Kindle: A Comprehensive Framework for Exploring OS-Architecture Interplay in Hybrid Memory Systems

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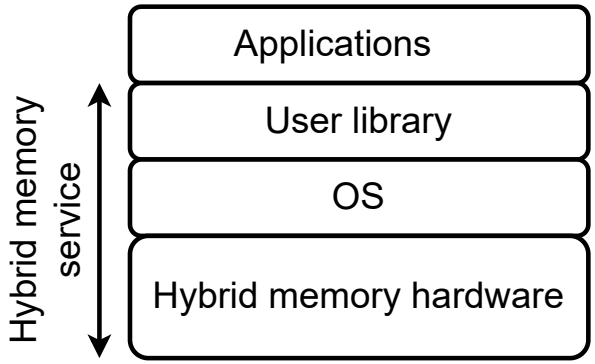
Hybrid Memory System

- Hybrid memory provides benefits of both DRAM and NVM.



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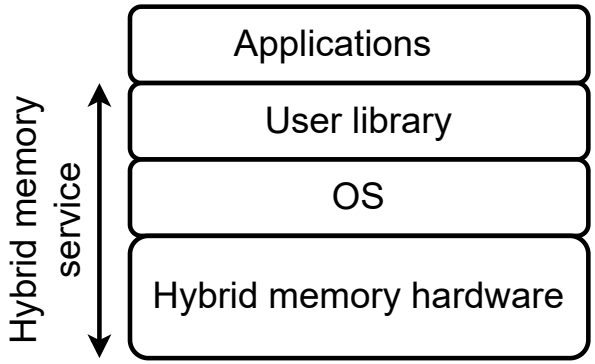

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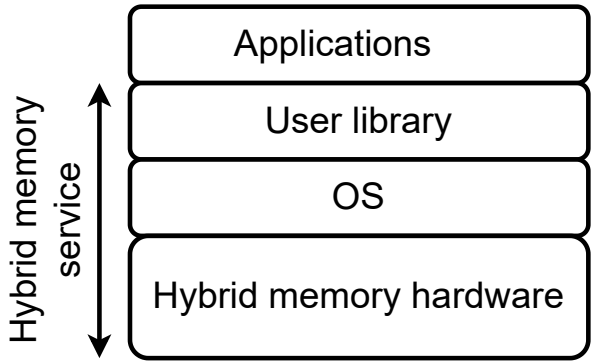
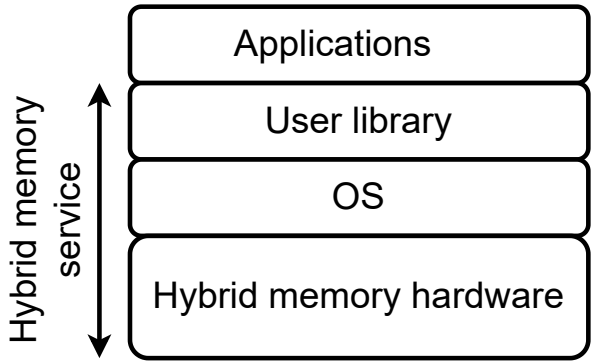
- Applications can take advantage of hybrid memory using services at different levels.
- Hybrid memory service example $\rightarrow$ page migration, data persistence, etc.



Hybrid Memory System

- Hybrid memory service may span multiple layers.



Hybrid Memory System

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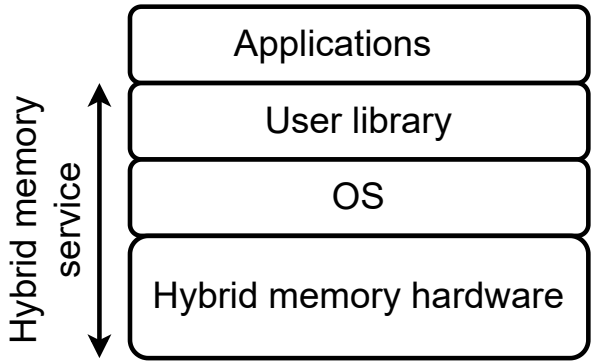

