Rethinking IOMMU Address Translation

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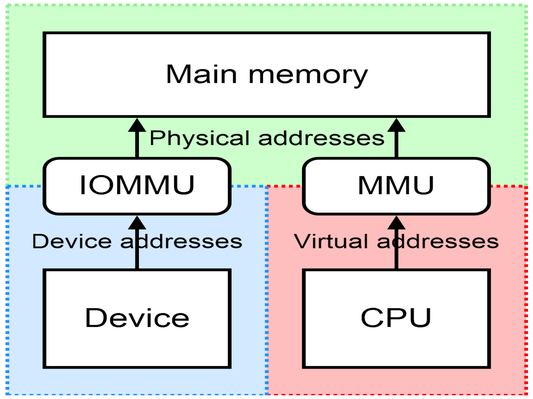
What is an IOMMU?

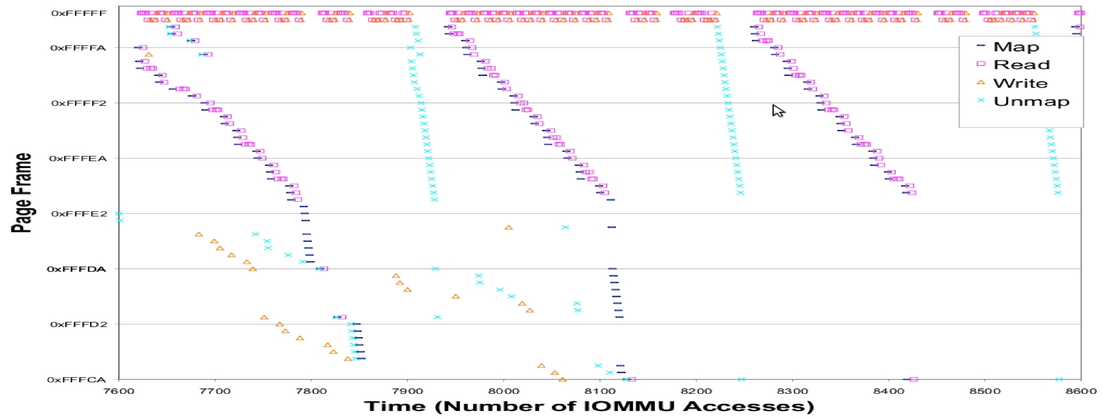


In a Nutshell

- IOMMUs translate and validate device accesses to main memory
- IOMMUs provide protection from misbehaving or malicious devices
- IOMMUs are used extensively on bare metal and in virtualized systems
- IOMMU translation overhead—caused by both software and hardware—can have a large effect on overall system performance and efficiency

Our main contribution is a combined software and hardware approach to IOMMU translation based on IOTLB injection and page table avoidance

Map/Unmap/DMA Read/DMA Write Traces

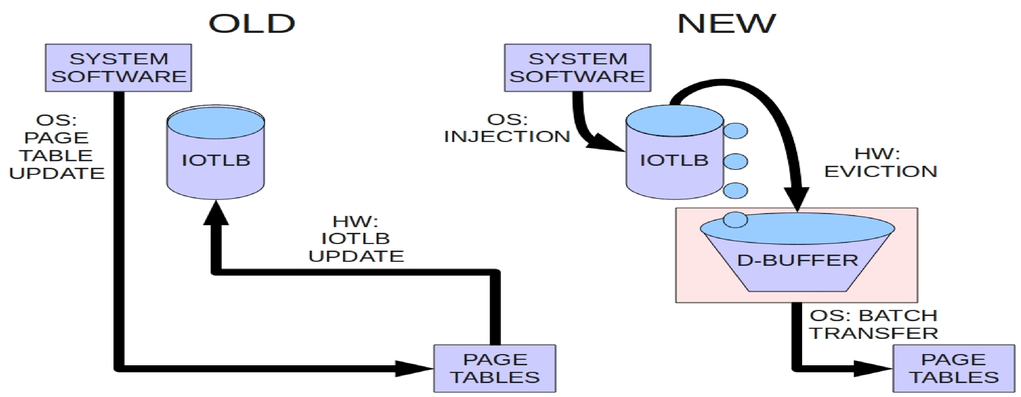


Map, unmap, and DMA reads and writes generated by an e1000 NIC when running `netperf` [Amit10]

