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Hermit: Low-Latency, High-Throughput, and Transparent Remote Memory via Feedback-Directed Asynchrony

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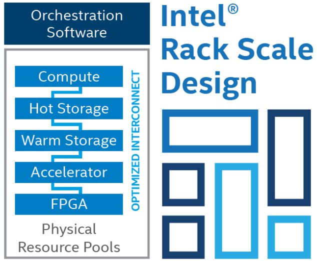
Adam Belay, Qingda Lu, Yiying Zhang, Miryung Kim, Guoqing Harry Xu

Datacenter Must Balance Latency With Utilization

Latency-Critical Applications



Remote Memory Systems

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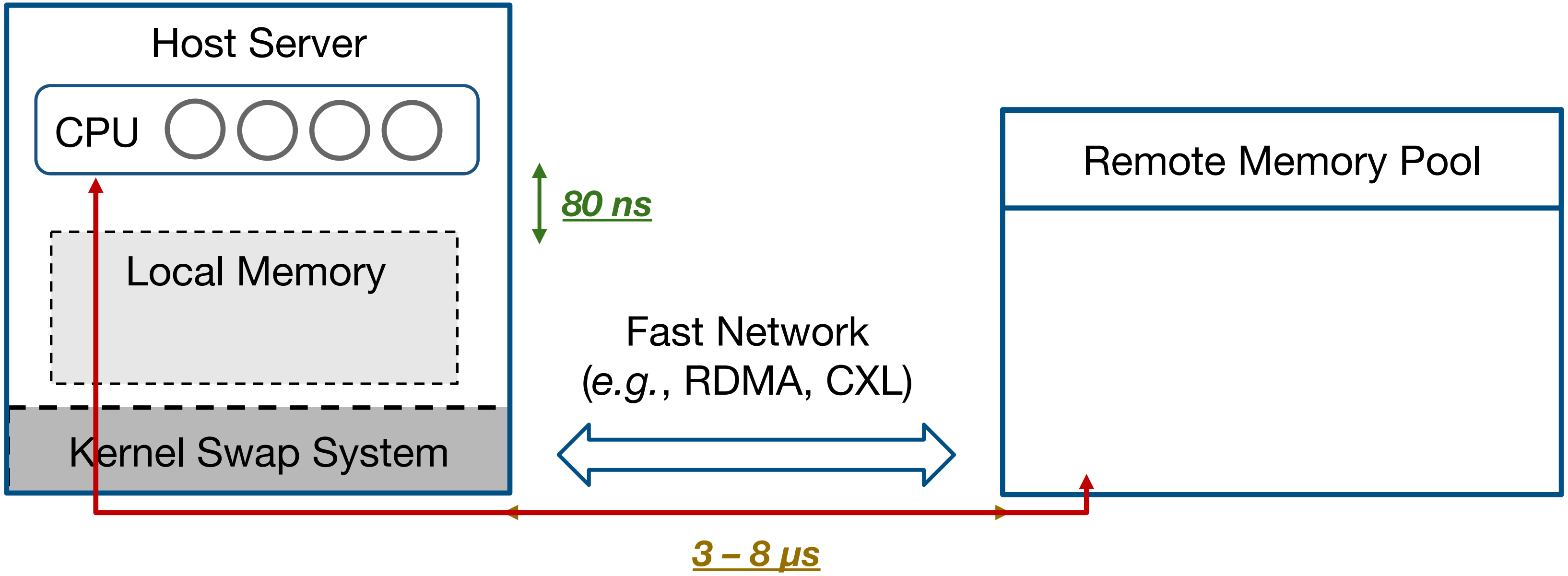
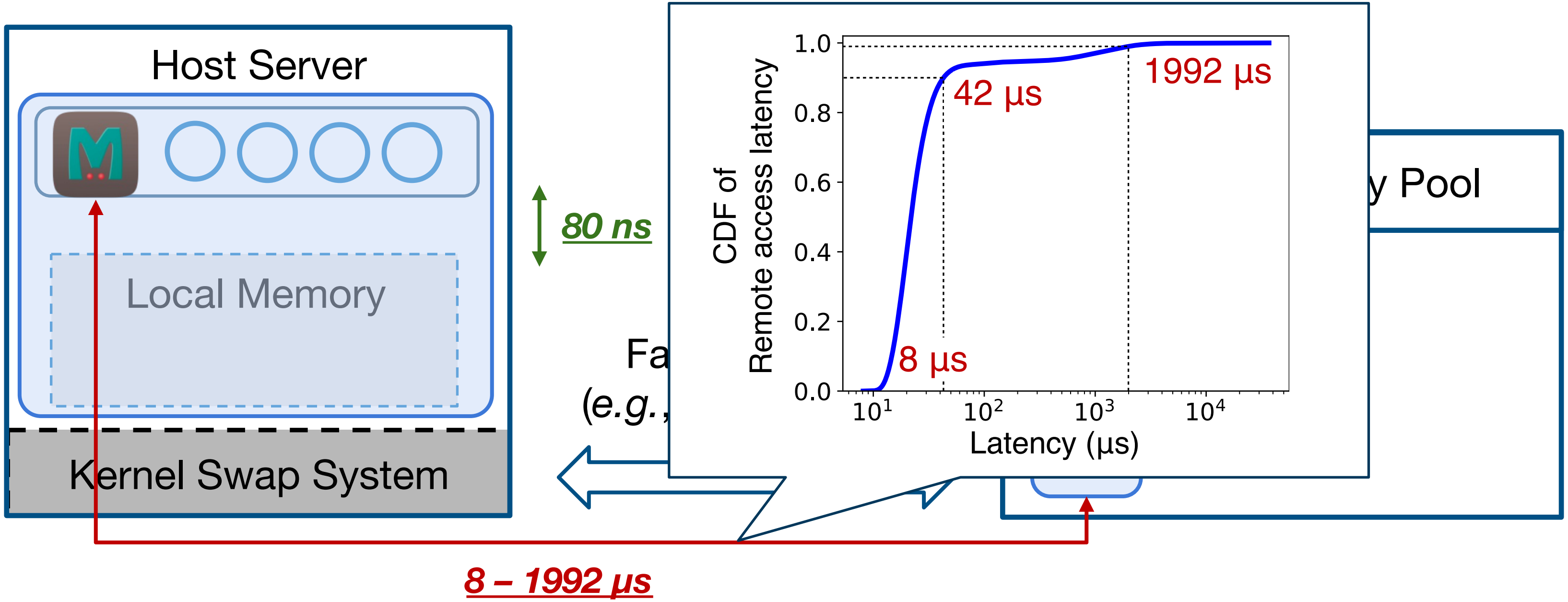