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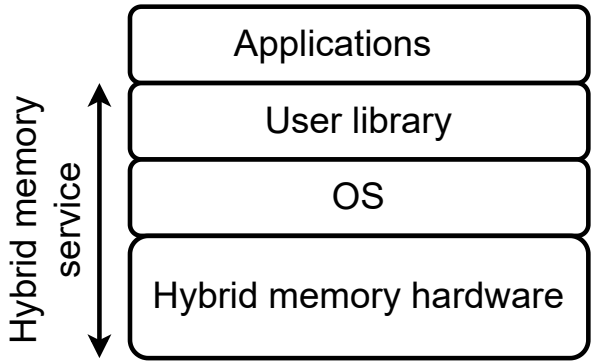

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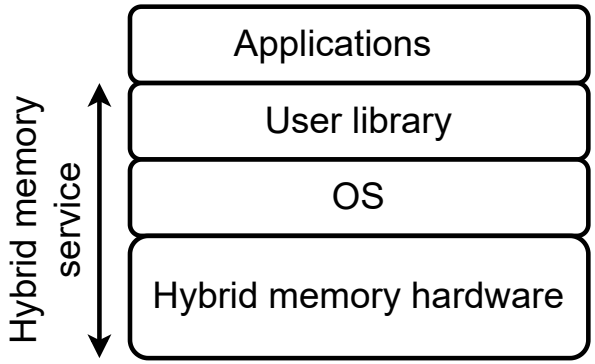
- SoftWrAP $\rightarrow$ data persistence (user library)



HSCC: Hardware/software cooperative caching for hybrid DRAM/NVM memory architectures

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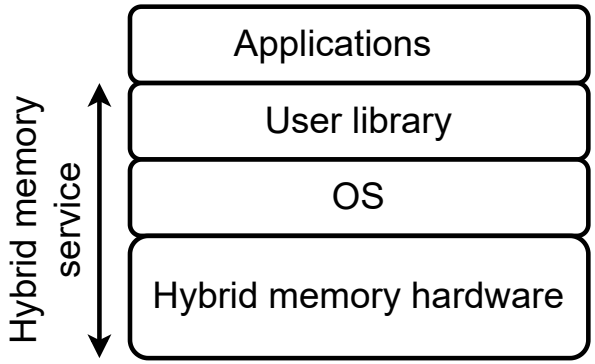
Softwrap: A lightweight framework for transactional support of storage class memory

Hybrid Memory System

- Exploration of ideas in hybrid memory systems require a framework.



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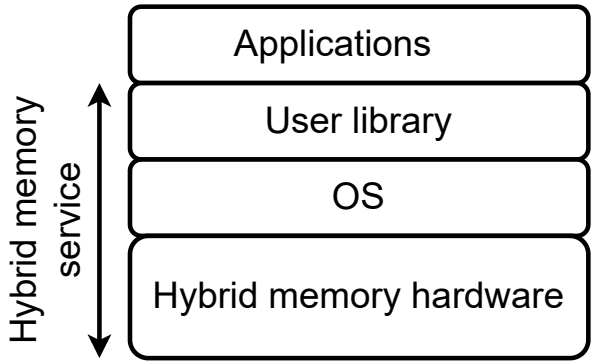

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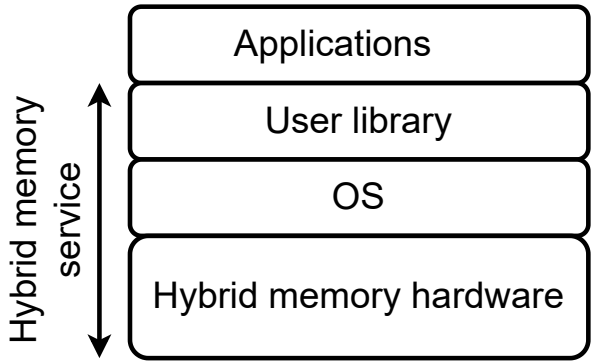

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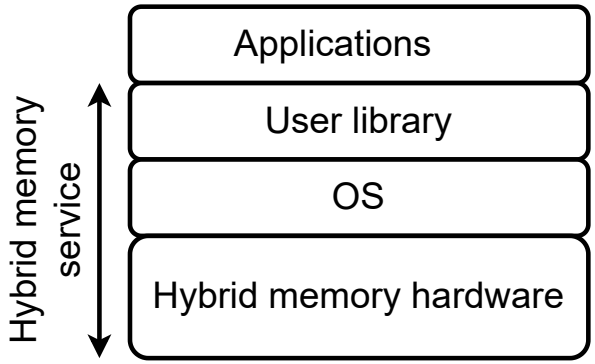
- Framework $\rightarrow$ allow quick prototyping of ideas.
- Framework $\rightarrow$ hosts lightweight OS.