Observations

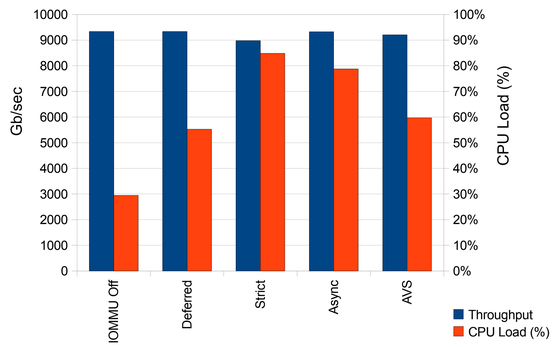
Observation #1: streaming DMA translation entries are used once and then discarded, leading to IOTLB miss on first access and unnecessary page table updates
Observation #2: many translation entries reused after a short (e.g., 10ms) period of time

Approach



- IOTLB injection: software injects streaming DMA entries which are likely to be accessed in the near future directly into the IOTLB, bypassing the page tables
- Page table avoidance: the d-buffer is positioned between the IOTLB and the page tables
  - On map: entries are injected directly to the IOTLB
  - When the IOTLB fills up and an entry needs to be evicted, the entry moves to the d-buffer
  - When the d-buffer is full, software moves all d-buffer entries to the page tables in a single batch
- On DMA access the hardware scans the IOTLB first, then the d-buffer, then the page tables
- IOTLB injection improves IOTLB hit rates and reduces page table walk memory access overhead
- Page table avoidance reduces page table update memory access overhead

IOMMU Translation Overhead



IOMMU translation overhead with different protection strategies [Amit11]. Strict protection requires 85% CPU vs. 30% for no IOMMU (×2.5)

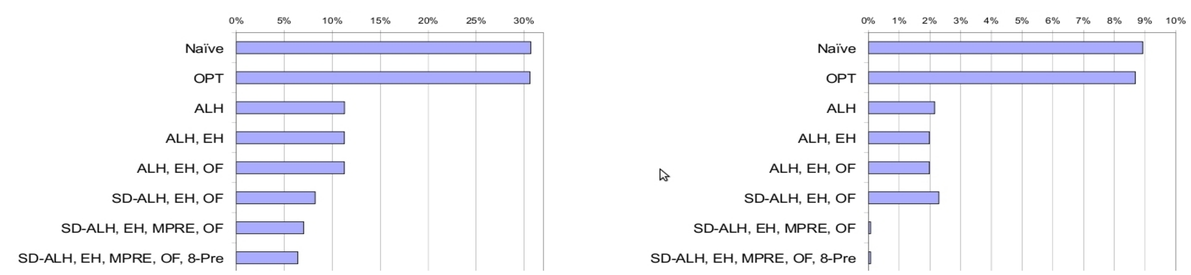
Methodology

- Use IOMMU emulation for generating map/unmap/DMA traces
- Rethink translation based on workloads

Related Work

- Translation is expensive [Ben-Yehuda07]
- IOMMU protection strategies [Willman08]
- On-demand mapping [Yassour10]
- Exploring IOTLB design [Amit10]
- Skip, don't walk (the page table) [Barr10]
- vIOMMU: IOMMU emulation [Amit11]

Results (Work in Progress)



IOTLB miss rates for different IOTLB configurations (lower miss rate is better). *left* shows e1000 with `netperf`, *right* shows SCSI controller with `bonnie++`. MPRE is mapping prefetch, which behaves similarly to IOTLB injection. Preliminary results and full experimental setup are available in [Amit10]