Network: Mellanox ConnectX-5 Ex (100 GbE, 7 μs for a 4 KB page)

Kernel Swap Can Incur High Tail Latency

1914x higher tail latency!



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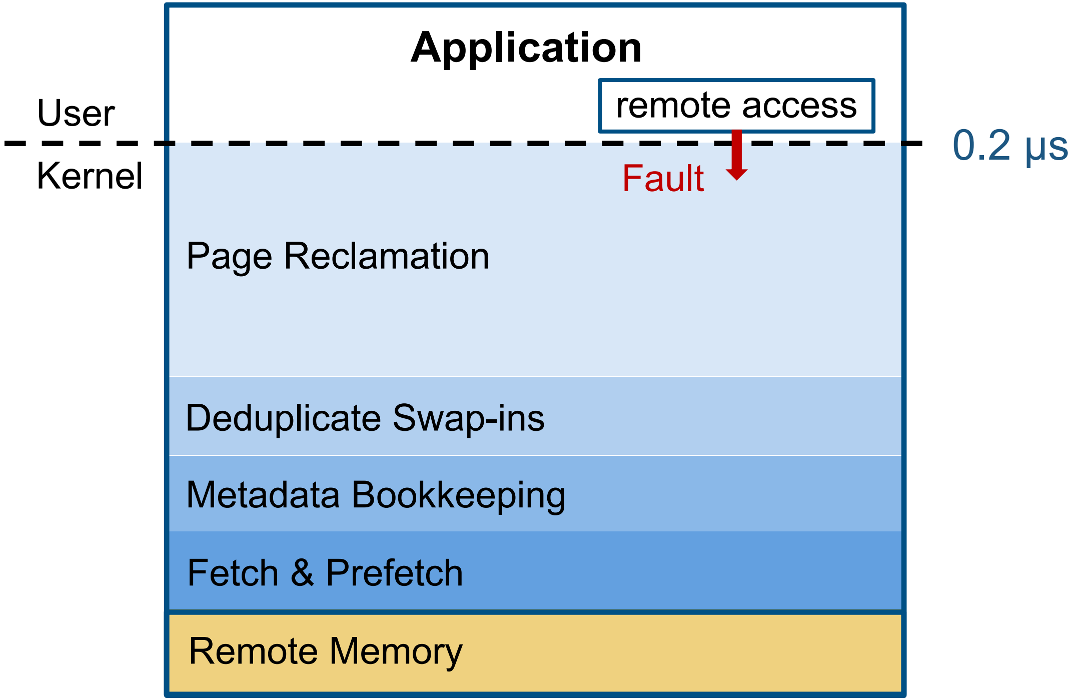
Where Does the Latency Come From?