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- Kindle is a lightweight full-system simulation framework for hybrid memory systems.

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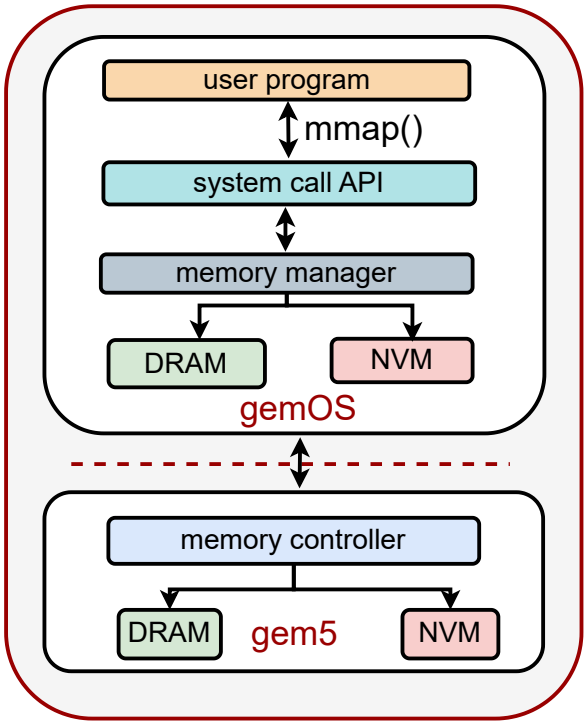
- Kindle uses *gemOS* as OS component in framework.



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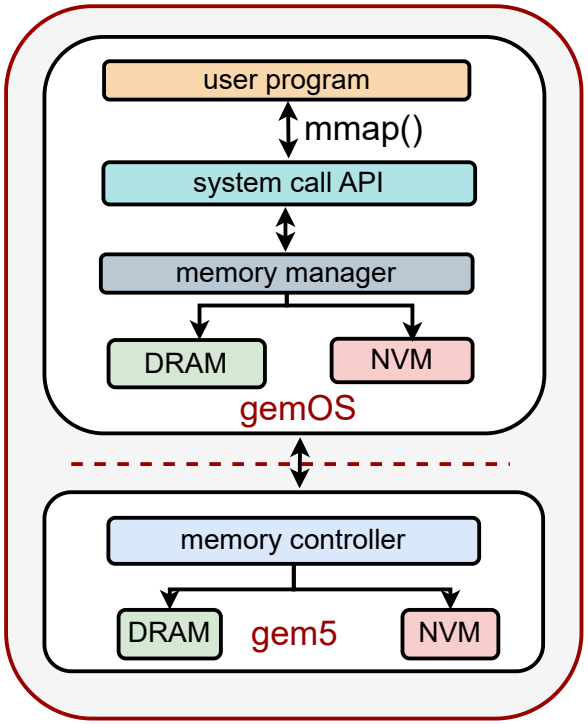

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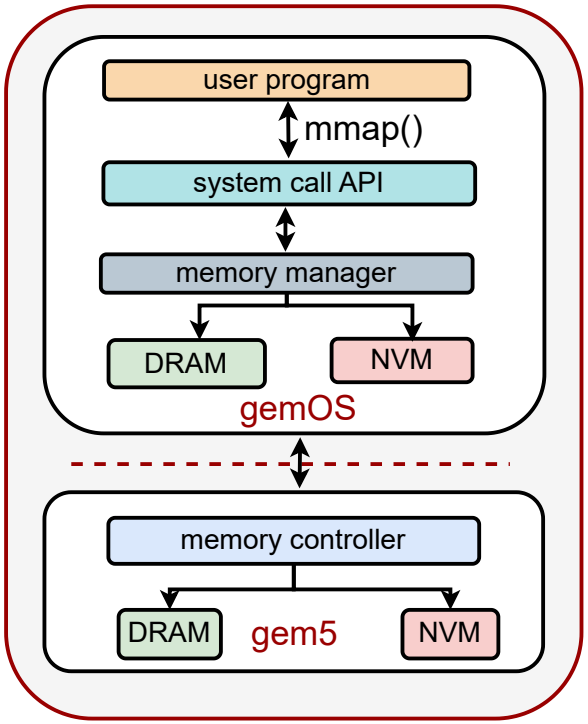
- Application allocates memory from DRAM, NVM using memory allocation API.



