MFence : Defending Against Memory Access Interference in a Disaggregated Cloud Memory Platform

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Kwangwon Koh, Hongyeon Kim, Kangho Kim, Youngjae Kim

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Sogang University, Seoul
South Korea

Agenda

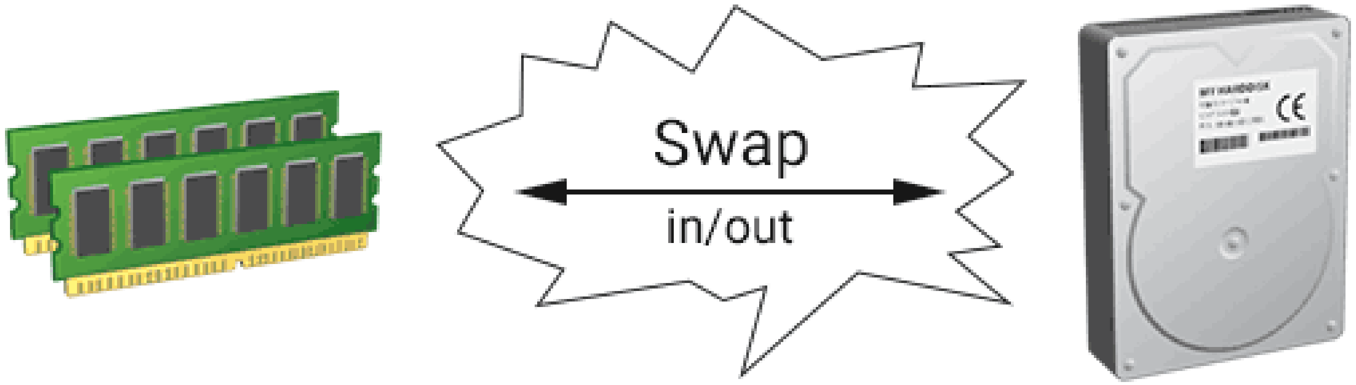
- Introduction & Background
- Motivation
- Design
- Evaluation

Memory-Intensive Applications

- Demand for processing memory-intensive applications is high
  - ✓ Machine learning, graph processing, KV Store
- Bigdata applications require a high memory and cause memory shortages

Memory-Intensive Applications

- Limited memory capacity per machine
  - ✓ OOM (Out of memory), application failures..
- Traditional solution for big memory
  - ✓ Disk swap



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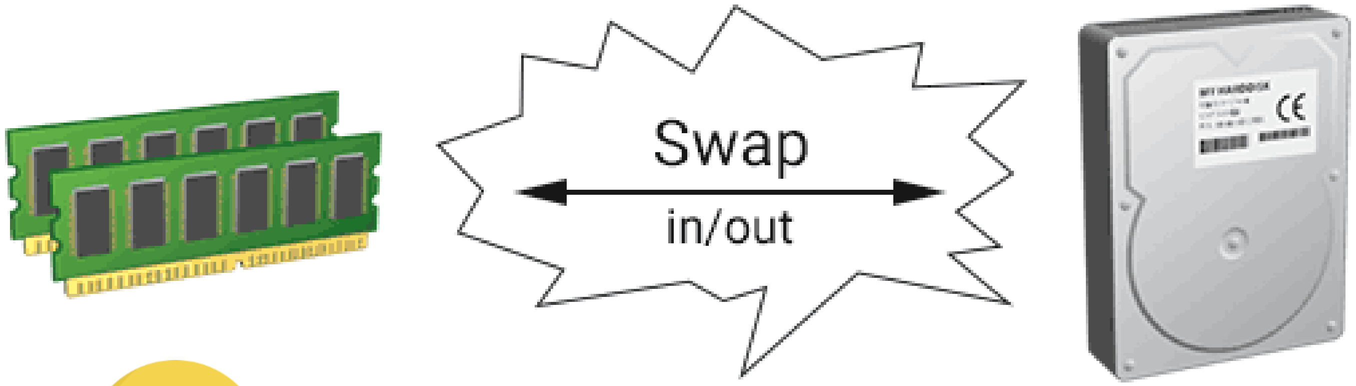
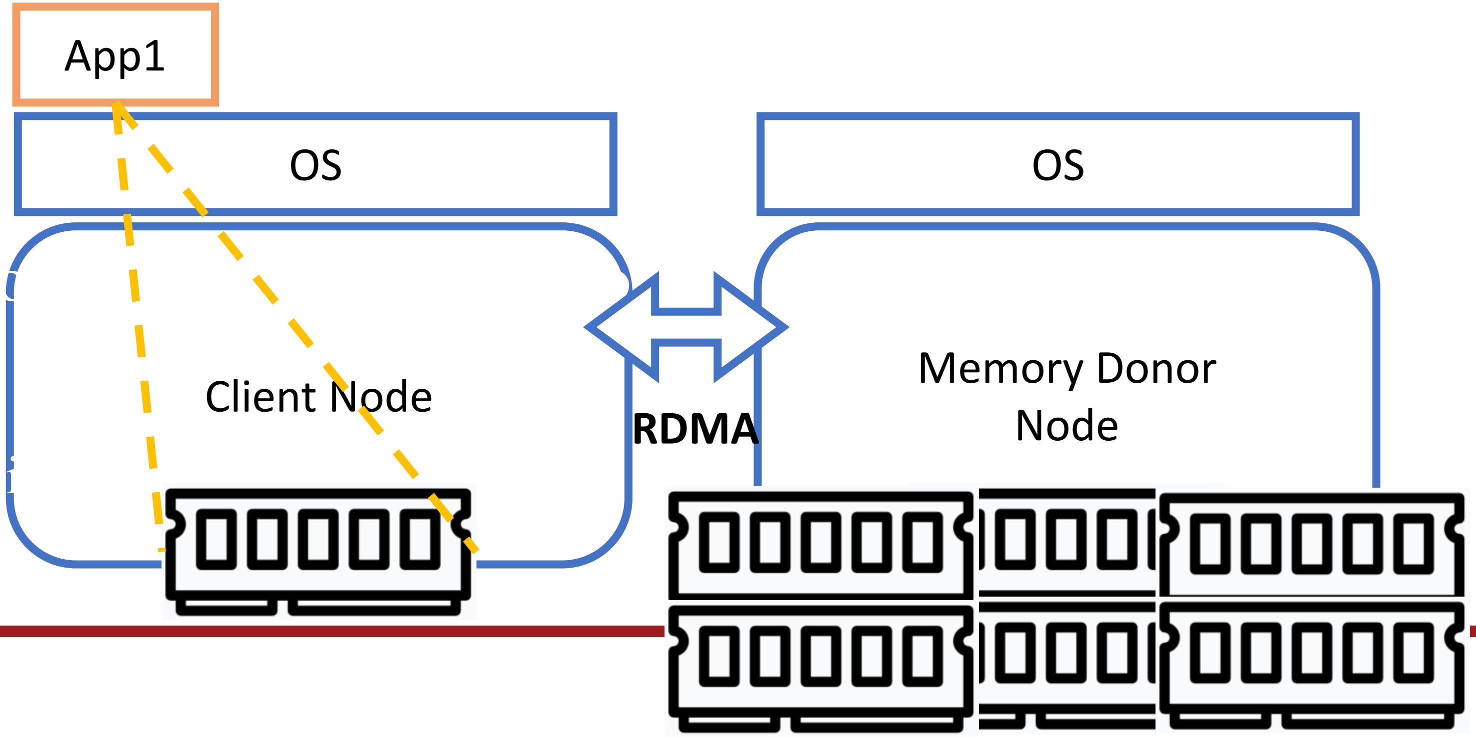


Higher access latency in disk swap!

Disaggregated Memory Platform

- Memory of a remote server as an extension of limited local memory
  - ✓ One machine **borrows** memory from remote machine with high-speed network
- VM-based remote memory solution
  - ✓ **Client machine** (borrows the memory)
  - ✓ **Donor machine** (provides the memory)



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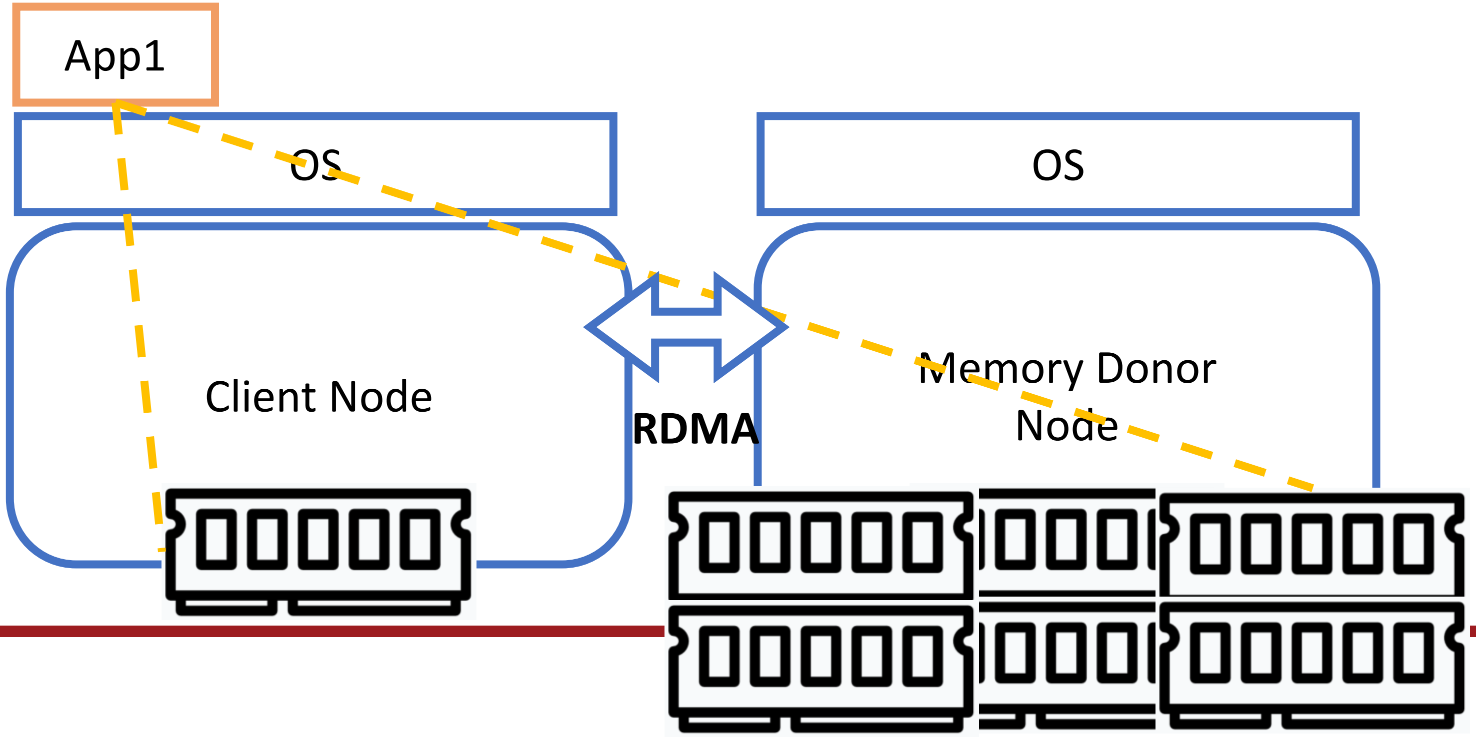

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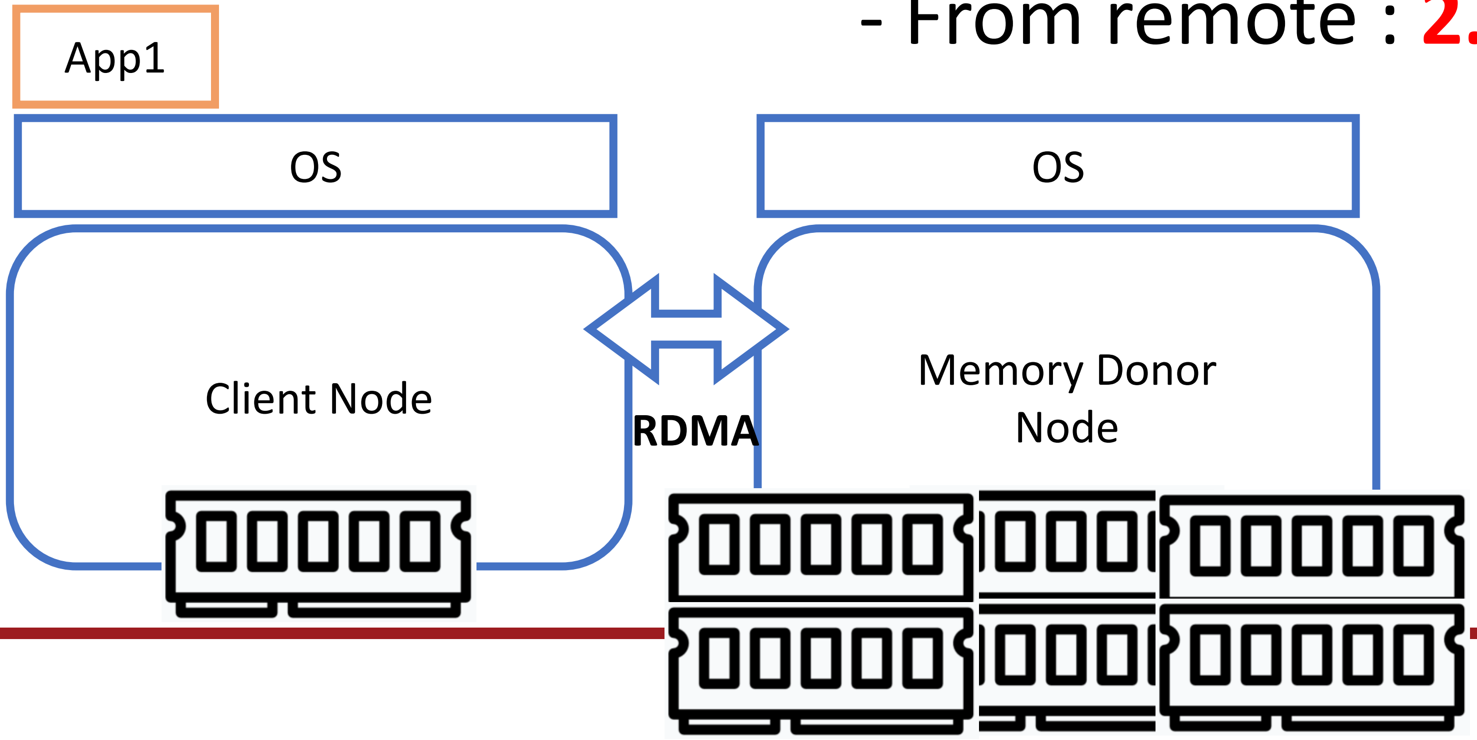
Memory Access Time

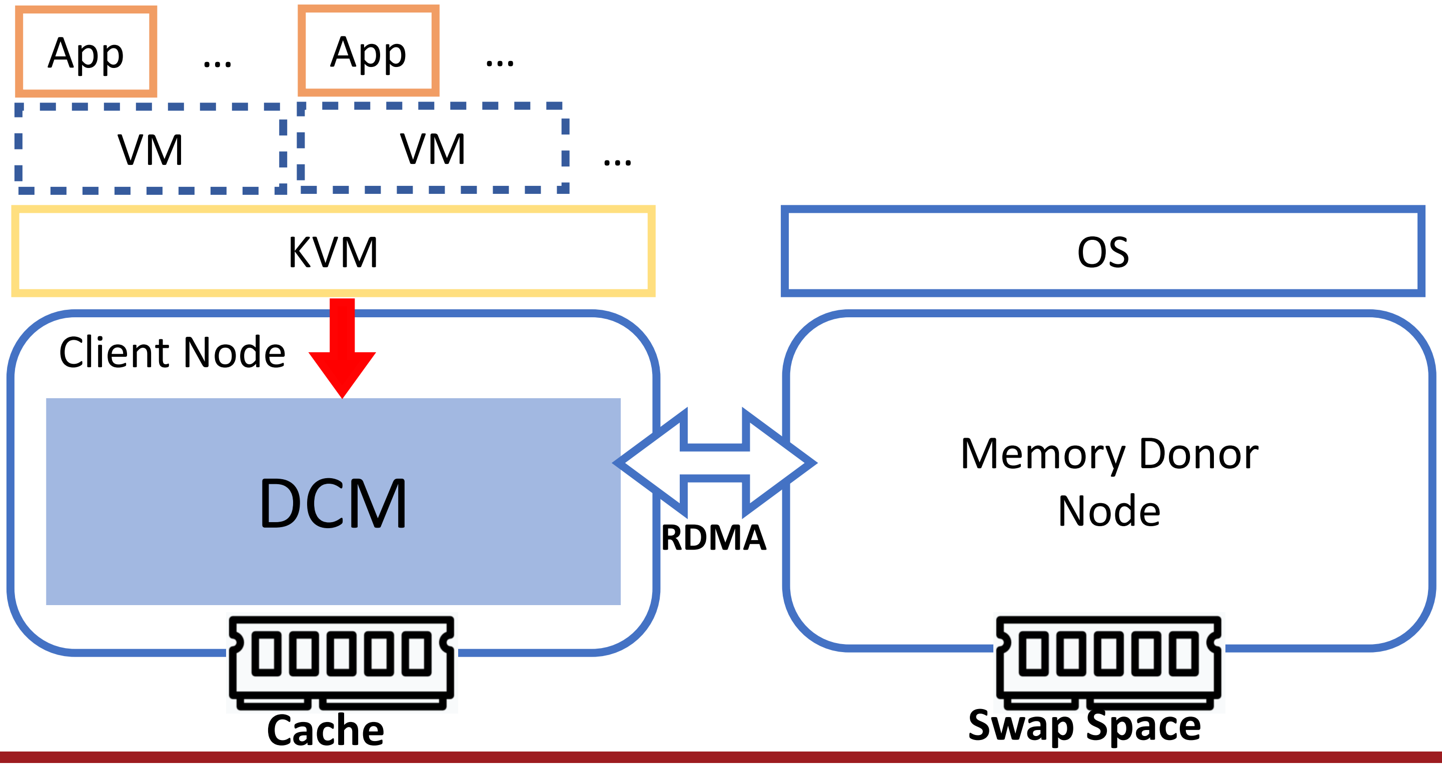
- From local : 10~256 ns

- From remote : **2.8 us**



Disaggregated Memory Platform

- DCM[TC'19]* uses **local memory** as an **inclusive cache** and maximizes the **hit rate** to reduce fetching from remote memory
- Using a VM, donor's memory can be perceived as its own memory space