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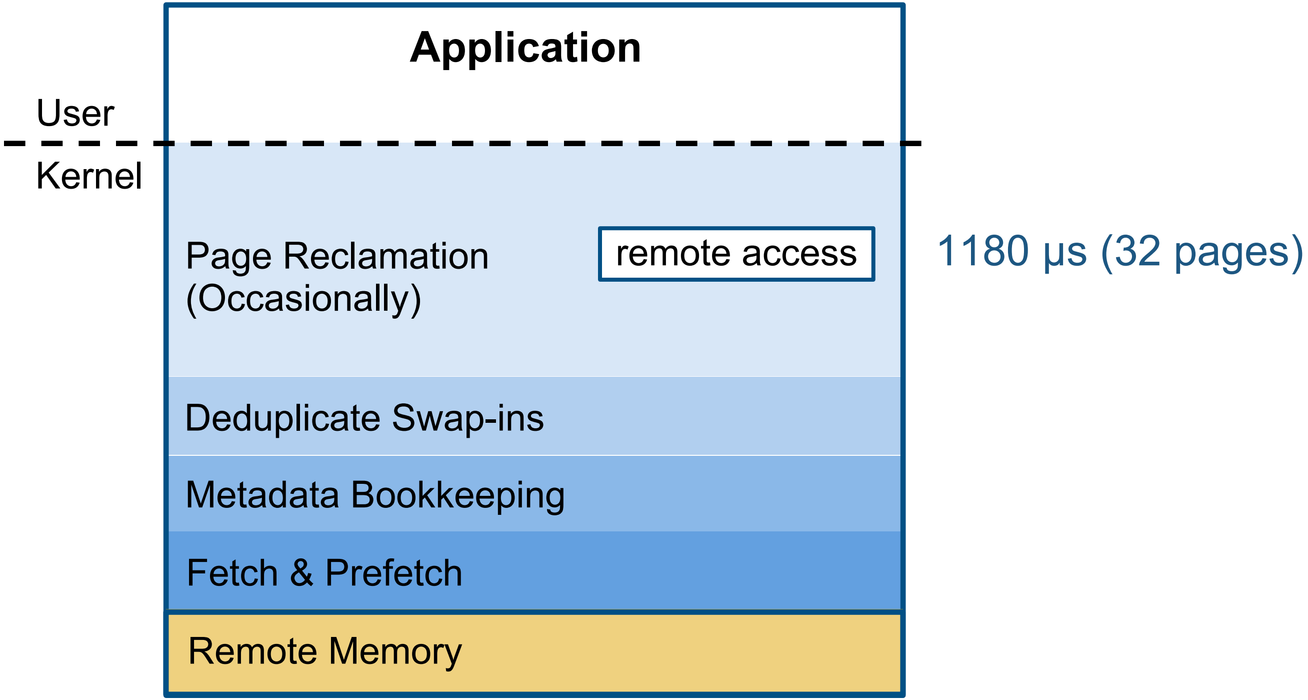

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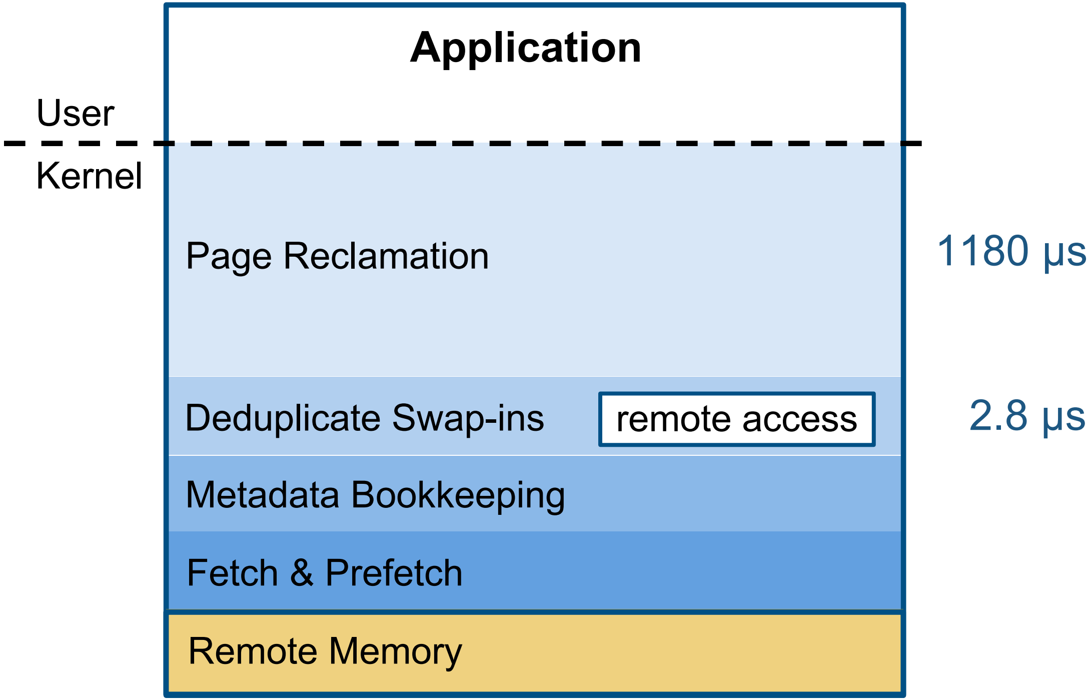