Kindle: Persistent Process Framework

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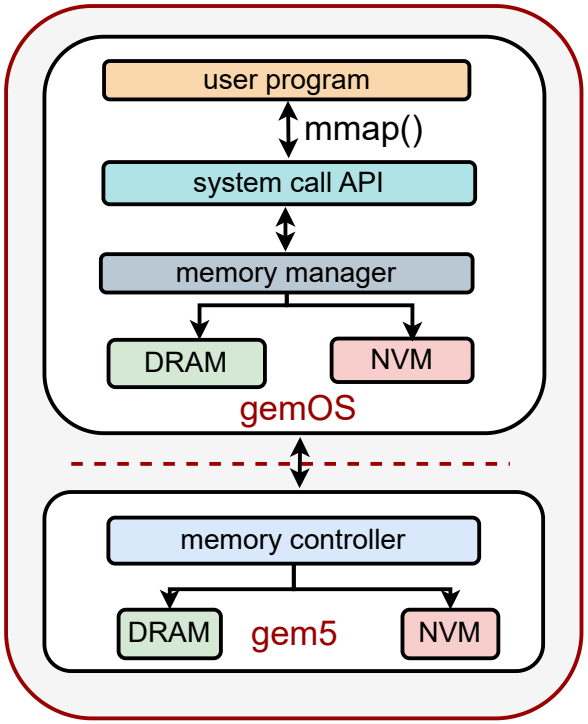

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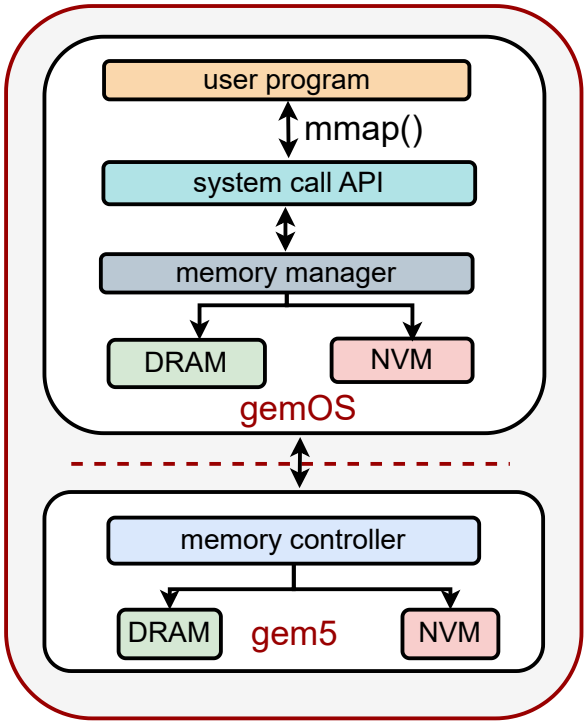
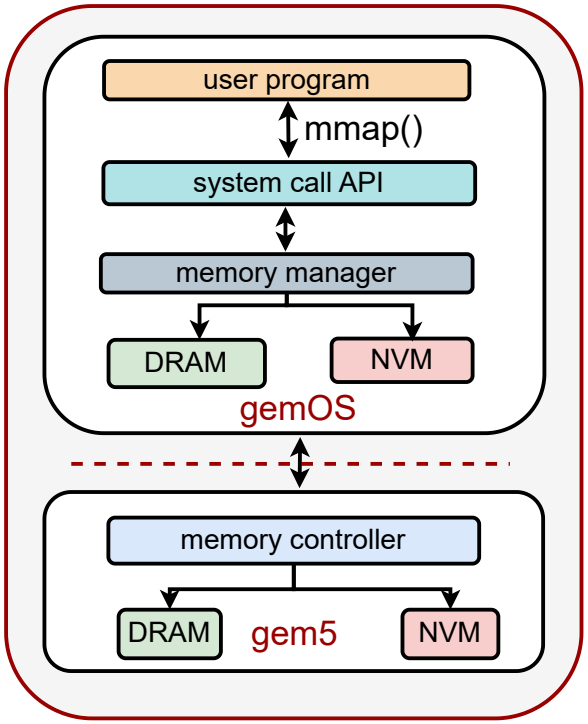


Kindle: Persistent Process Framework

- Kindle provides full process persistence in hybrid memory system.
- Kindle uses *gem5* as hardware component in framework.
- Enables prototyping solutions crossing OS-Architecture boundaries.