* Koh, K. Disaggregated cloud memory with elastic block management. *IEEE Transactions on Computers 68*, 1 (2019)

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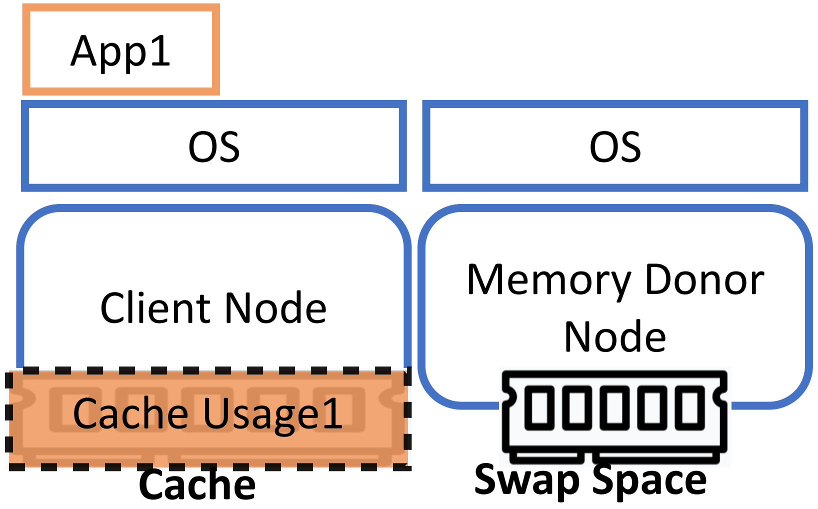
Cache Contention on DCM

- Processes in VM use the shared cache concurrently, a memory race condition occurs



Single run

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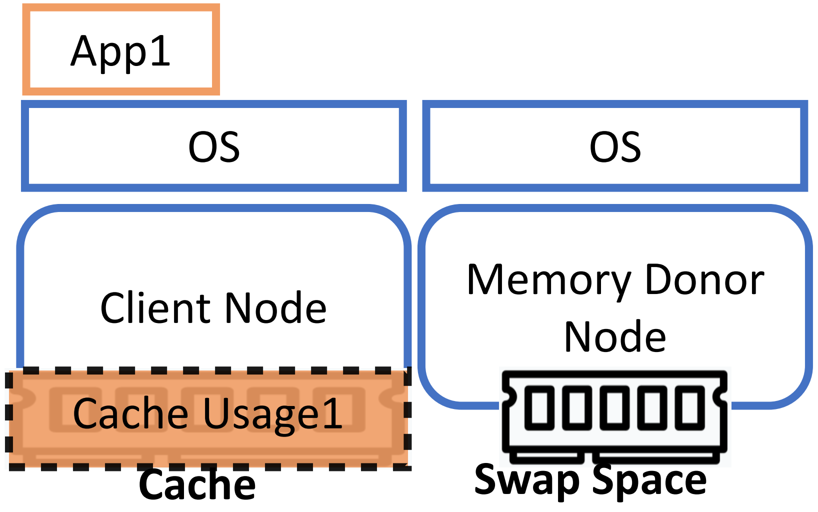

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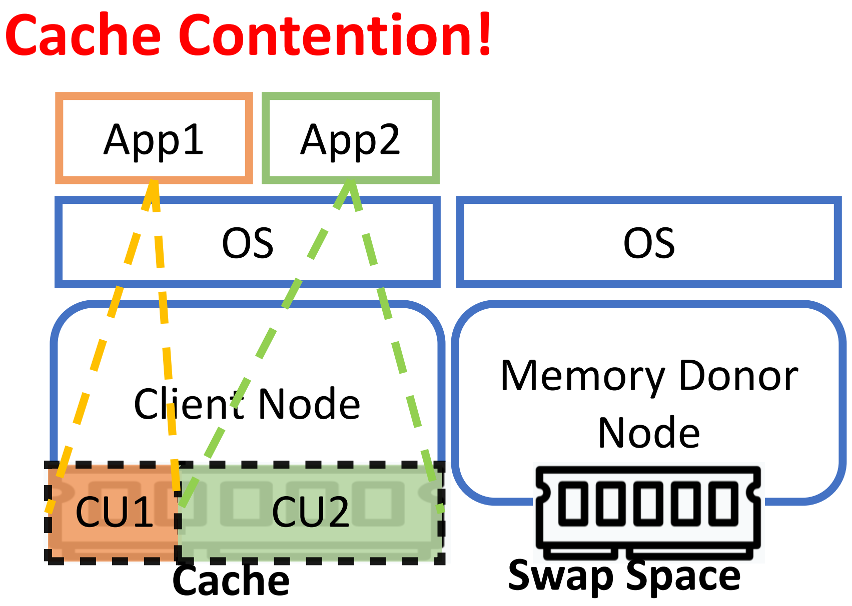
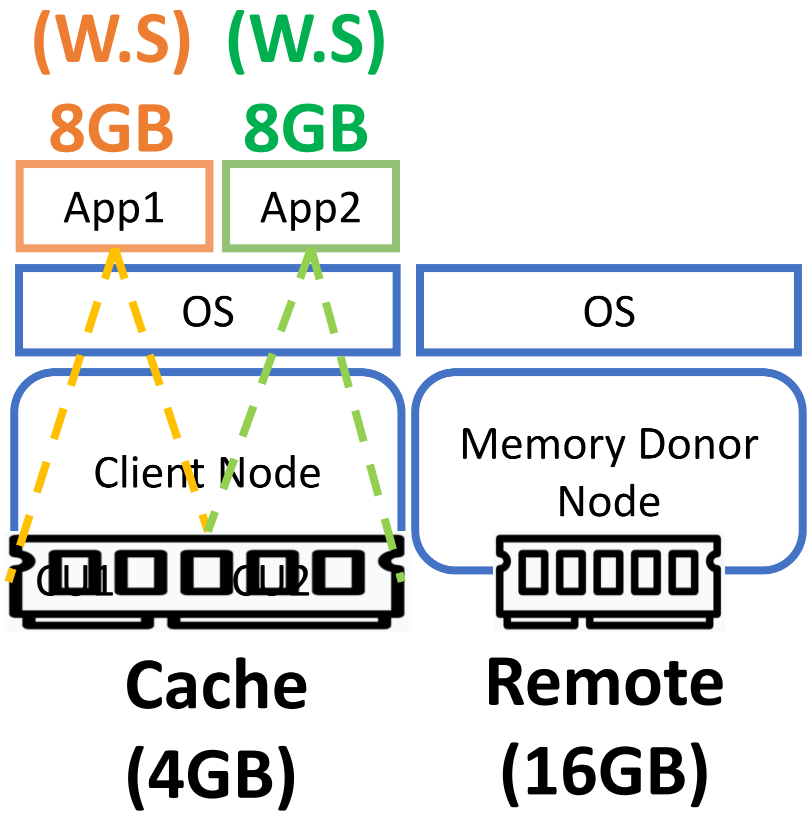


Shared run

Cache Contention on DCM

- Evaluation with micro memory benchmark(PmBench*) on DCM
  - ✓ Workload : 1 linear/random memory-access
  - ✓ All process memory footprint : 8GB
  - ✓ Local memory capacity in VM : 4GB



*Jisoo, Y. Pmbench: A micro-benchmark for profiling paging performance on a system with low-latency ssds. In Proceedings of the Information Technology New Generations (2018)

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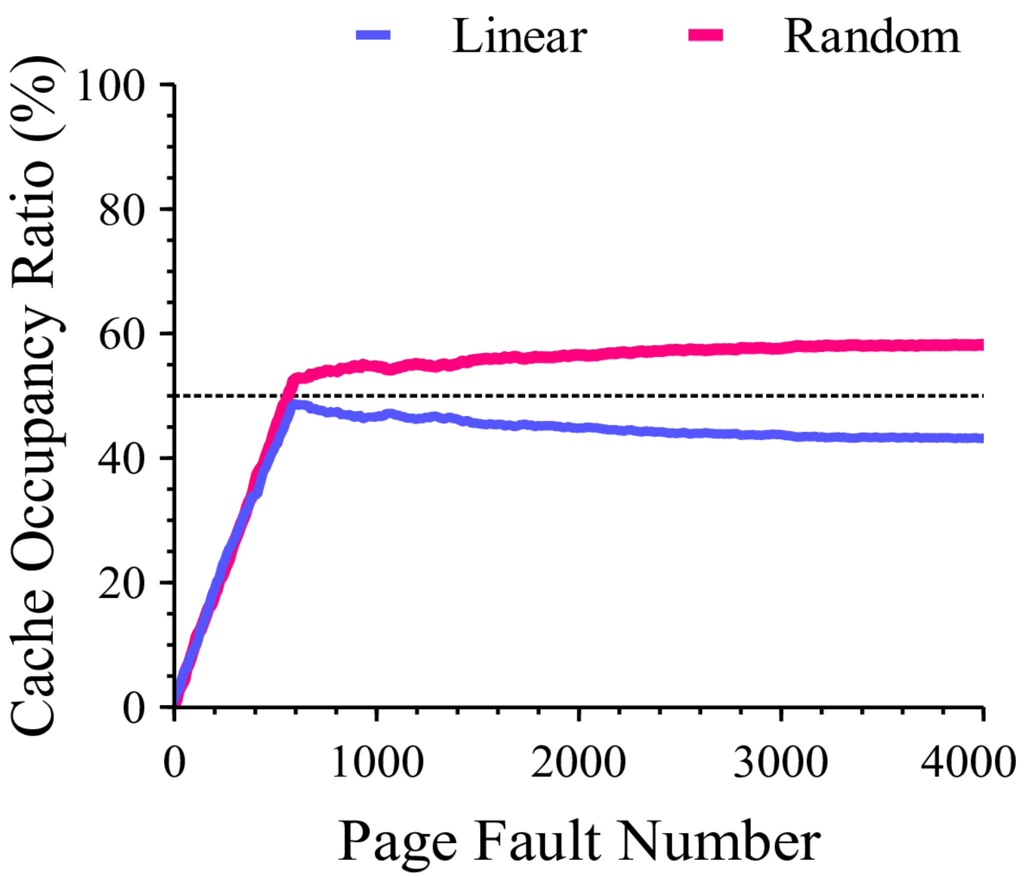

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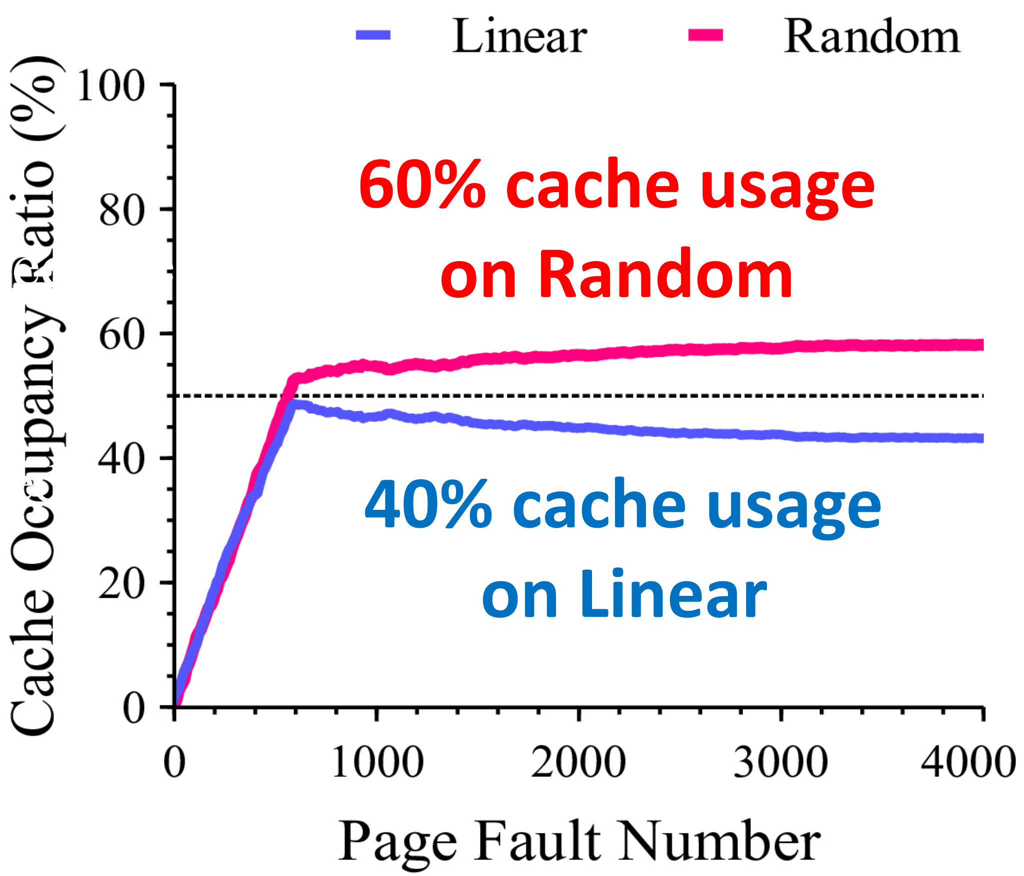

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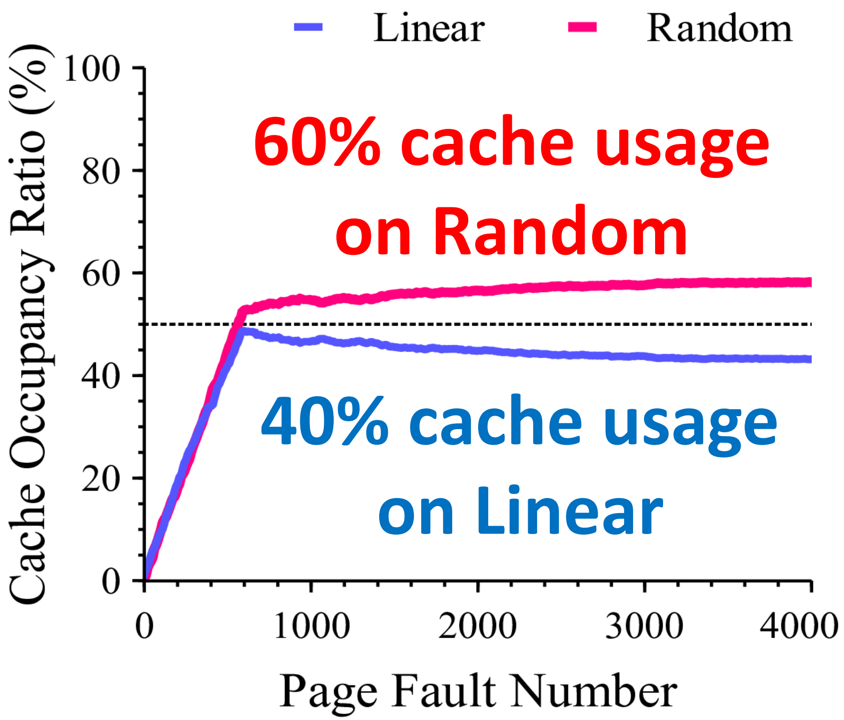

Unfair cache occupancy per process in DCM

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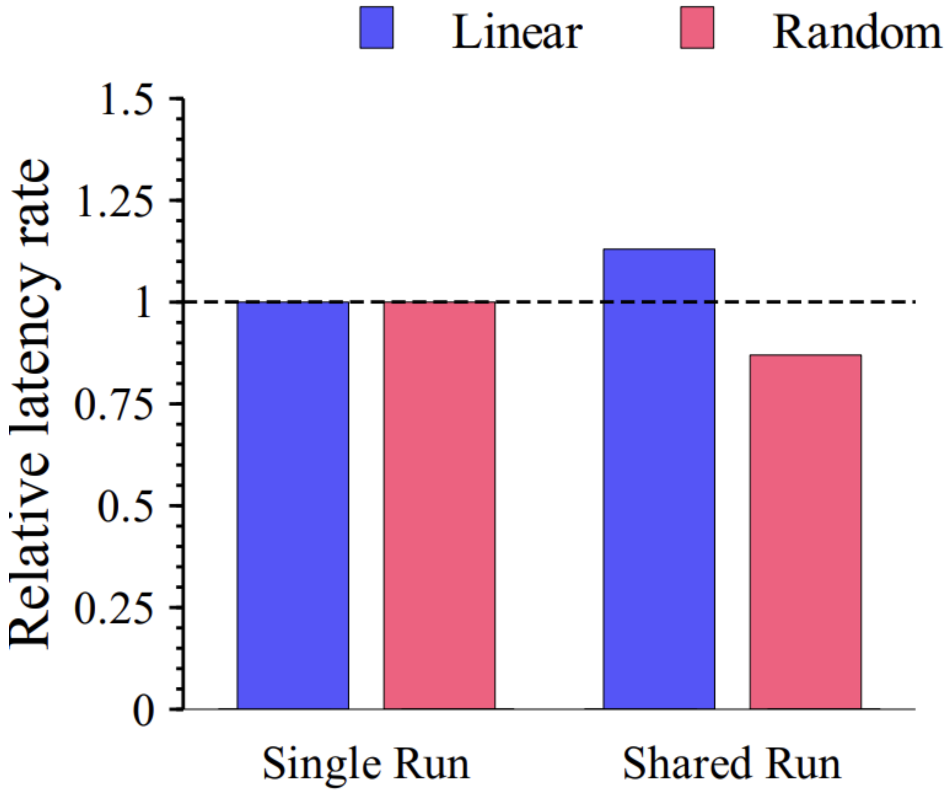