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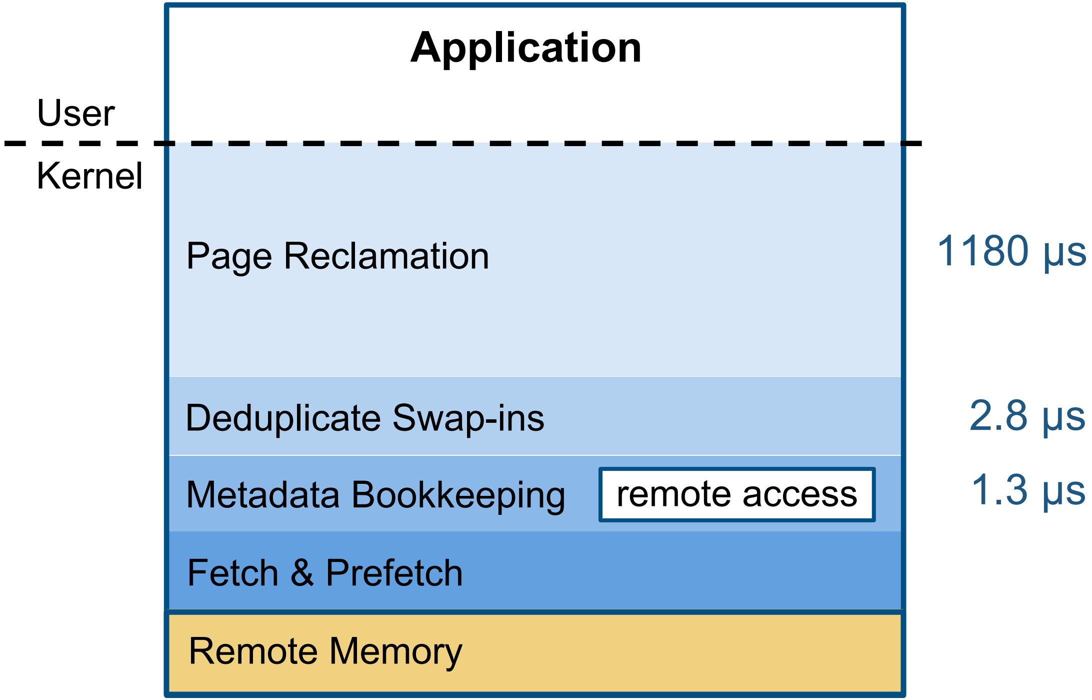