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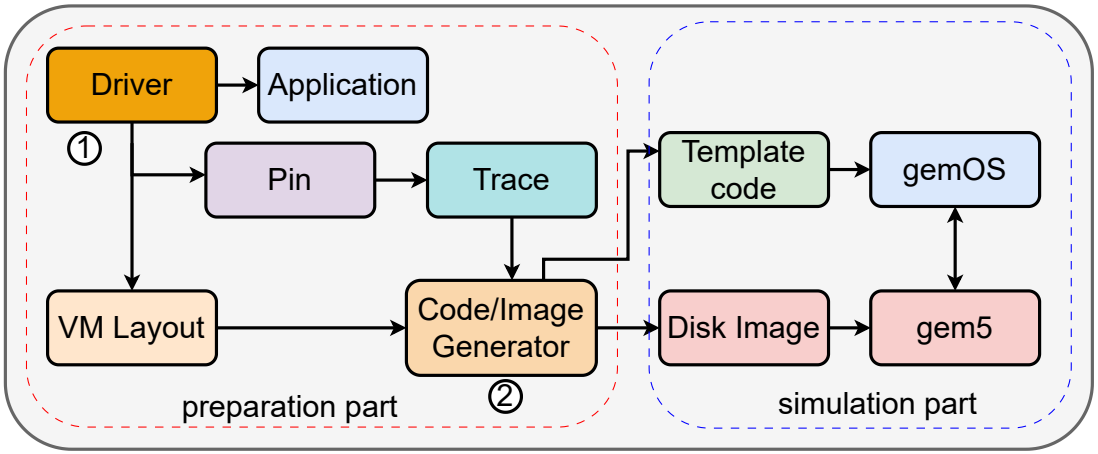
- Kindle consists for two parts.



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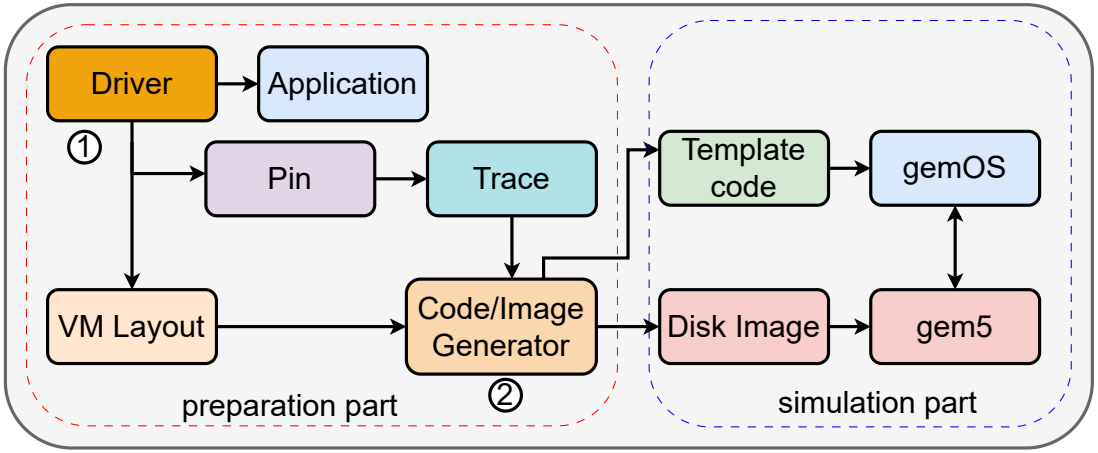
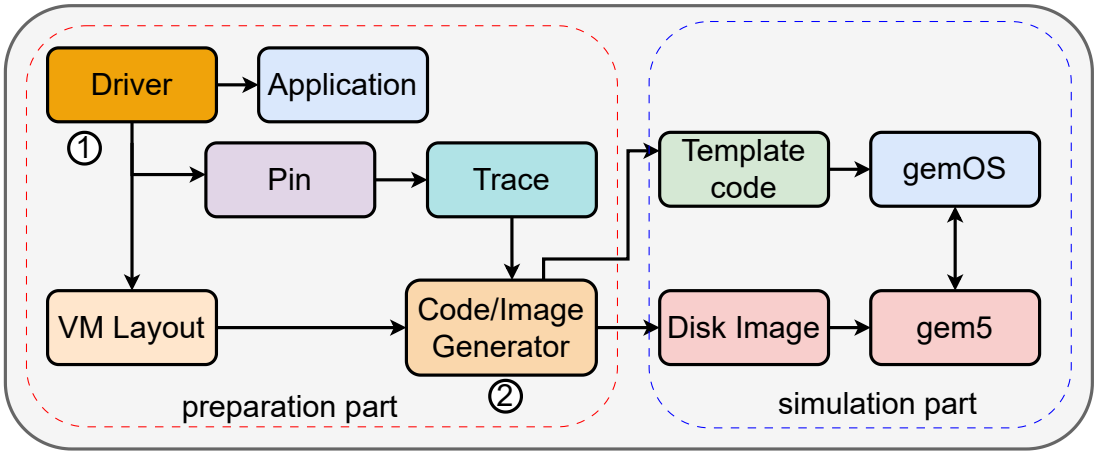