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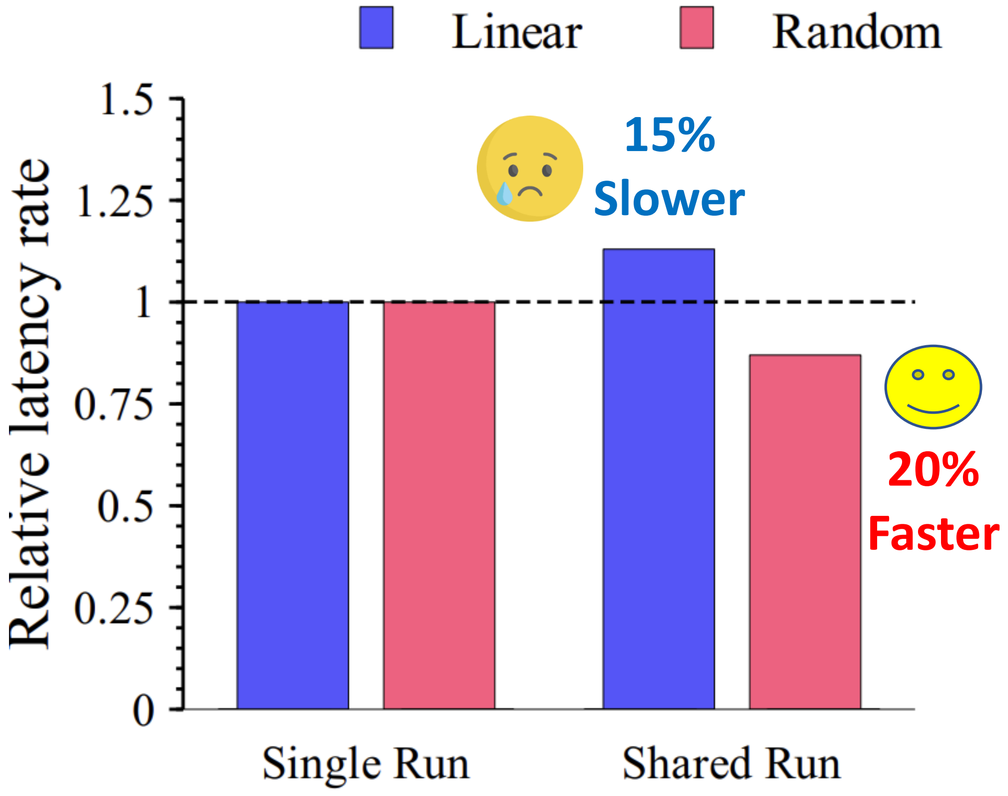

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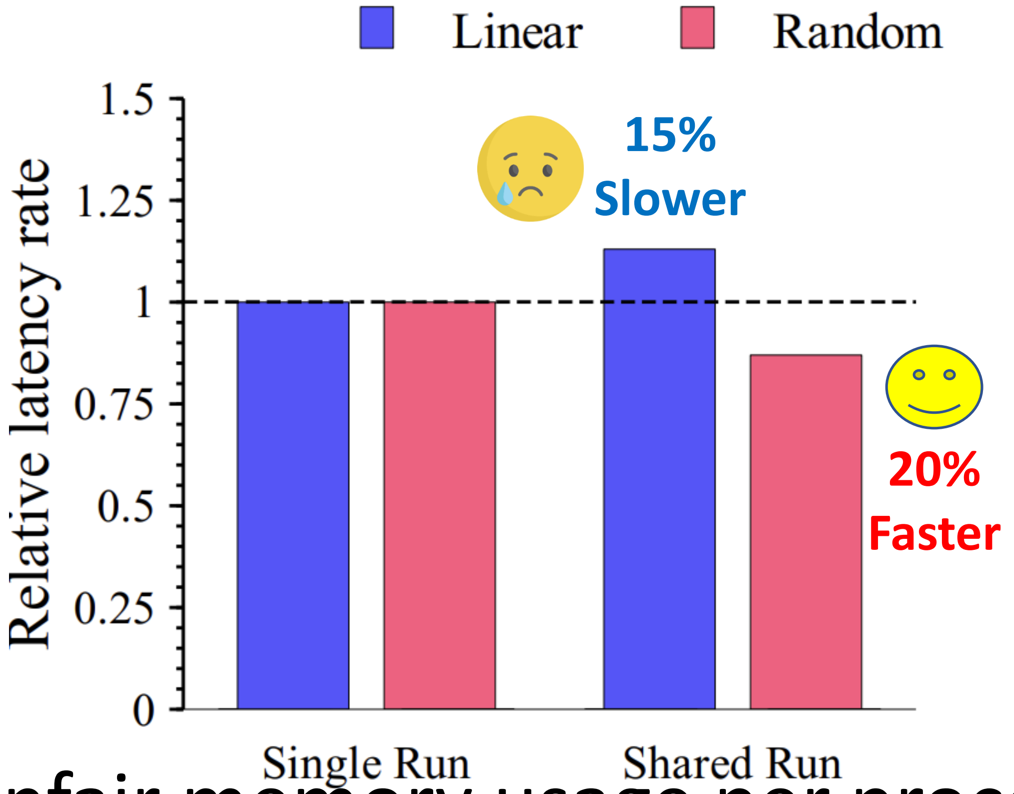

Unfair memory usage per process

sharing local memory affects the performance

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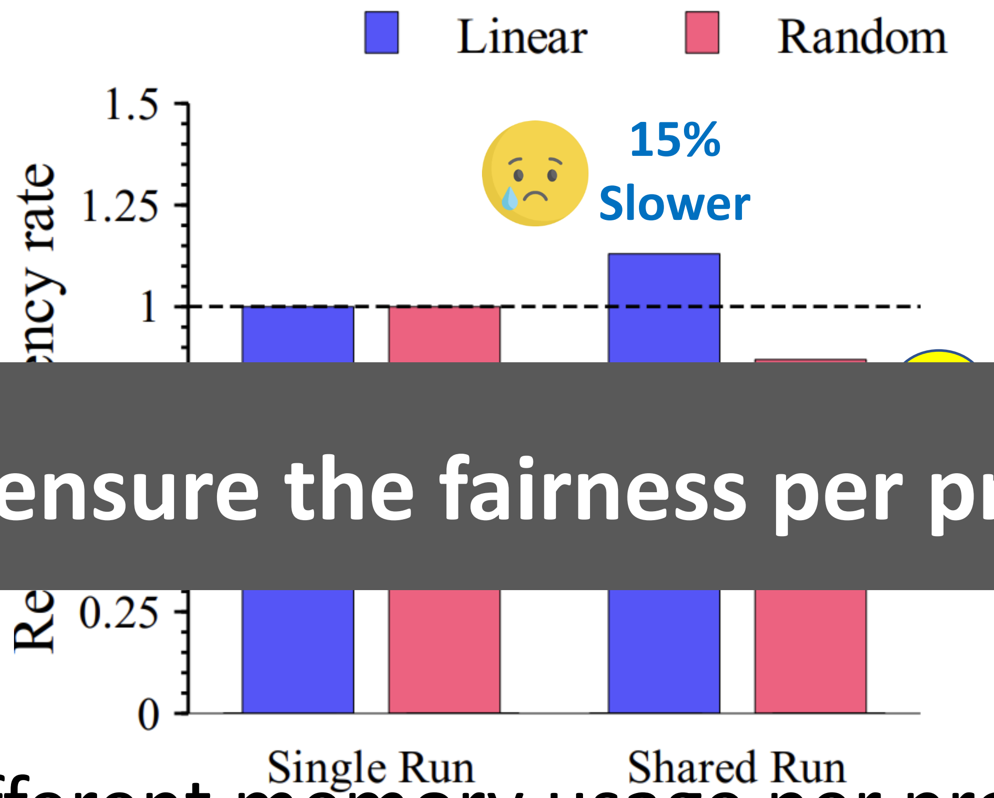

Can we ensure the fairness per process?

Different memory usage per process

sharing local memory affects the performance

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Opportunity with Cache Partitioning

- **Cache partitioning** can overcome the unfair utilization of local cache between memory-greedy processes

- **Challenges**
  - ✓ Host kernel cannot directly know page information of the process running on guest OS/VM
  - ✓ Overhead of page identification per process between host/guest area is not trivial

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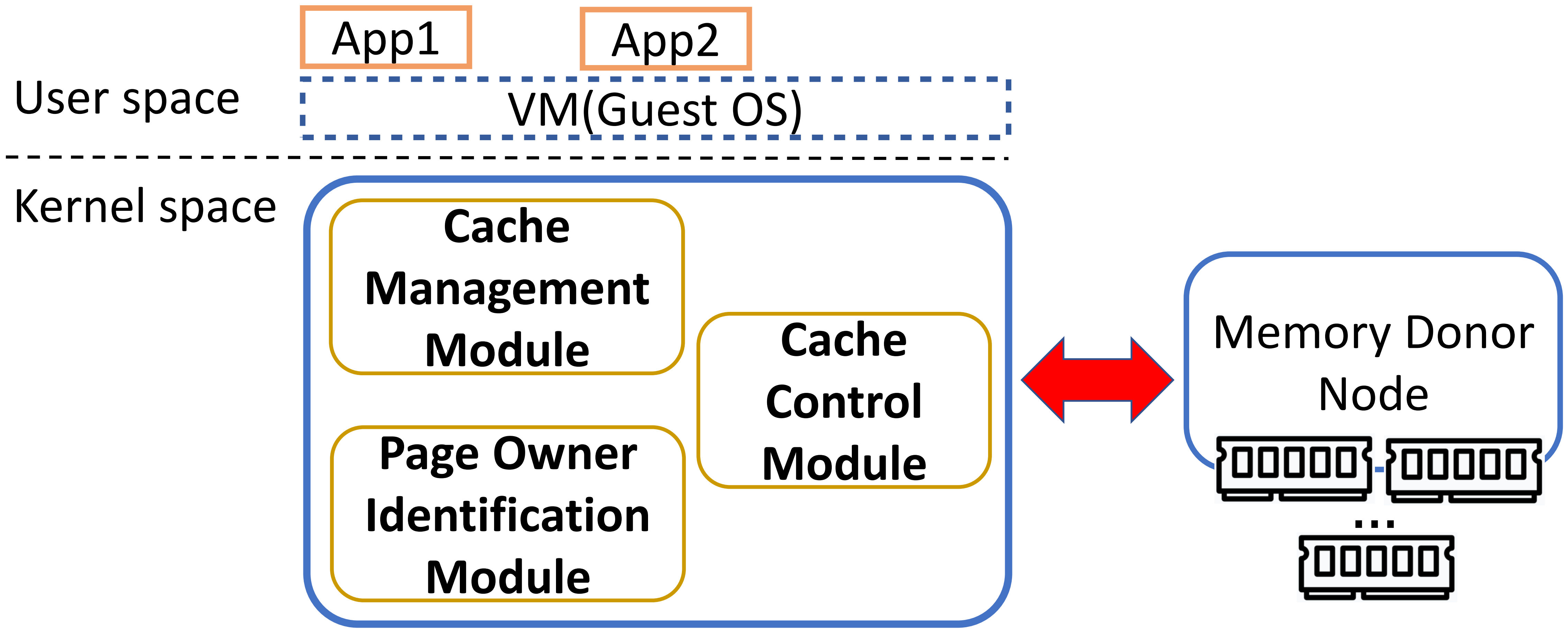
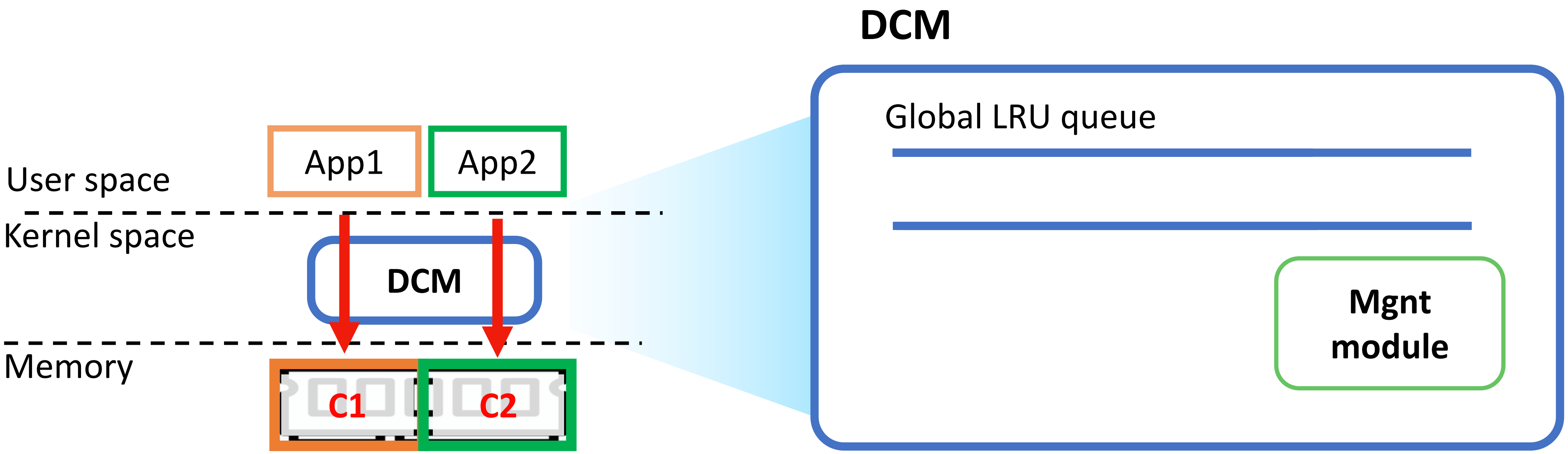
MFence


App1
App2
User space
VM(Guest OS)
Kernel space
Cache Management Module
Page Owner Identification Module
Cache Control Module
Memory Donor Node
...

MFence

- **Cache Management Module**
  - ✓ MFence manages a per-process LRU queue, providing local memory partitions of varying sizes
  - ✓ The split queue (cache) has a unique ID[group ID (**GID**)] is assigned



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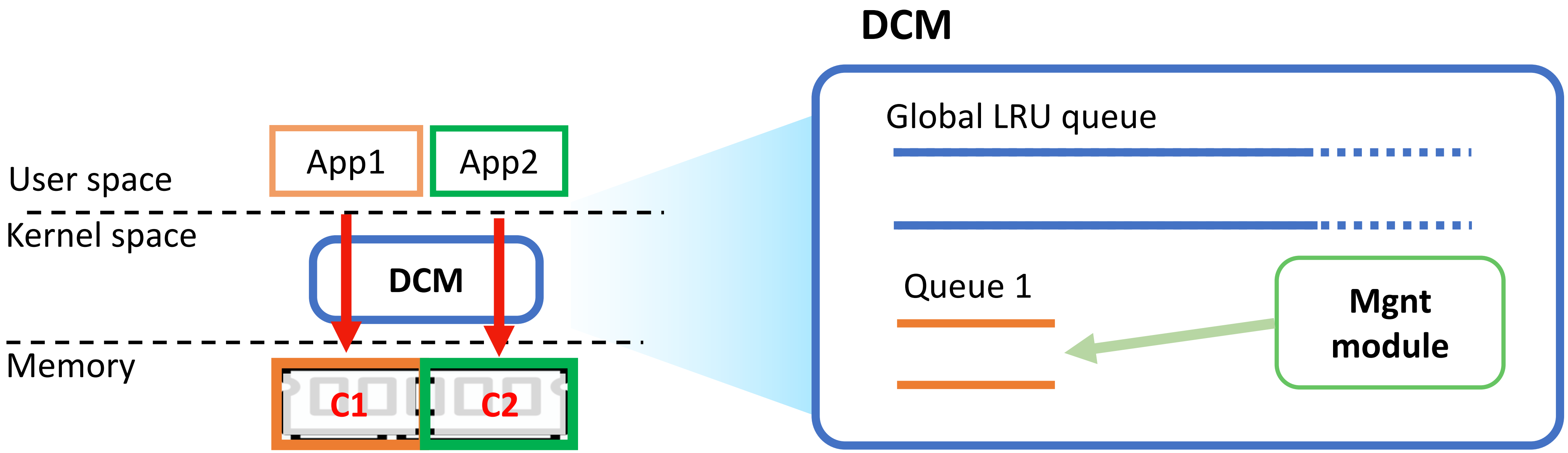

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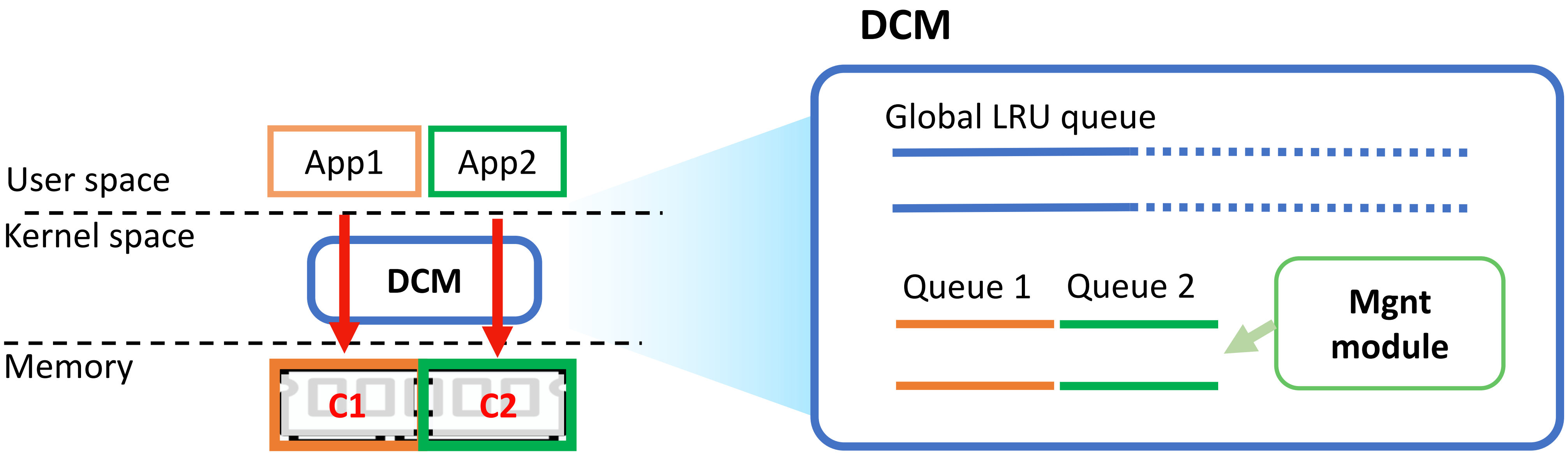