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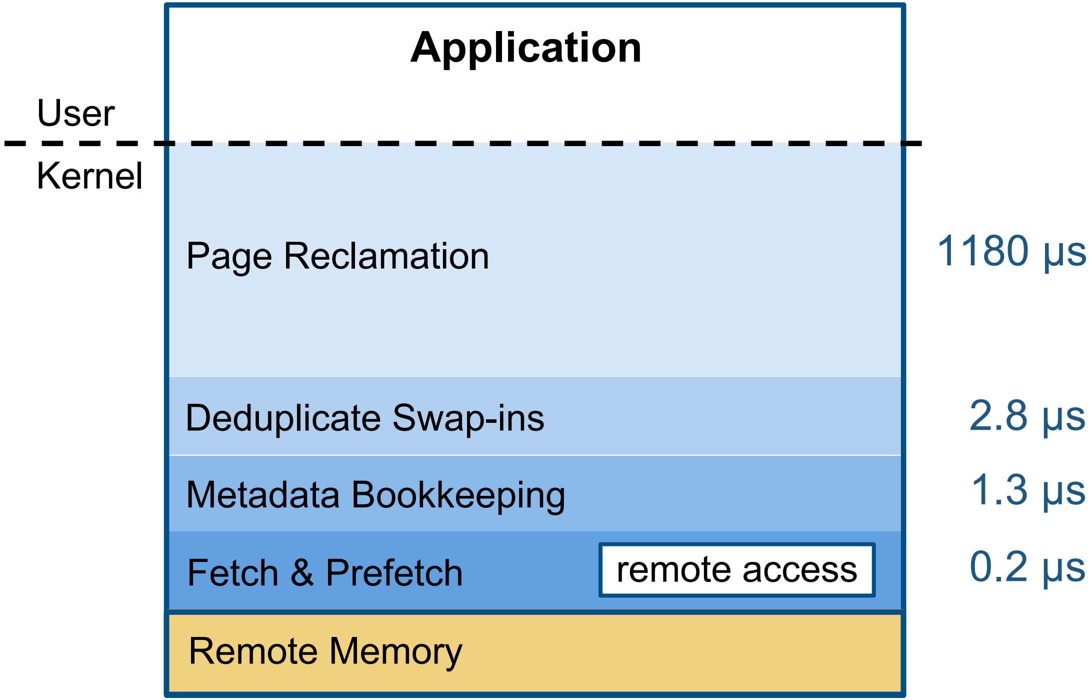

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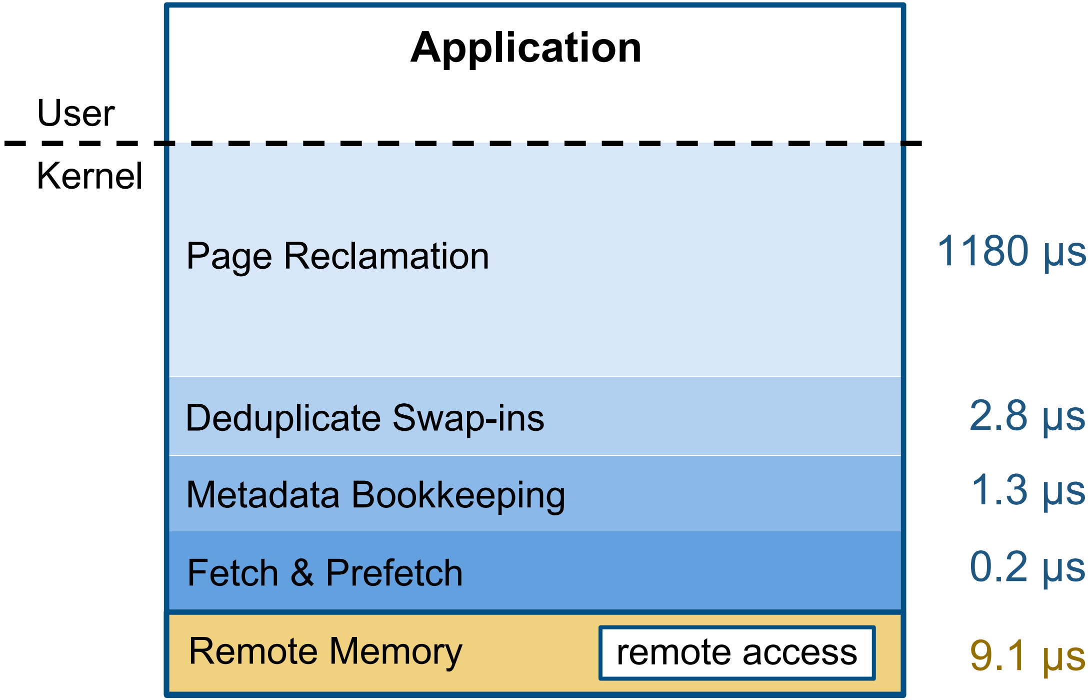