- Preparation part → generate artifacts for simulation.

Kindle: Persistent Process Framework



- Preparation part → generate artifacts for simulation.
- Simulation part → run application with persistence.

Kindle: Page Table Consistency

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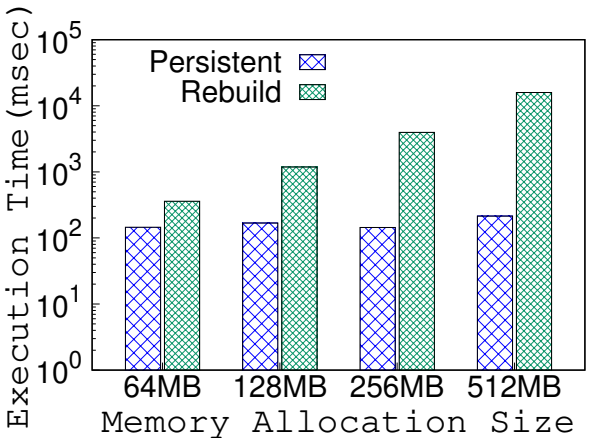
- Process persistence $\rightarrow$ consistent virtual address space management.
- Page table in NVM $\rightarrow$ Wrap modifications in failure atomicity (persistent scheme).
- Page table in DRAM $\rightarrow$ Checkpoint state to NVM periodically (rebuild scheme).

Kindle: Page Table Consistency

- Micro-benchmark sequentially access all pages in the allocated space.
- End-to-end execution time for consistently maintaining execution context.



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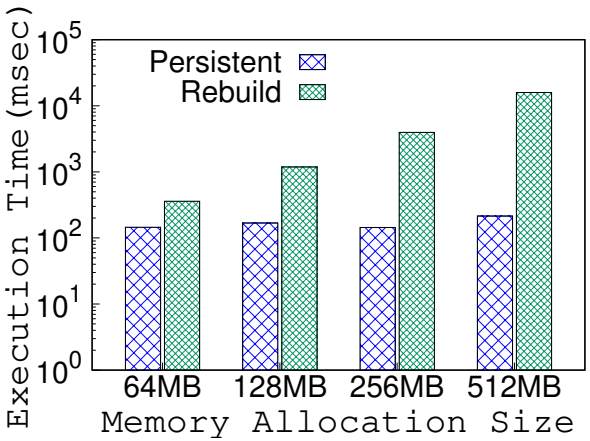

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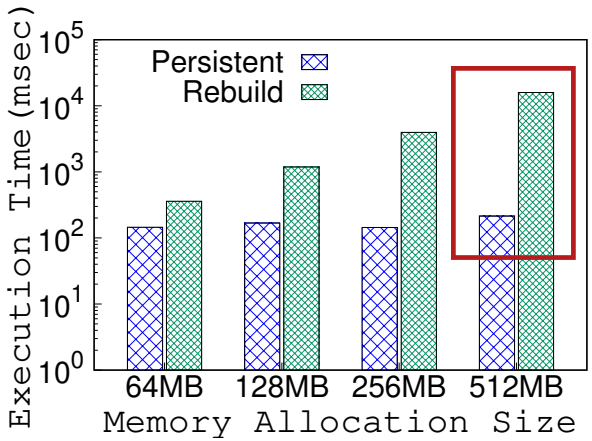
- Overhead $\rightarrow$ $\sim$74.2$\times$ (512MB) w.r.t Persistent.



