB (Zeroized)
LLM Weight Extraction Rate	> 90% vector fidelity	Indistinguishable from noise

Context Switch Overhead	~12 microseconds	~18-24 microseconds (+50%)
Affected Vendors	AMD, Apple, Qualcomm	Patched via kernel drivers
CVSS Vulnerability Score	7.5 (High)	Remediated via zero-fill