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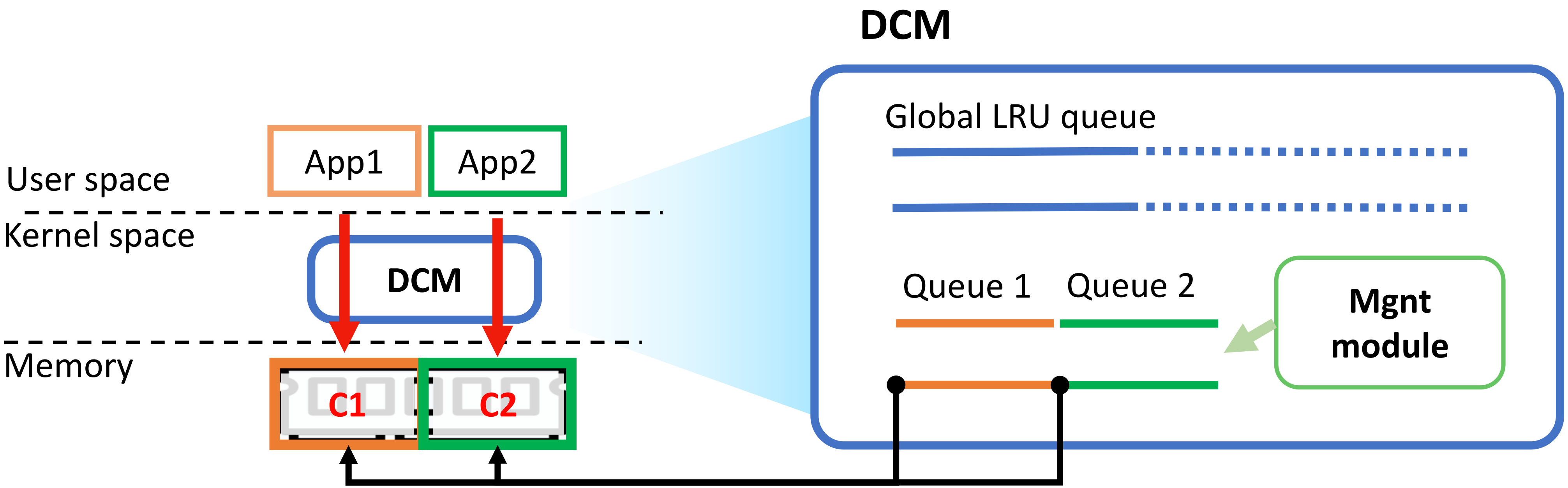

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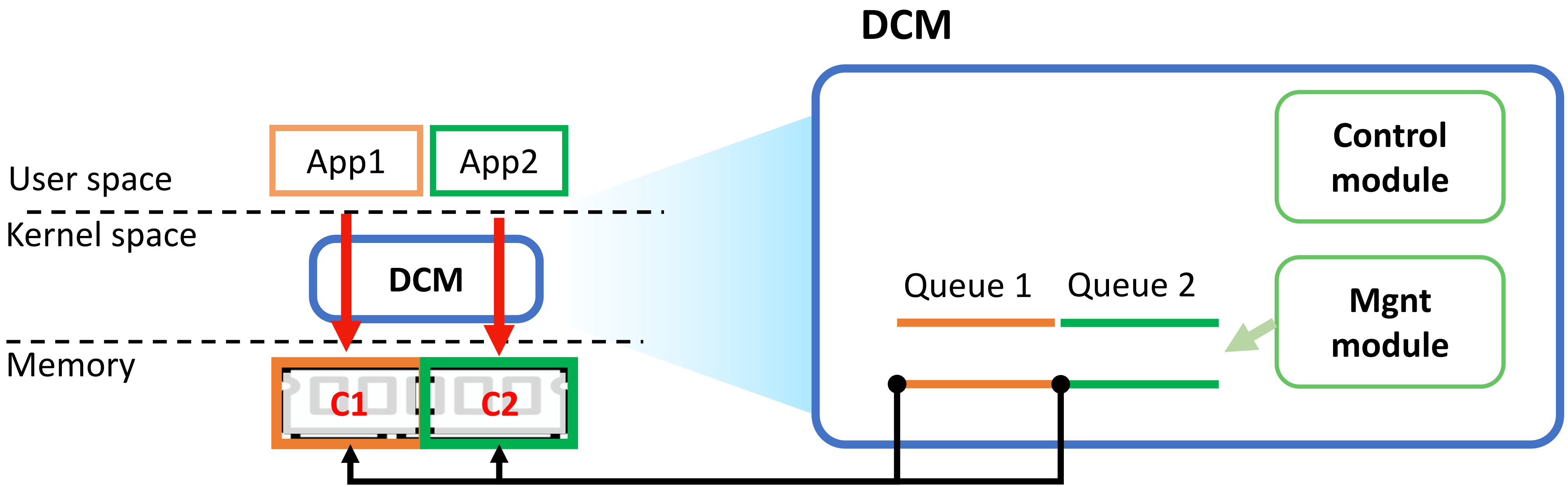
  - ✓ Cache group allocation, cache area creation, cache area release via user API



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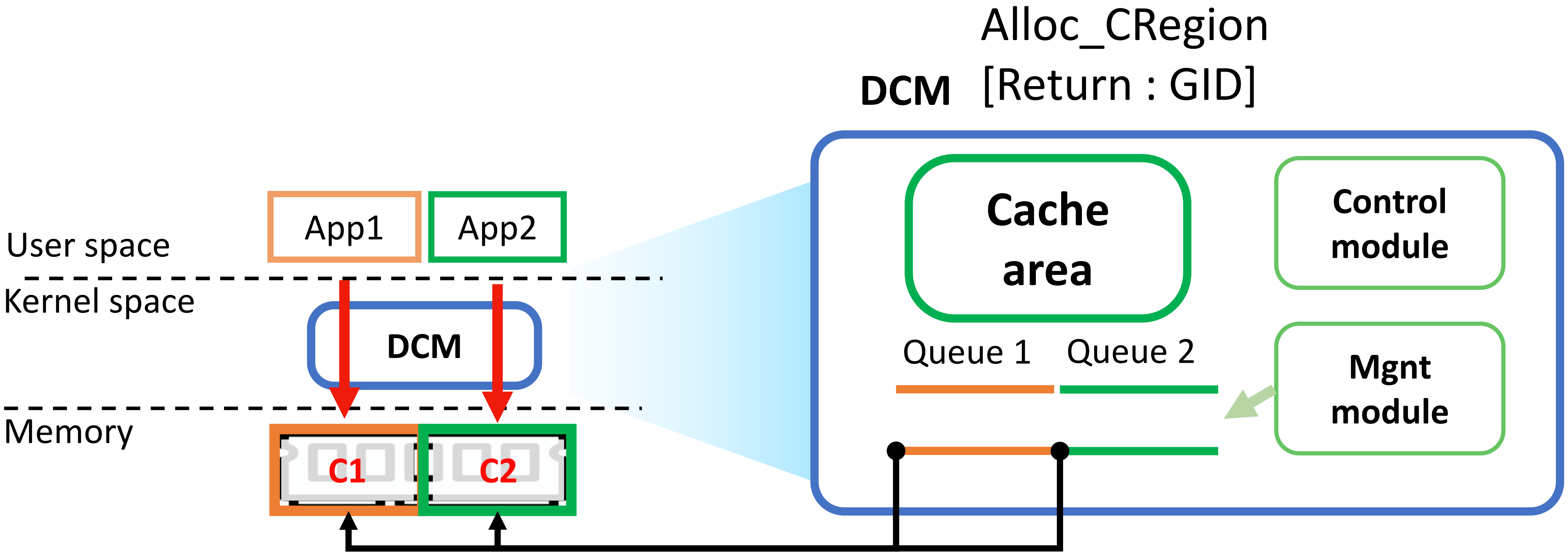

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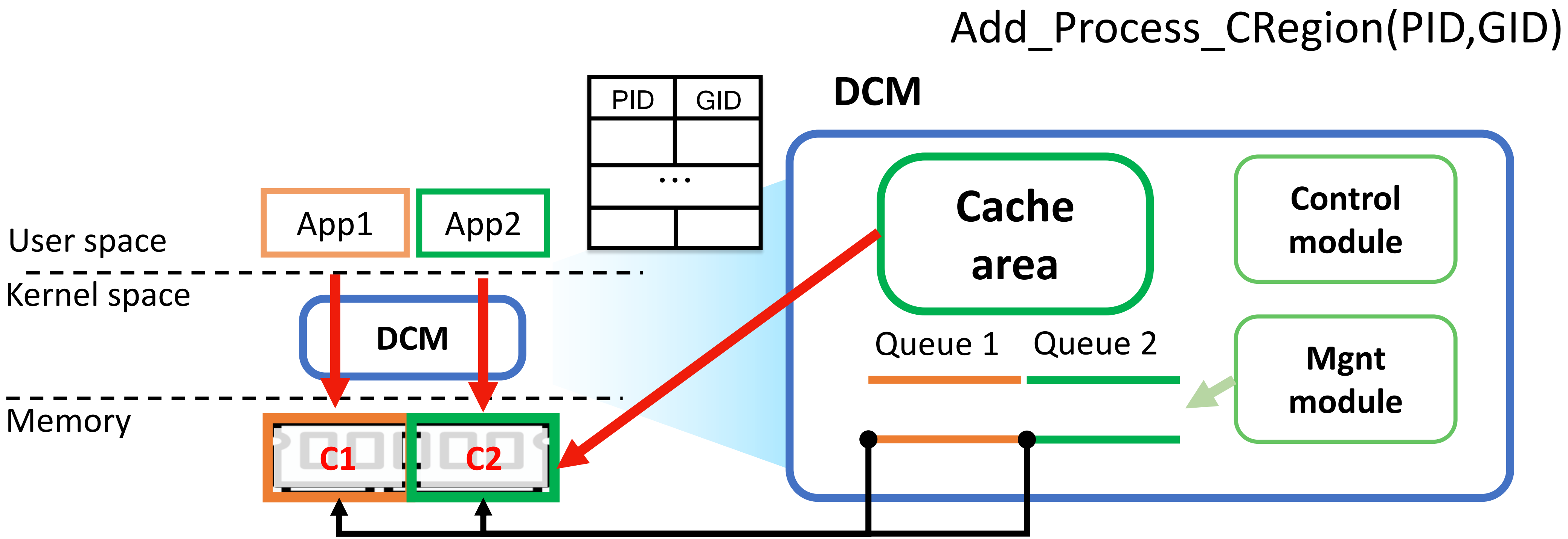

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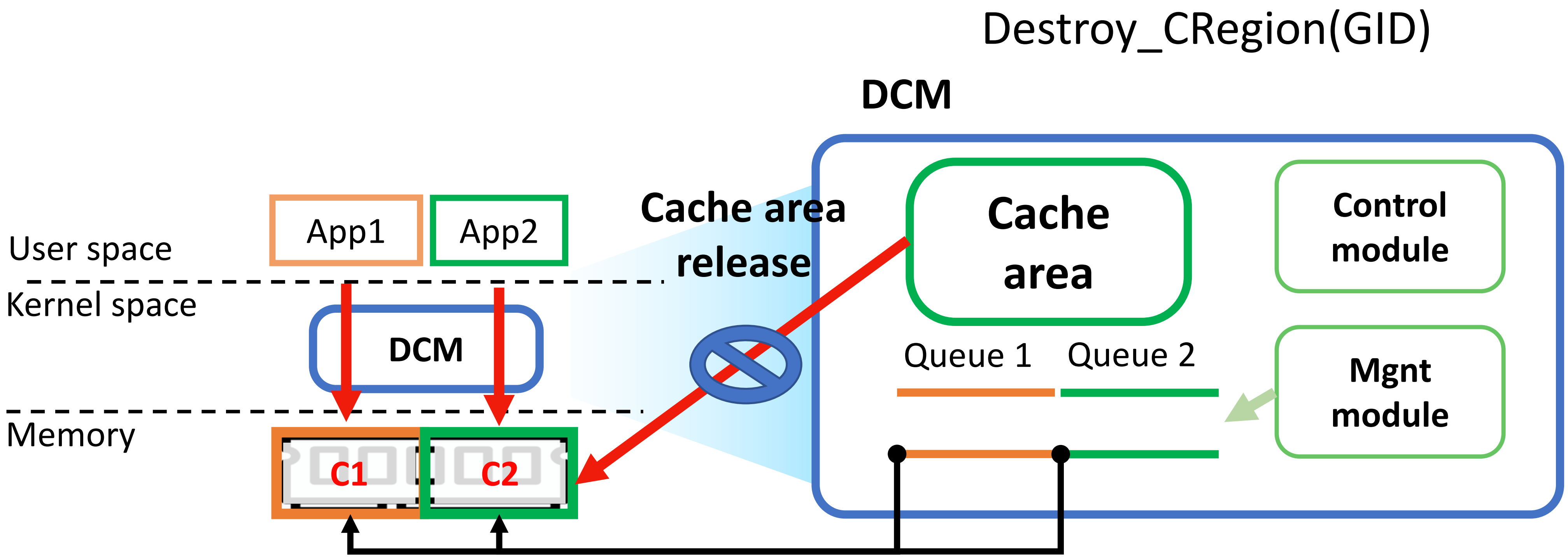

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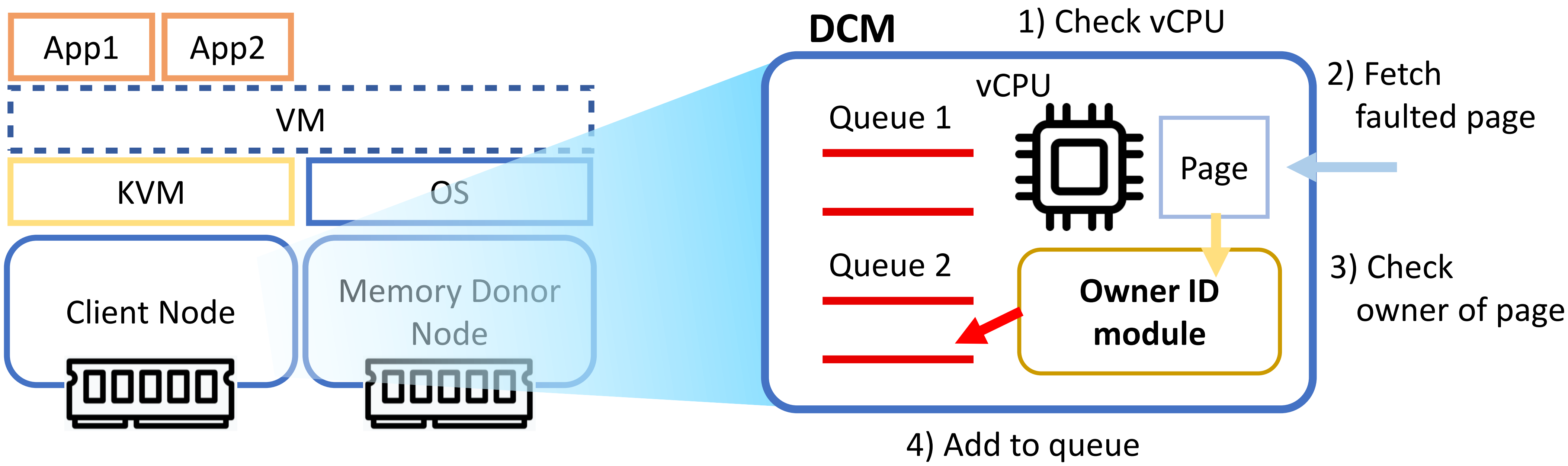
  - ✓ Each LRU queue caches only pages that belong to the process
  - ✓ Determine the queue into which to insert a page fetched from a remote server



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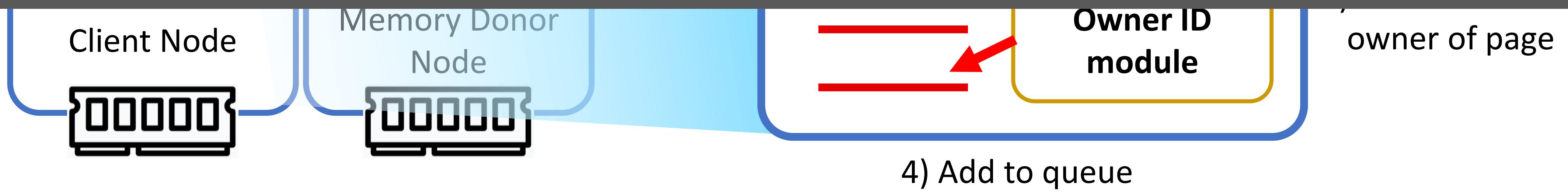
- ✓ **Kernel cannot be aware of upper layer's processes**
- ✓ **Kernel cannot confirm page's owner and perform memory separation between processes**

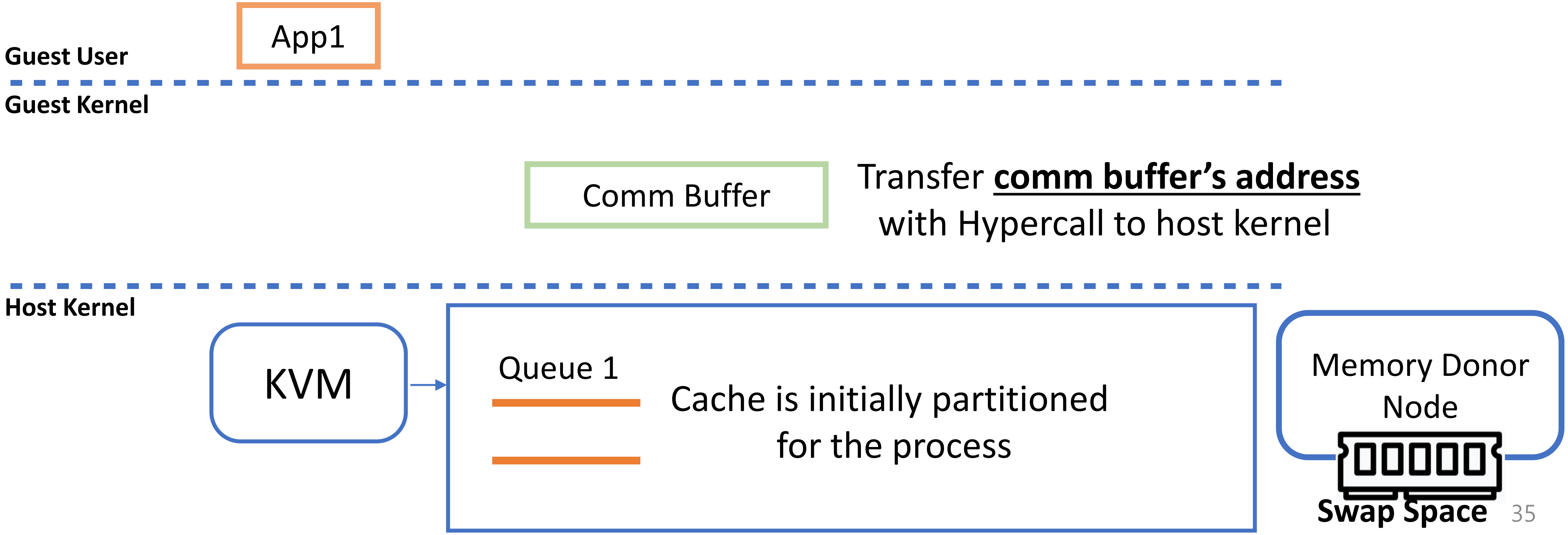


MFence

- **Page Owner Identification Module**
  - Hypercall method
  - gCR3 method

MFence

- **Page Owner Identification Module (Hypercall)**
  - It communicates with the guest kernel to find PID of a fetched page
  - Requires one Hypercall handshake to establish communication buffer