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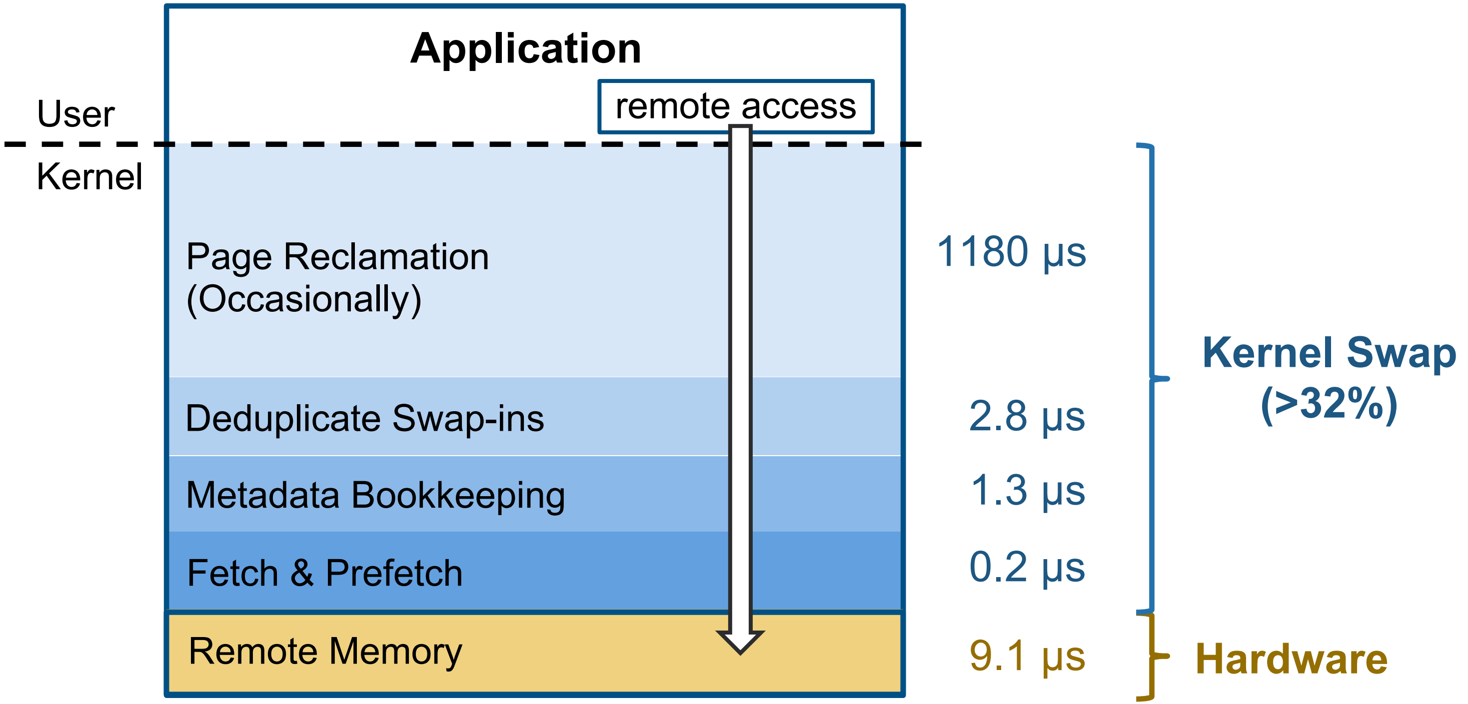