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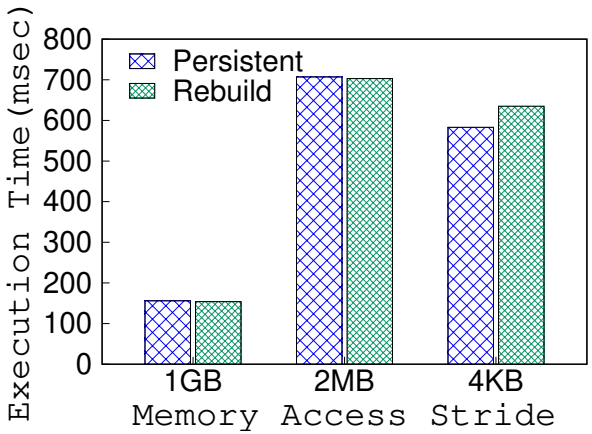
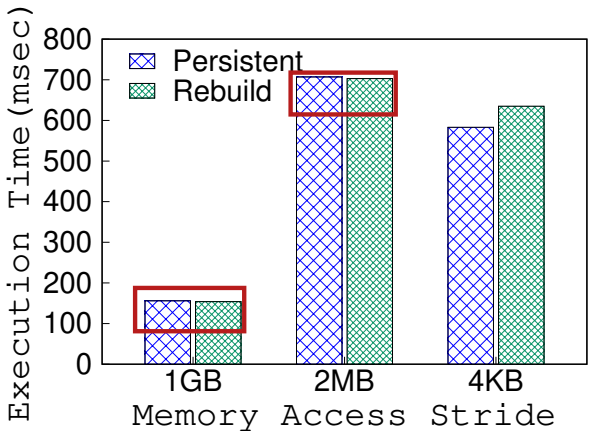


Kindle: Page Table Consistency

- Micro-benchmark stride access with predefined gap, e.g. 1GB, to map different page table levels.
- End-to-end execution time for consistently maintaining execution context.
- Persistent $\rightarrow$ slightly more execution time compared to Rebuild for 1GB, 2MB.



Kindle: Page Table Consistency

Alloc/Free Size	Persistent (msec)	Rebuild (msec)
64MB	325	19377
128MB	389	23438
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- Micro-benchmark $\rightarrow$ sequence of fixed size `mmap` and `munmap` operations.
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- Rebuild scheme overhead $\rightarrow \sim 1.5\times$ from 64MB to 256MB.

Existing work re-evaluation using Kindle

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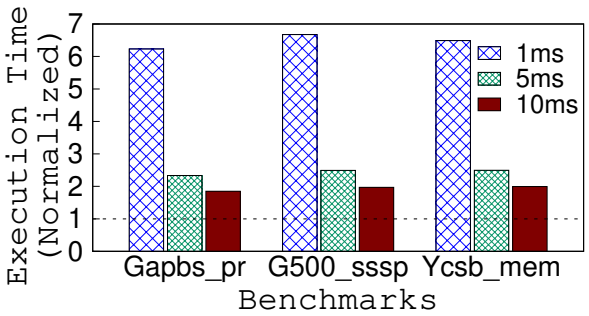

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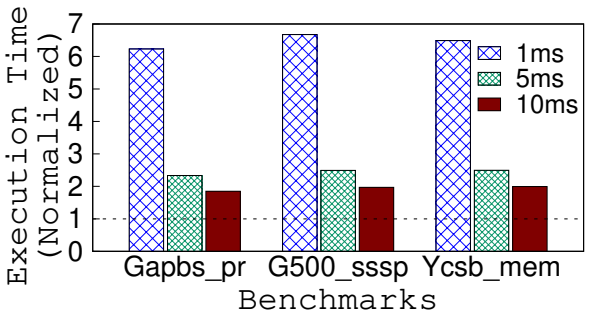

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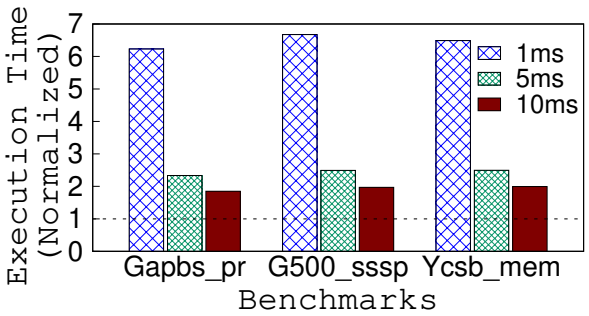