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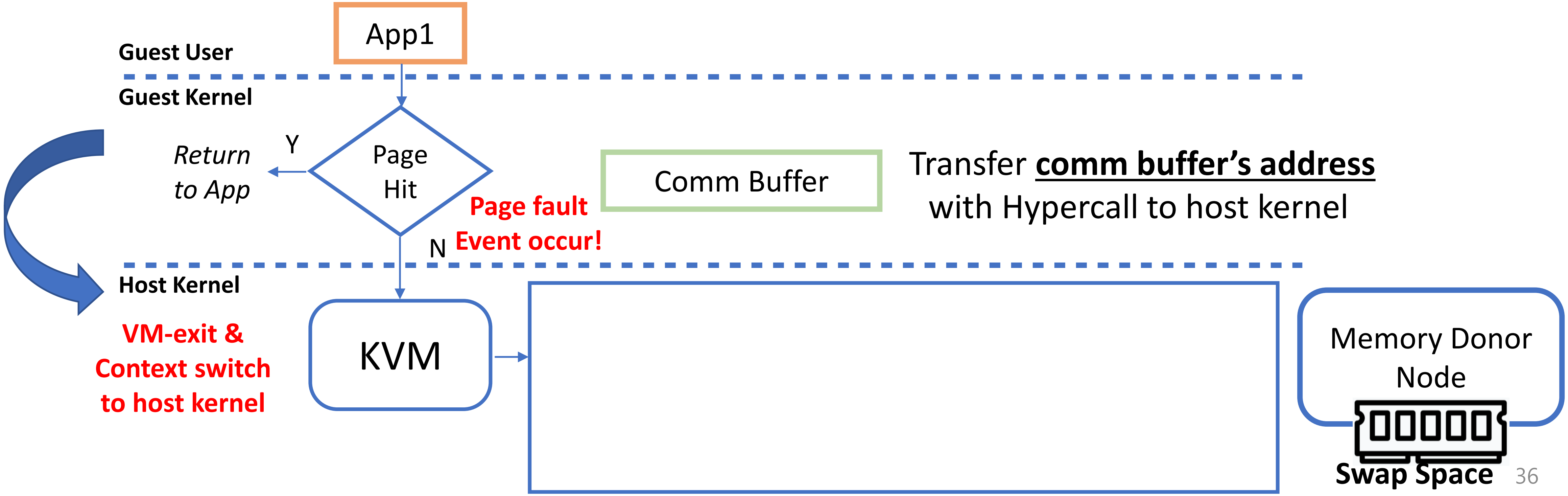

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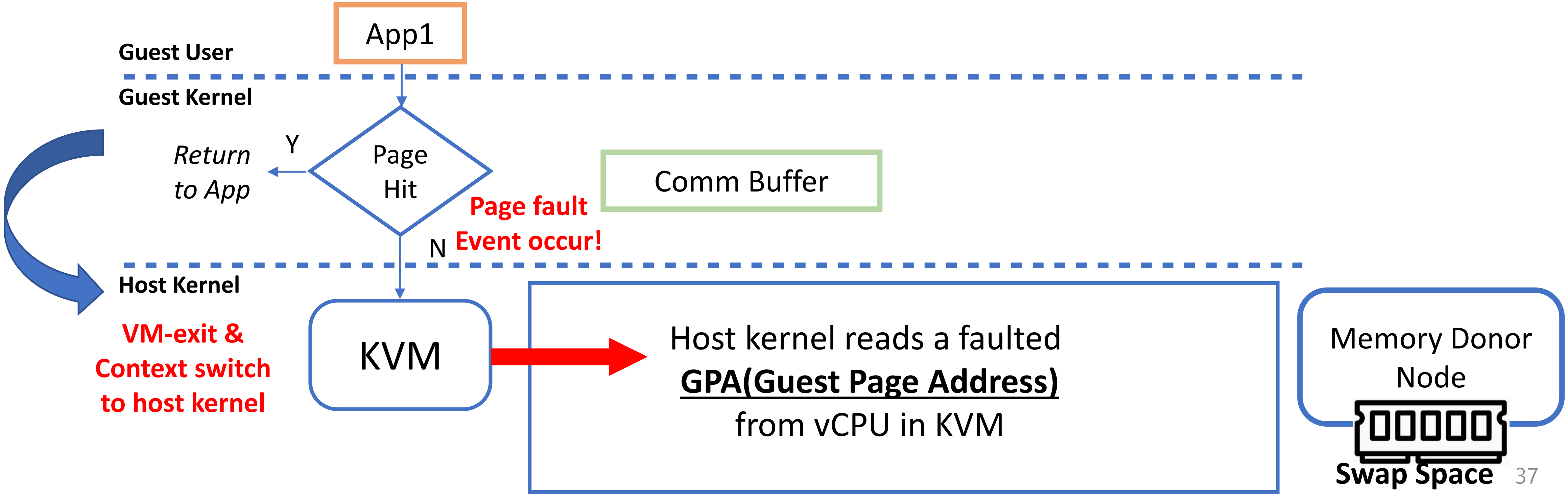

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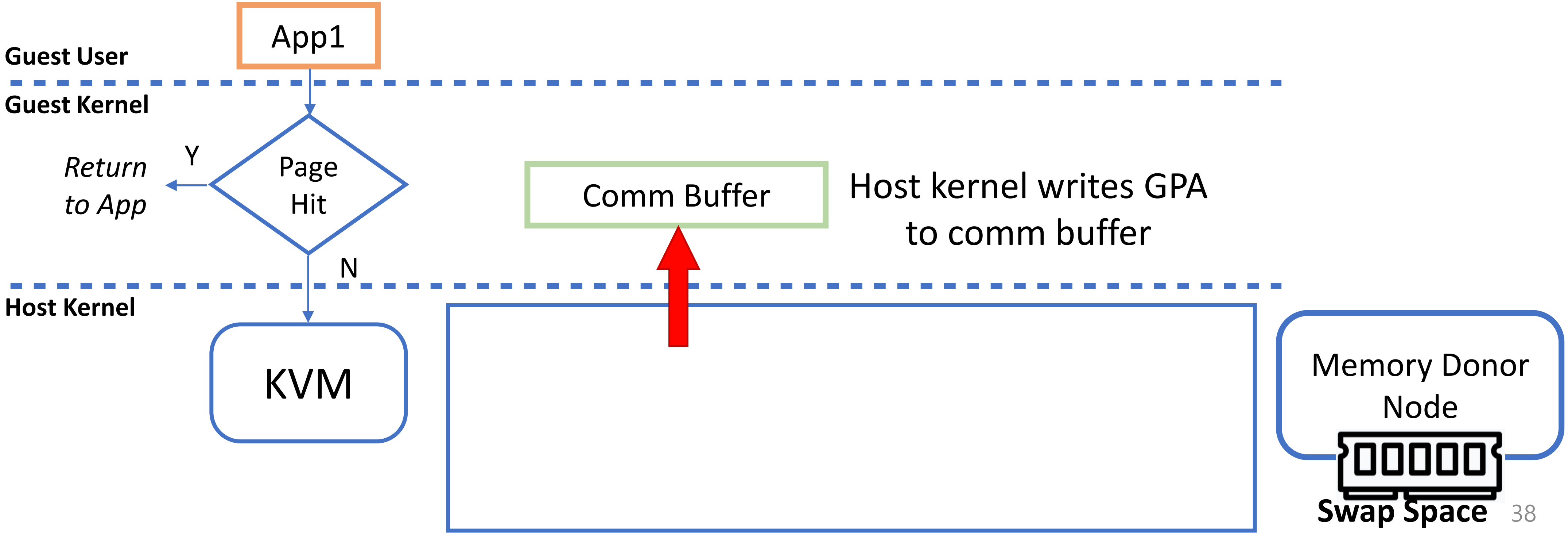

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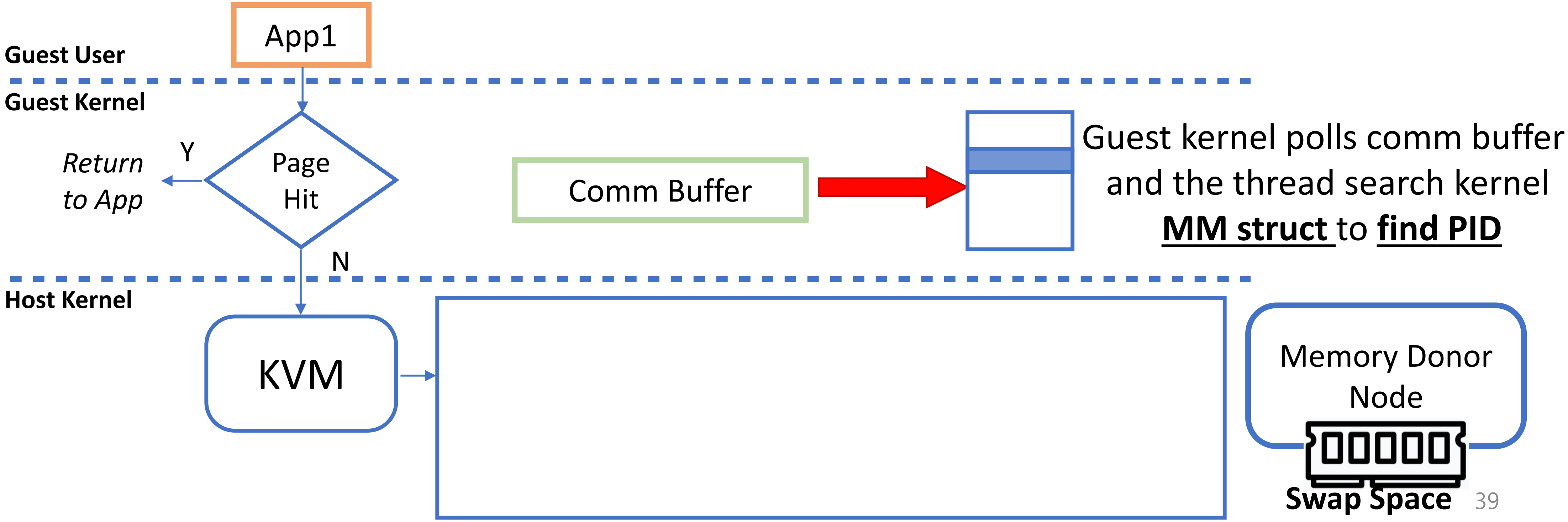

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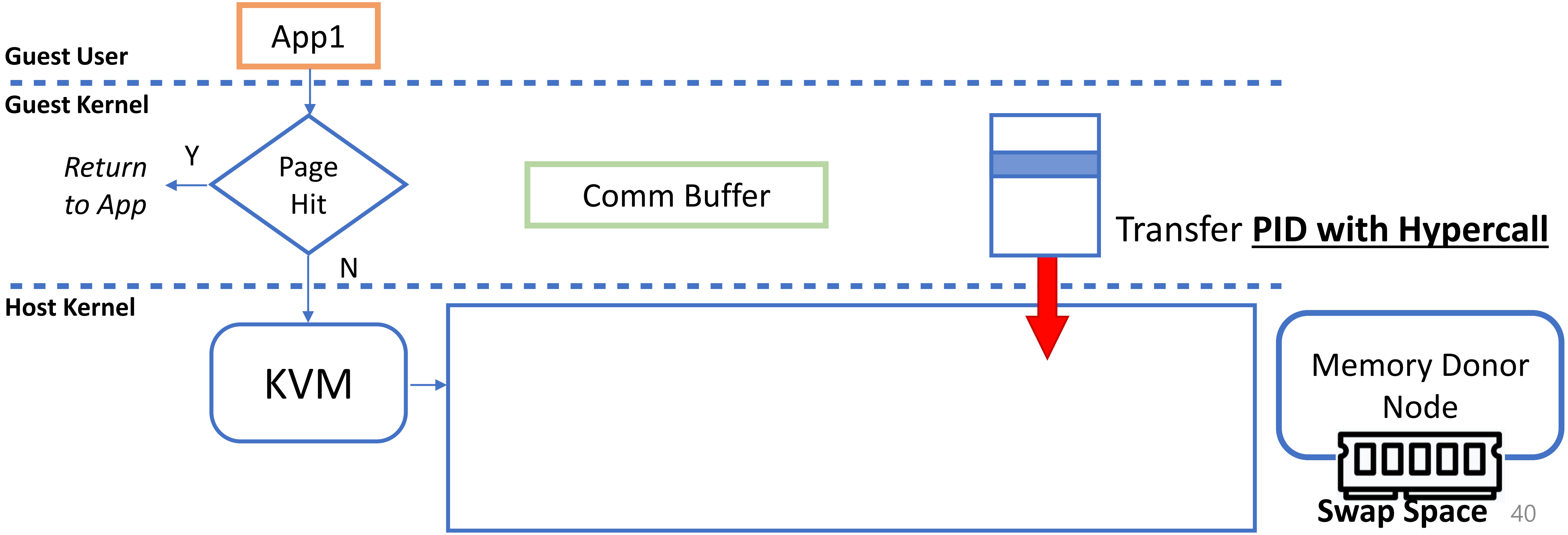

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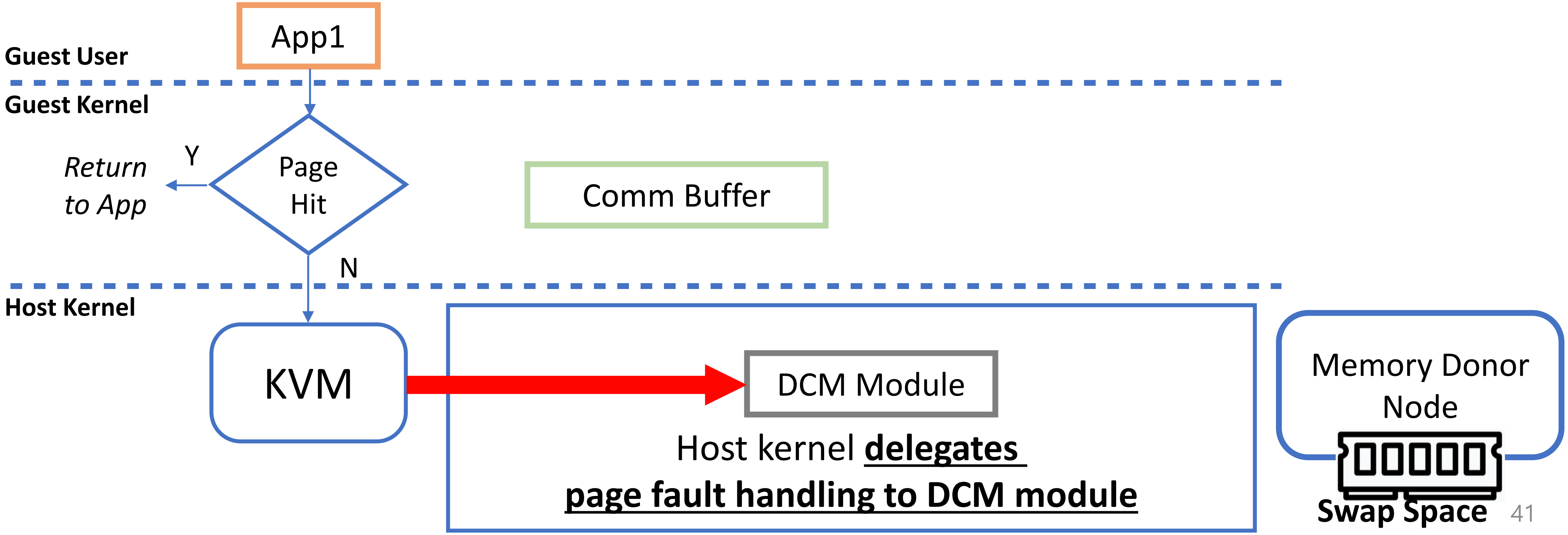

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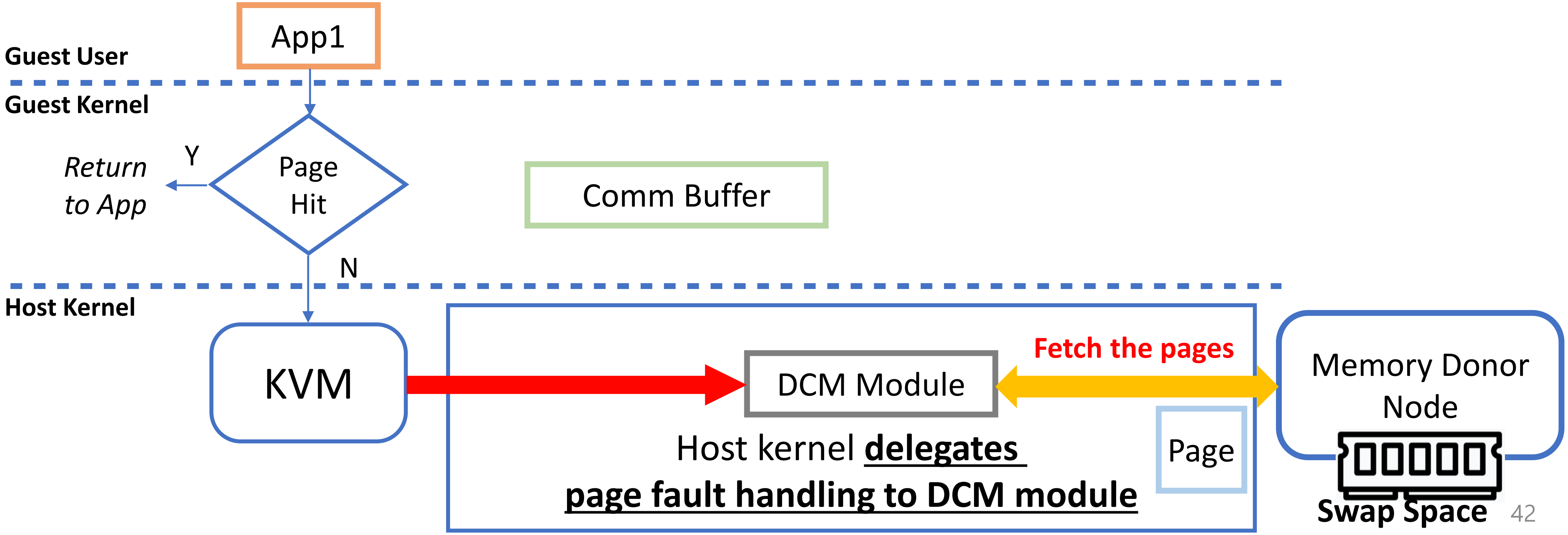