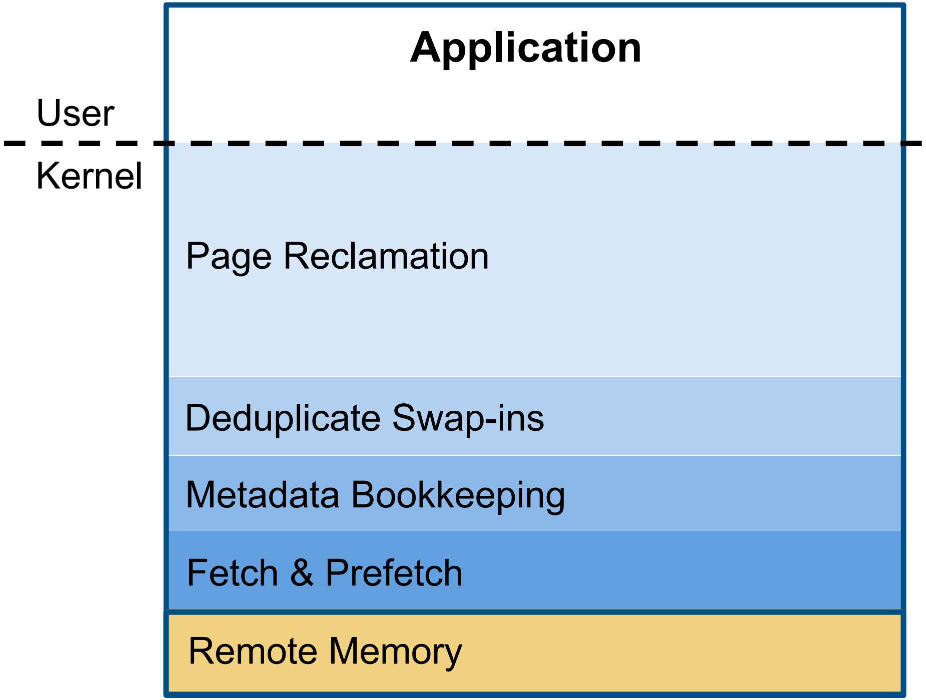
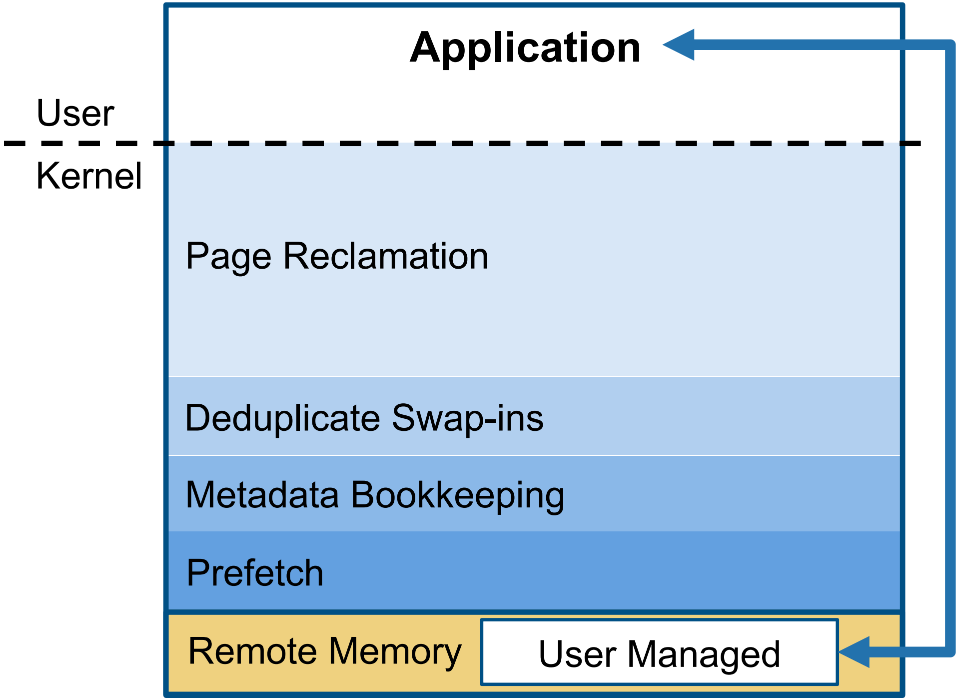