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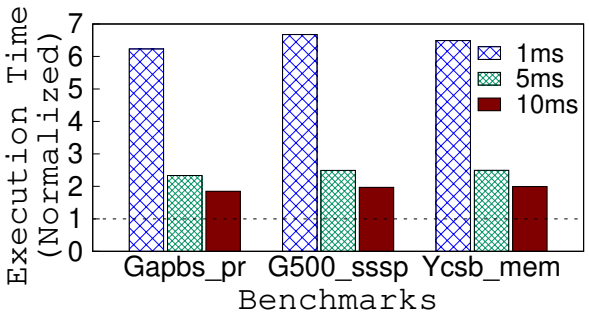
  - Average $\sim 3\times$ reduction in overhead from 1 msec to 10 msec.



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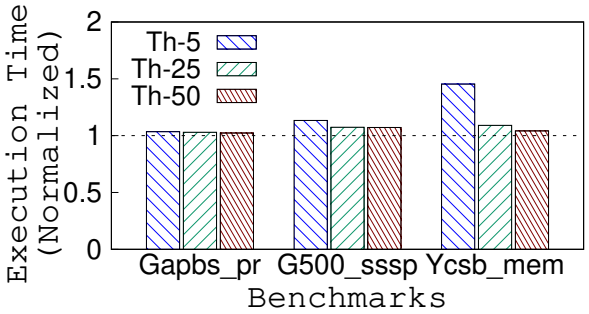

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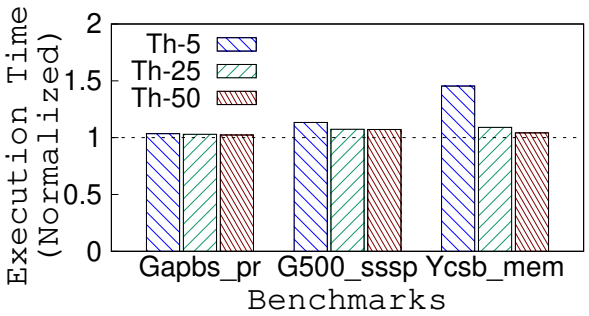

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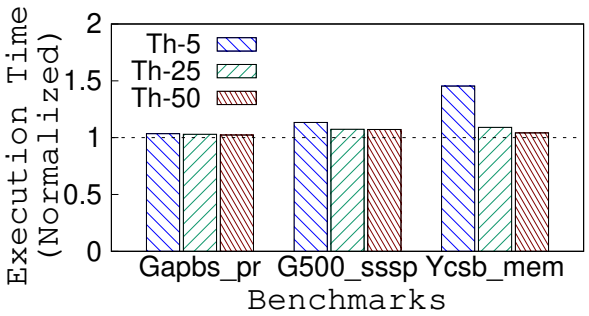

- Execution time with OS migration activities normalized to time without OS activities.
- Migration interval is 31.25 msec and fetch thresholds are 5, 25 and 50
- Gapbs_pr shows the minimum overhead.

HSCC using Kindle

Benchmark	Th-5	Th-25	Th-50
Gapbs_pr	354	273	132
G500_sssp	4489	1475	1346
Ycsb_mem	23093	1661	221

- Table shows number of pages migrated for different thresholds.

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- Number of pages migrated reduces with increase in fetch threshold.
- Ycsb_mem $\rightarrow \sim 13\times$ reduction in number of pages migrated for Th-25 compared to Th-5.

HSCC using Kindle

Benchmark	Fetch Threshold	Page Selection (%)	Page Copy (%)
Gapbs_pr	Th-5	1.74	98.26
	Th-25	1.92	98.08
	Th-50	2.06	97.94

- Migrating a page to DRAM consists of *page selection* and *page copy*

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- Table shows percentage of time spent as part of OS migration activity.
- Gapbs_pr $\rightarrow$ Page selection time is less than $\sim$2% across all fetch thresholds.

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- Table shows percentage of time spent as part of OS migration activity.
- Gapbs_pr $\rightarrow$ Page selection time is less than $\sim$2% across all fetch thresholds.
- Page copy occupies majority of execution time across all benchmarks.

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- Kindle provides full process persistence.
- We compared two schemes to consistently maintain page table using Kindle.
- We showed utility of Kindle with two prototype implementations of state-of-the-art hybrid memory schemes, SSP and HSCC.

Questions?

Scan for Kindle