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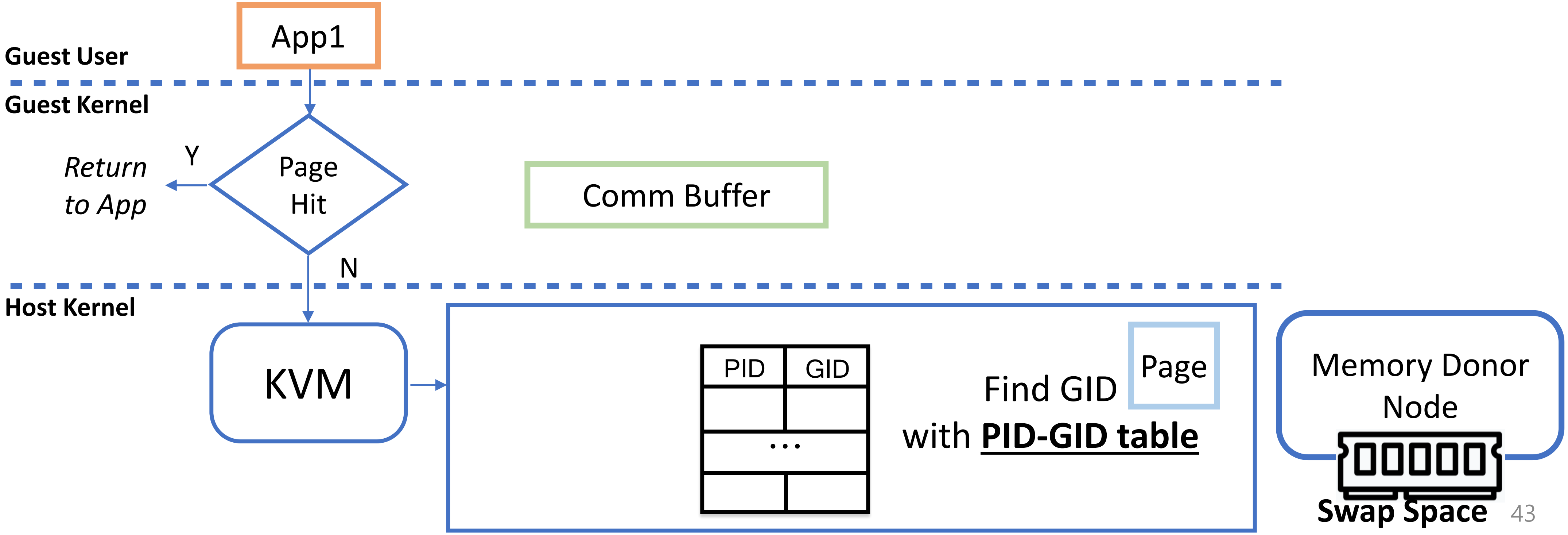

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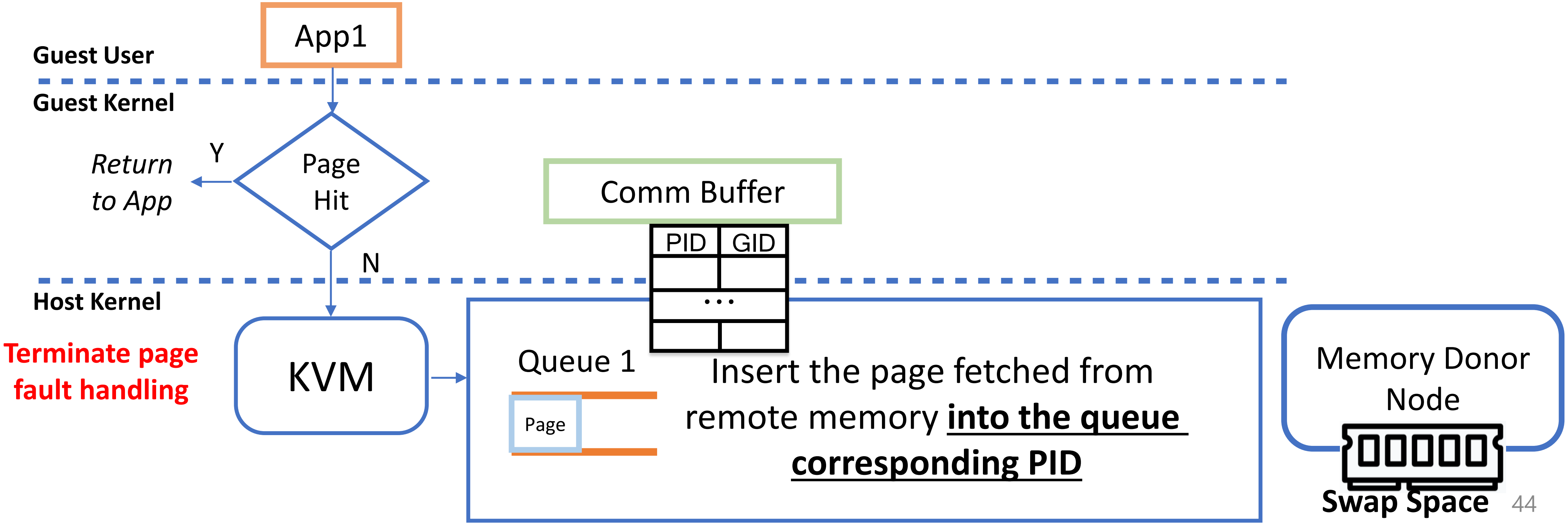

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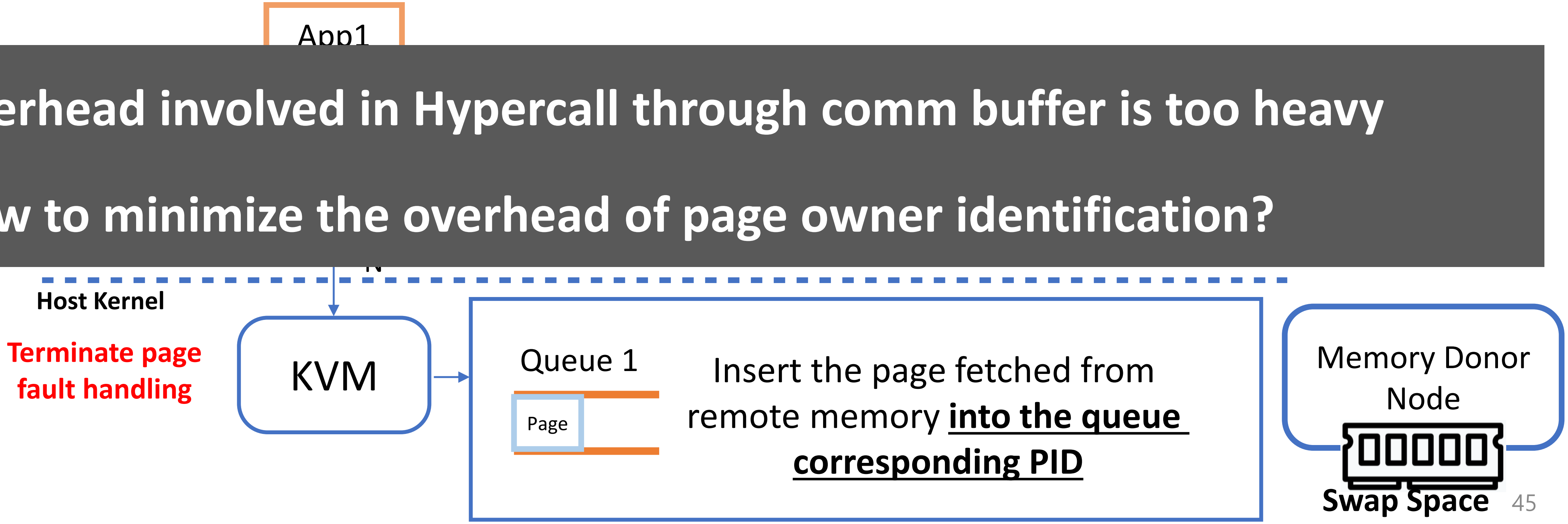
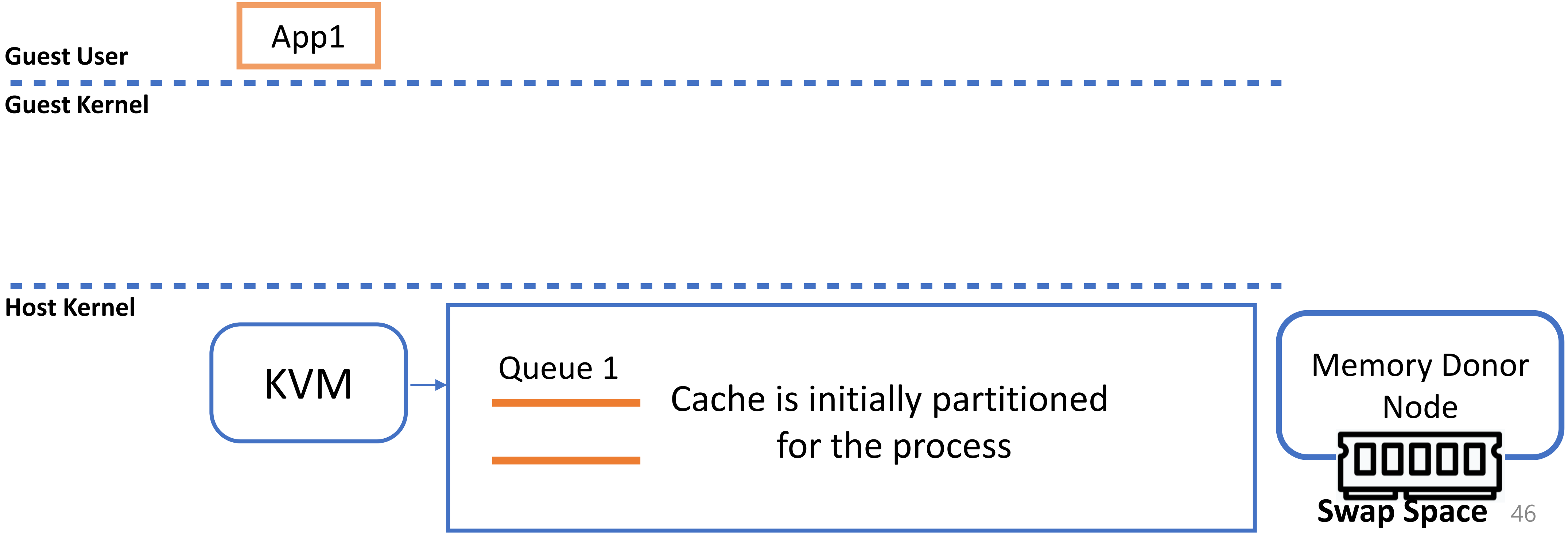


✓ **Overhead involved in Hypercall through comm buffer is too heavy**

✓ **How to minimize the overhead of page owner identification?**

MFence

- **<u>Page Owner Identification Module (gCR3)</u>**
  - It uses PGD (Page Global Directory), the address of the page table, as a PID
  - PGD can be obtained by reading the vCPU's guest CR3 register value



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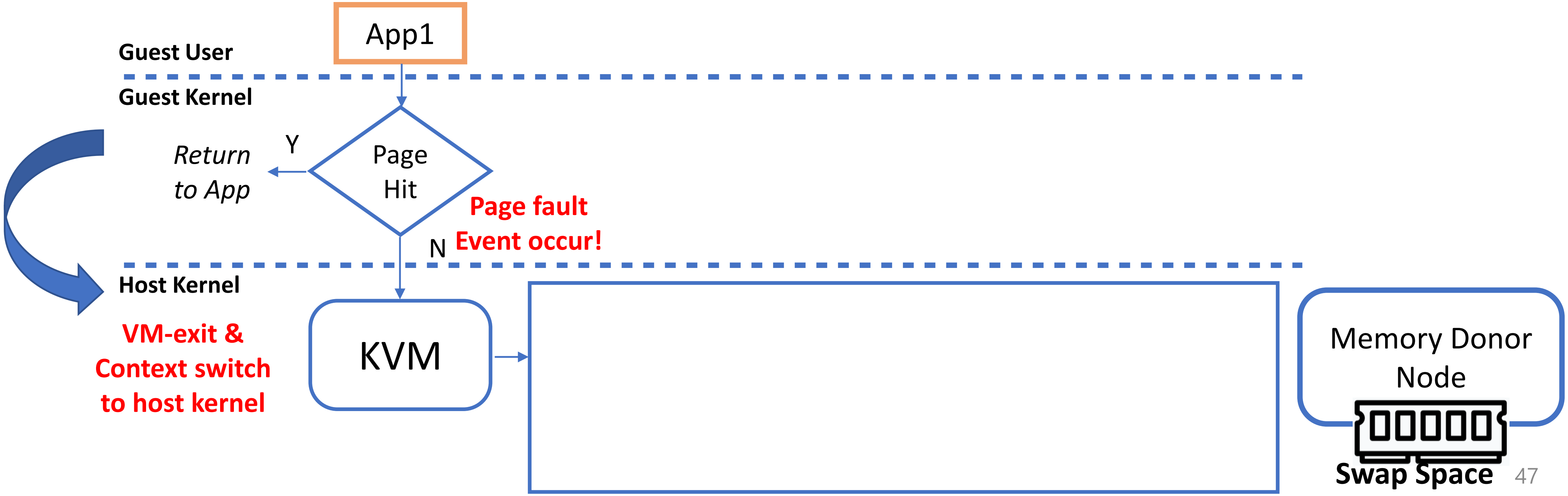

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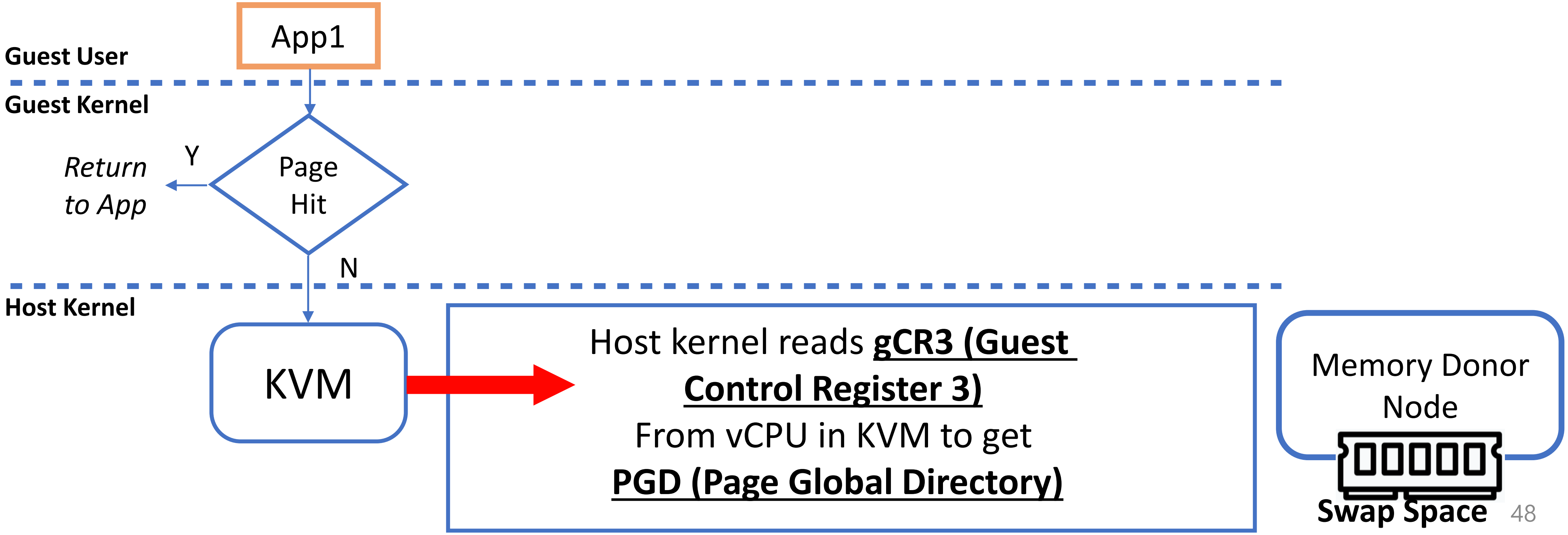

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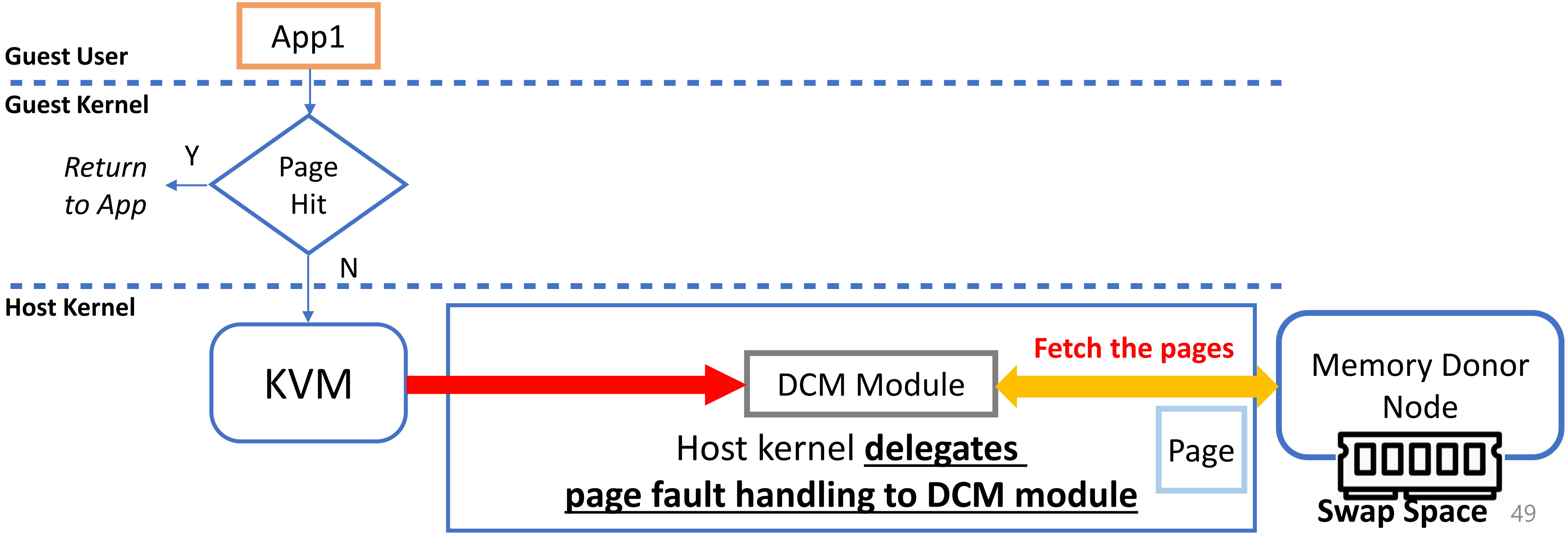

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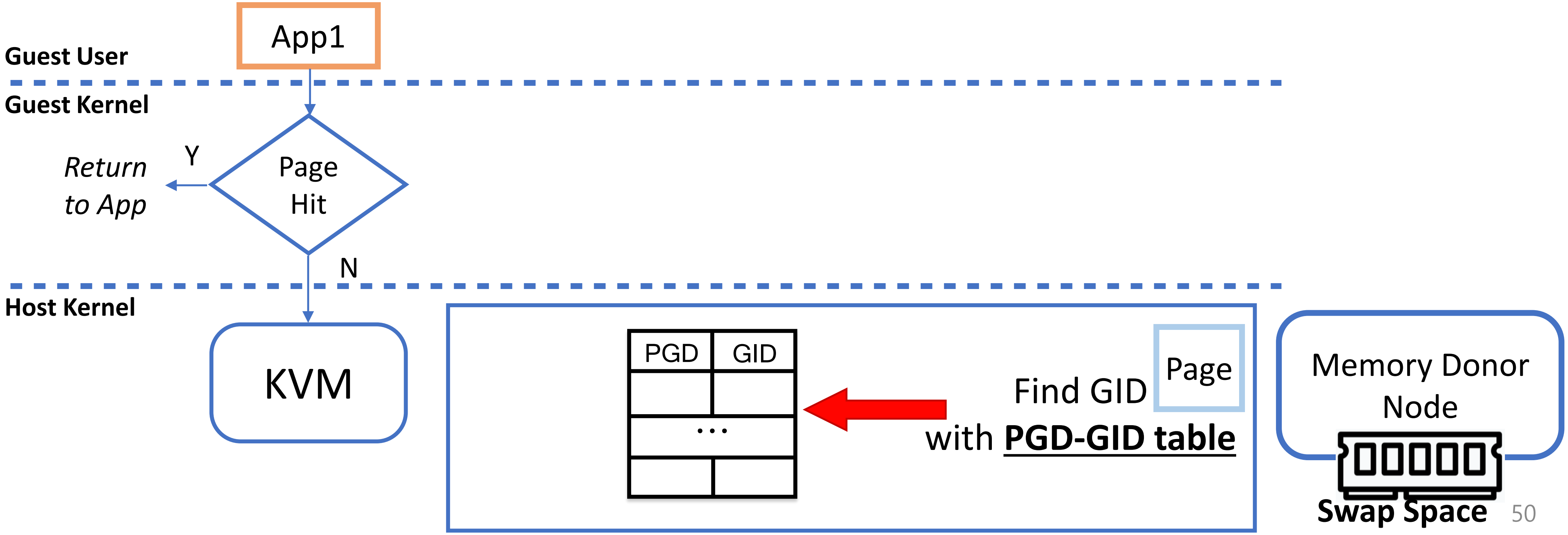

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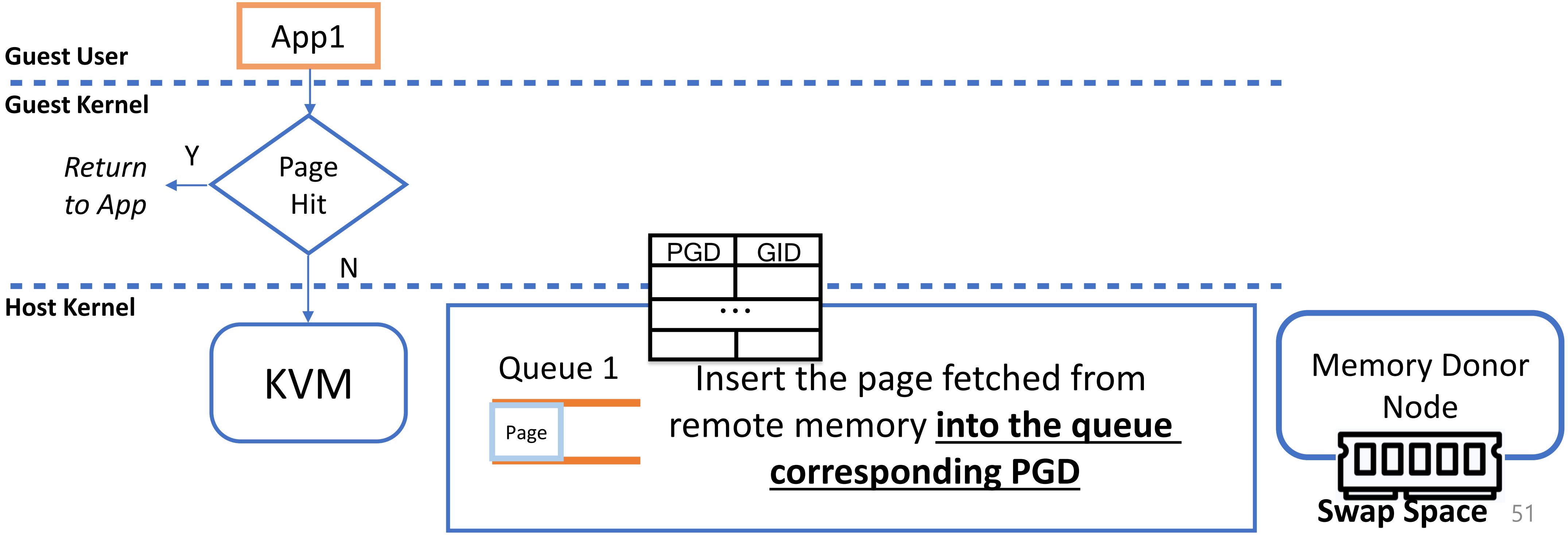

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- **Evaluation**

Evaluation

- Evaluation Setup

CPU	Intel® Xeon Gold 6330, 2.00 GHz 28core * 2
Memory	16GB (DDR4, 3200MHz) * 8
Network	Mellanox ConnectX-5 100Gb/s EDR HCA
SSD	Intel SSD 750 (Read: 2.2 GB/s, Write: 900 MB/s)
OS	Linux kernel-4.18.0-240.10.1.el8

- Comparisons
  - ✓ DCM(A): DCM where the workload is running alone
  - ✓ DCM(S): DCM where the workload is executed in combination with other workload, which can cause interference between workload
  - ✓ MFence(**gCR3**): DCM with cache partitioning adopting gCR3
  - ✓ MFence(Hypercall): DCM with cache partitioning adopting the Hypercall

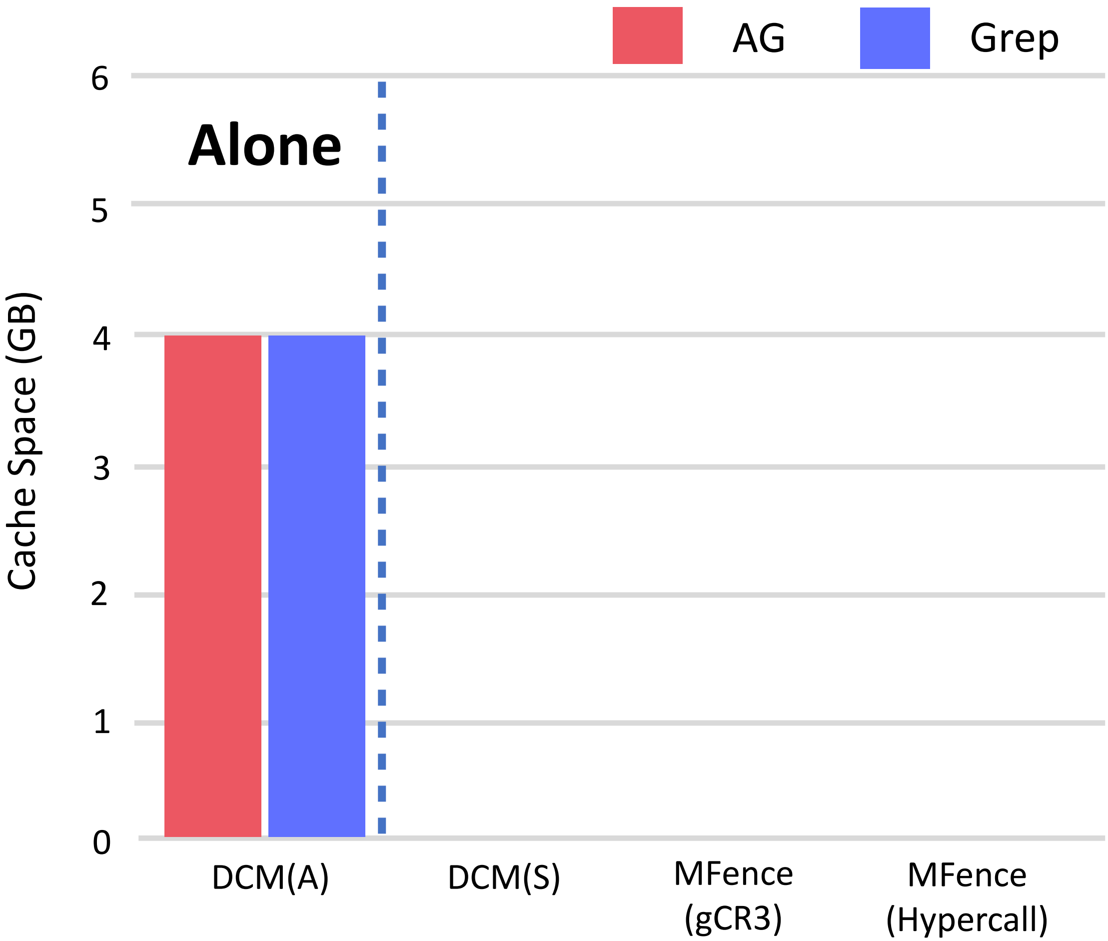
Evaluation

- Workloads (Bigdata kernel applications)
  - ✓ Grep
  - ✓ AG(Aggregation)
  - ✓ GAG(Group By Aggregation)

- Evaluation Setting
  - ✓ Memory footprint 8GB for each workload
  - ✓ Local cache size is half the sum of the workload's footprints for each comparison

Evaluation

- MFence performance of cache partitioning with workload combination



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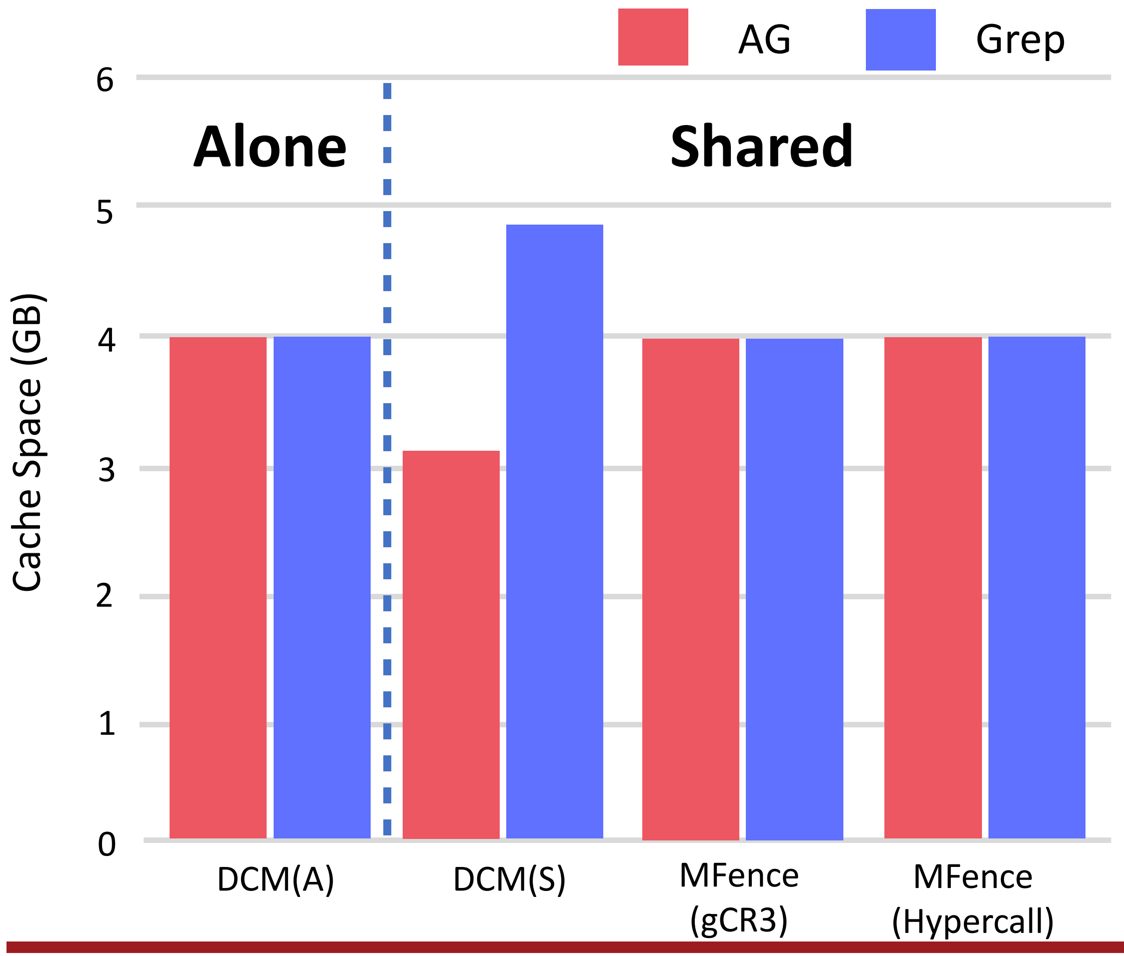

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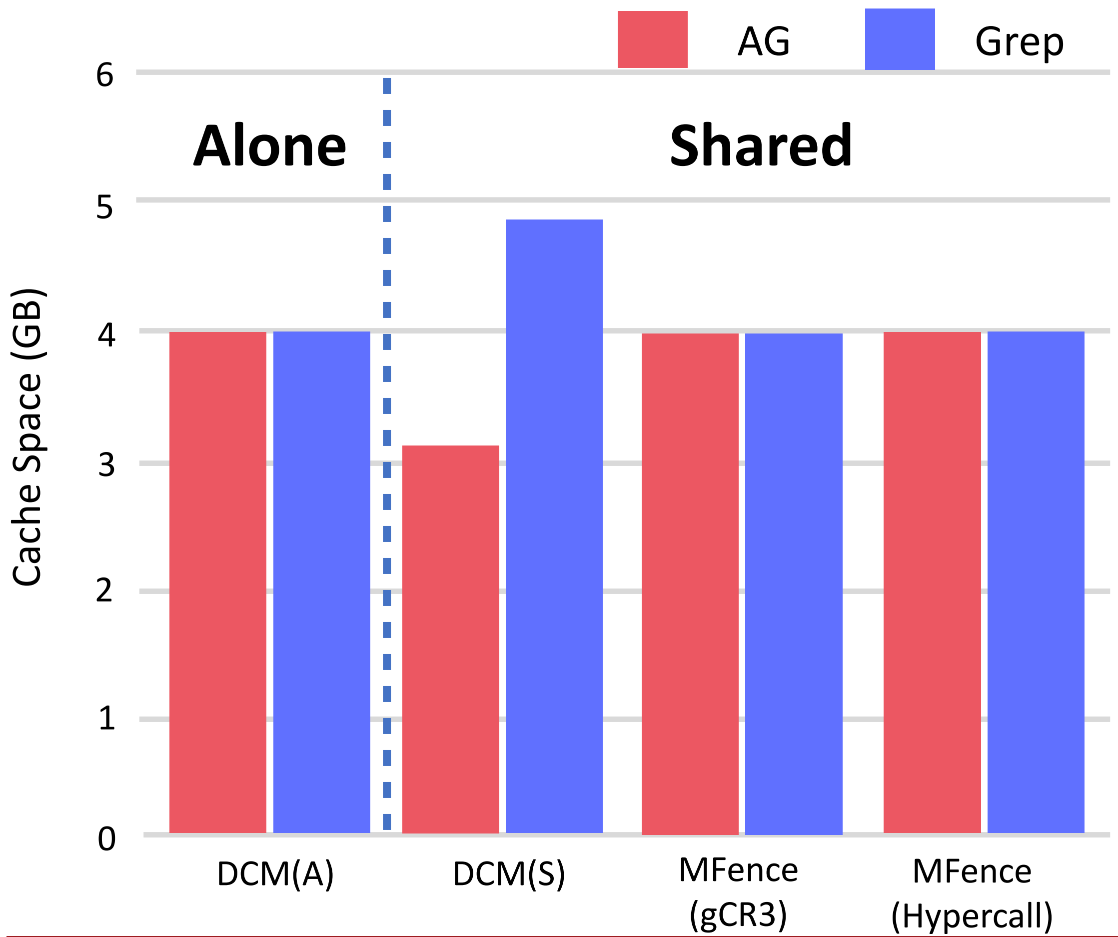

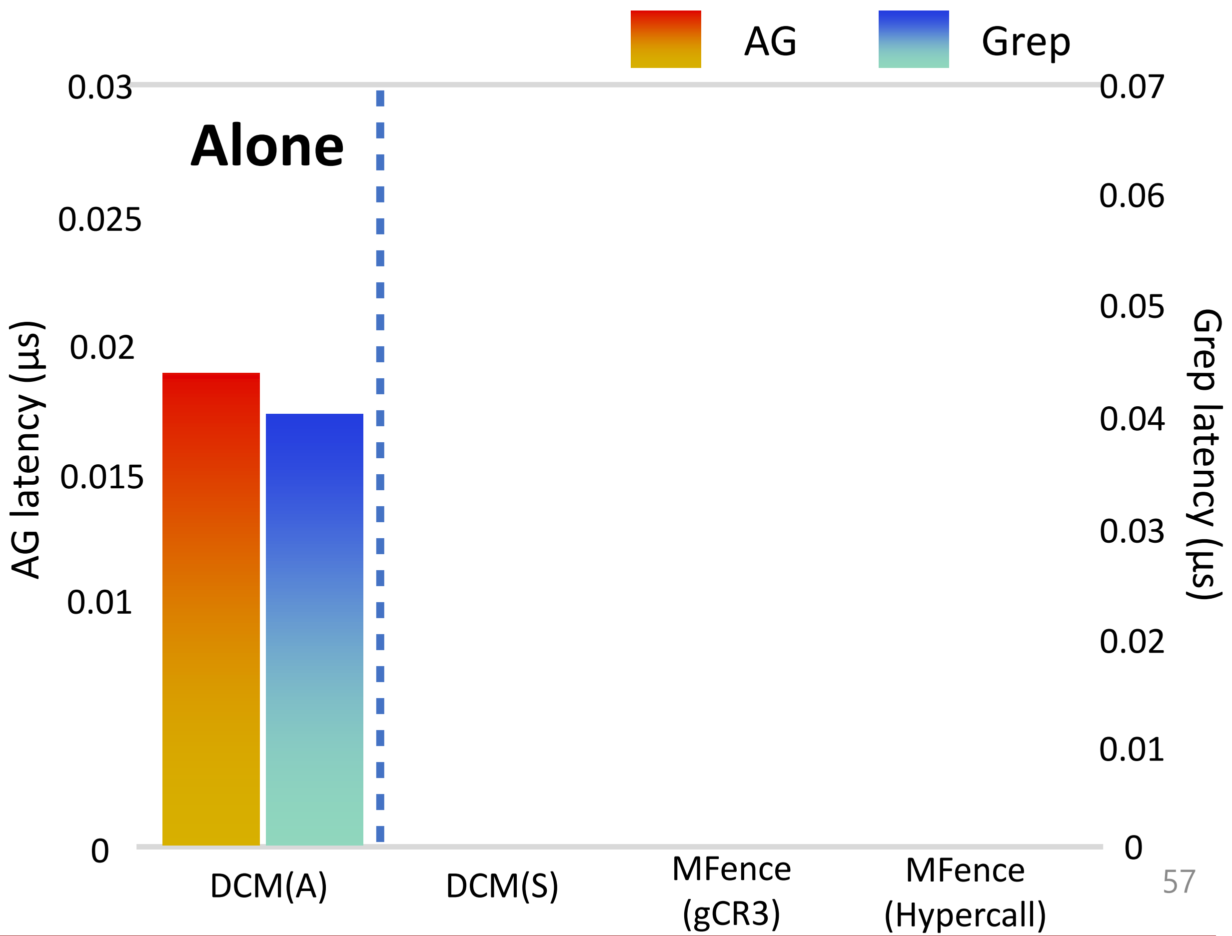

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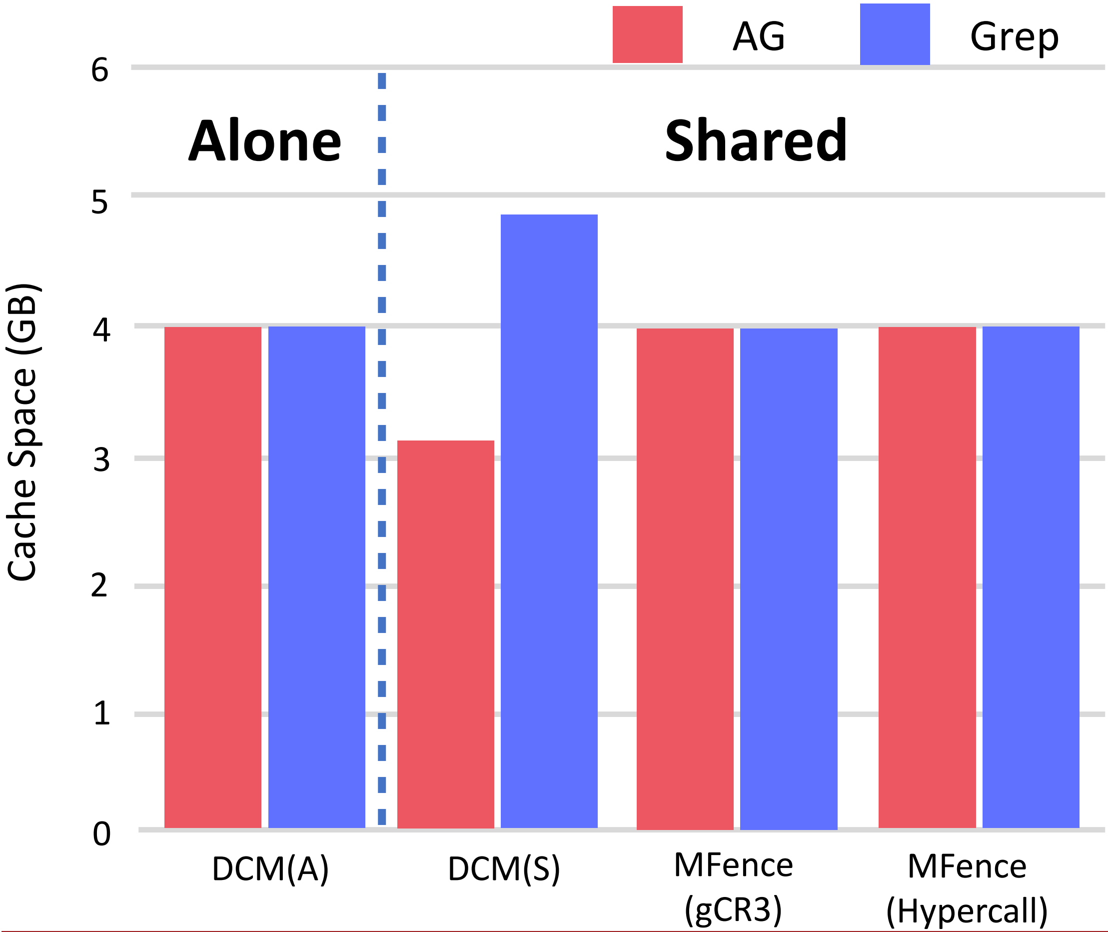

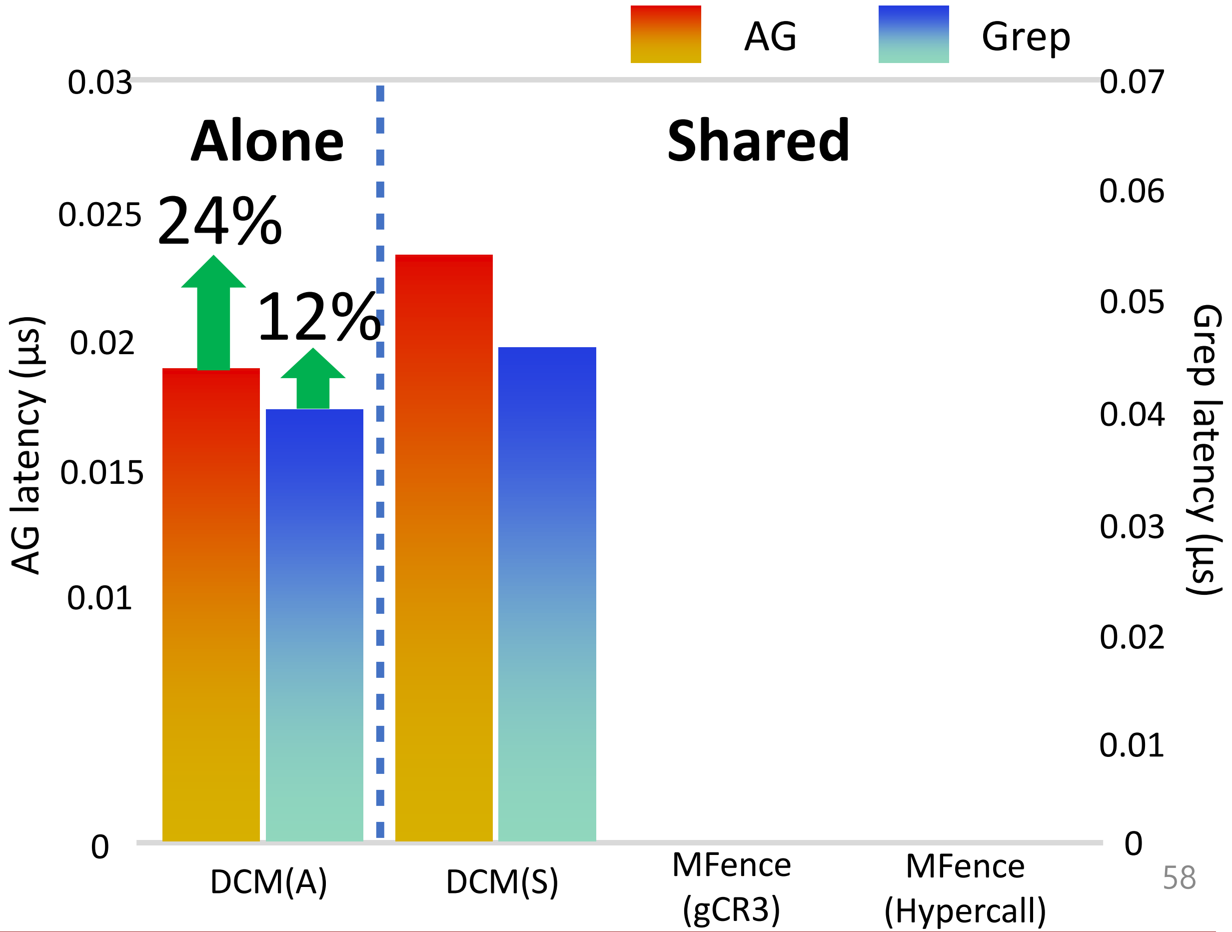

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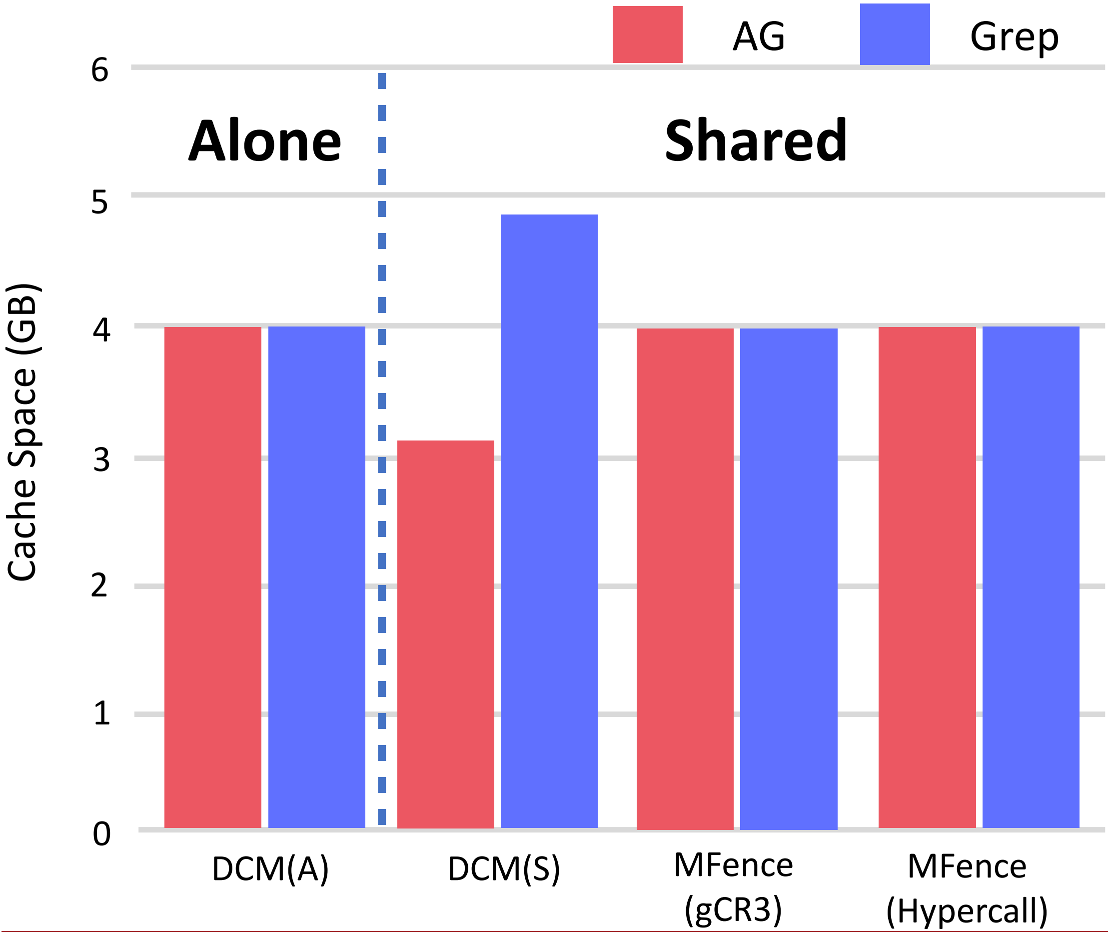

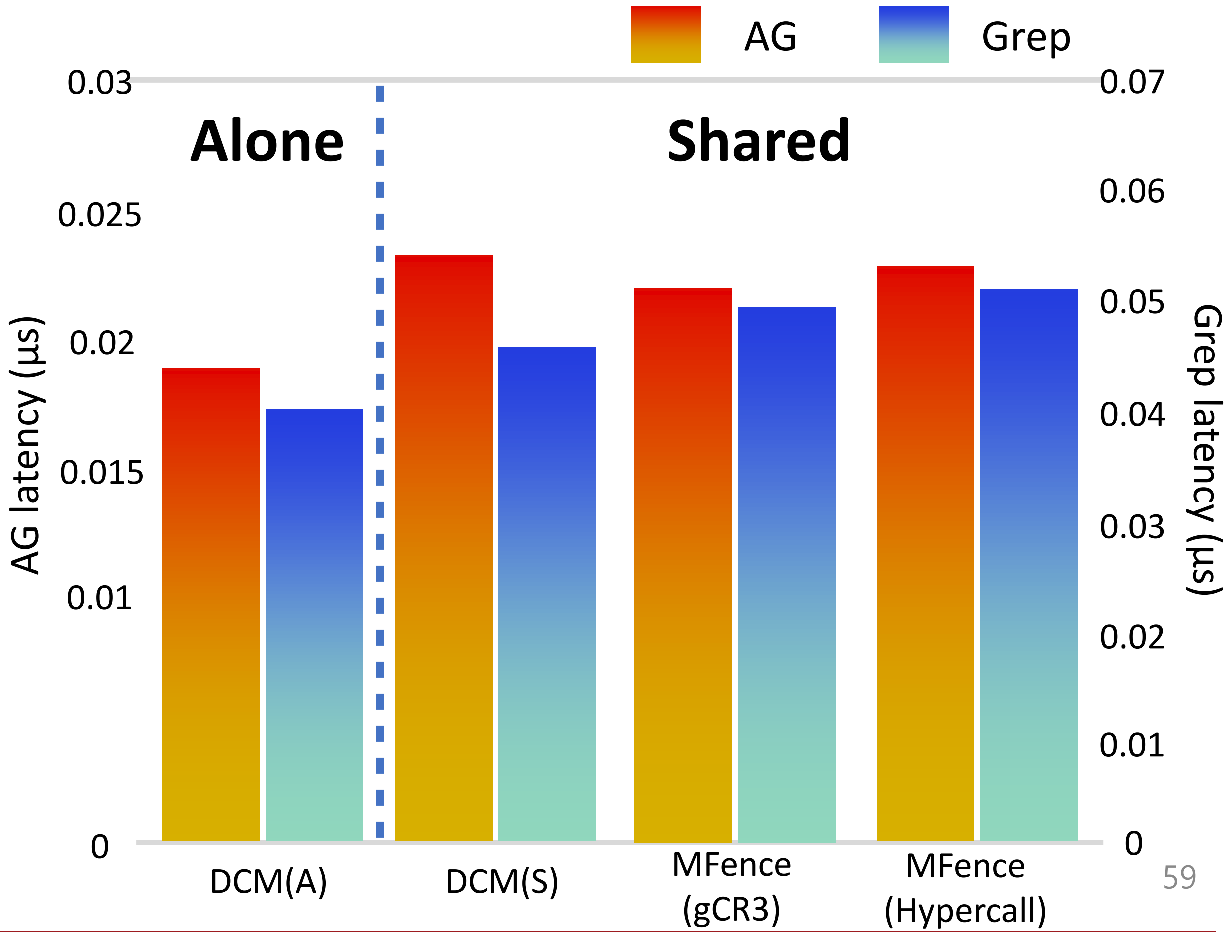

Conclusion

- Memory races between processes on disaggregated memory platform causes memory imbalance and ultimately causes a difference in performance
- We proposed MFence, a mechanism to prevent memory race on a VM-based disaggregated memory platform (DCM)
- MFence devised a lightweight identification module (gCR3) to get the page information of the process running on guest OS from Host OS
- The experiment showed that there was no memory race when each workload combination provided half the memory of the local cache, and the corresponding change in performance was measured

Questions?

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