Network: Mellanox ConnectX-5 Ex (100 GbE)

How To Reduce Latency?



Kernel Bypassing Is Not a Panacea

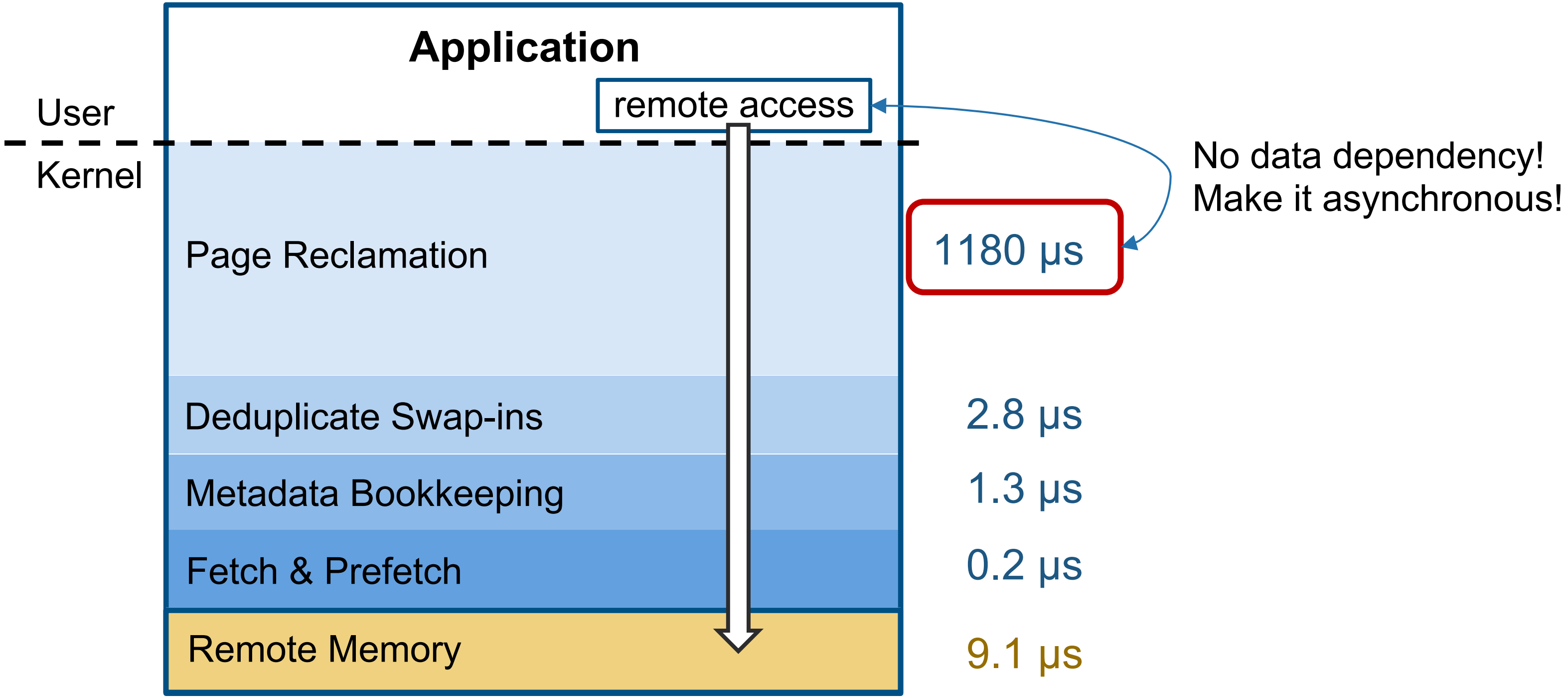


Lose Transparency

Lose kernel protection & isolation

Can we eliminate performance bottlenecks in the kernel directly?

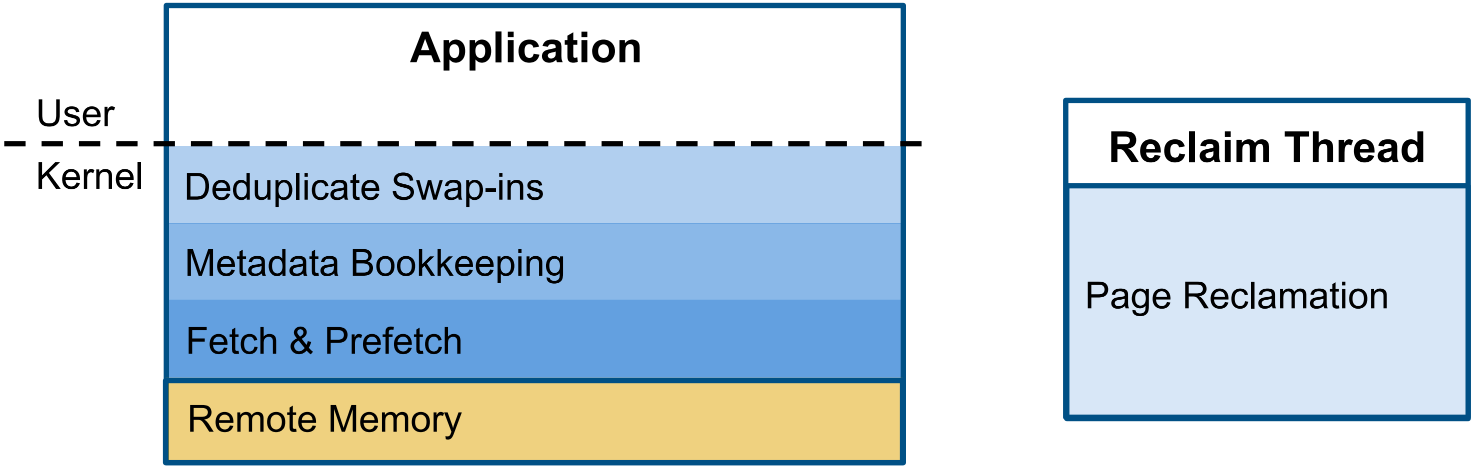
Can Asynchrony Reduce Latency?



Network: Mellanox ConnectX-5 Ex (100 GbE)

Naive Asynchrony Is Not Enough

- Linux: kswapd
- Fastswap [EuroSys'20]: dedicated core



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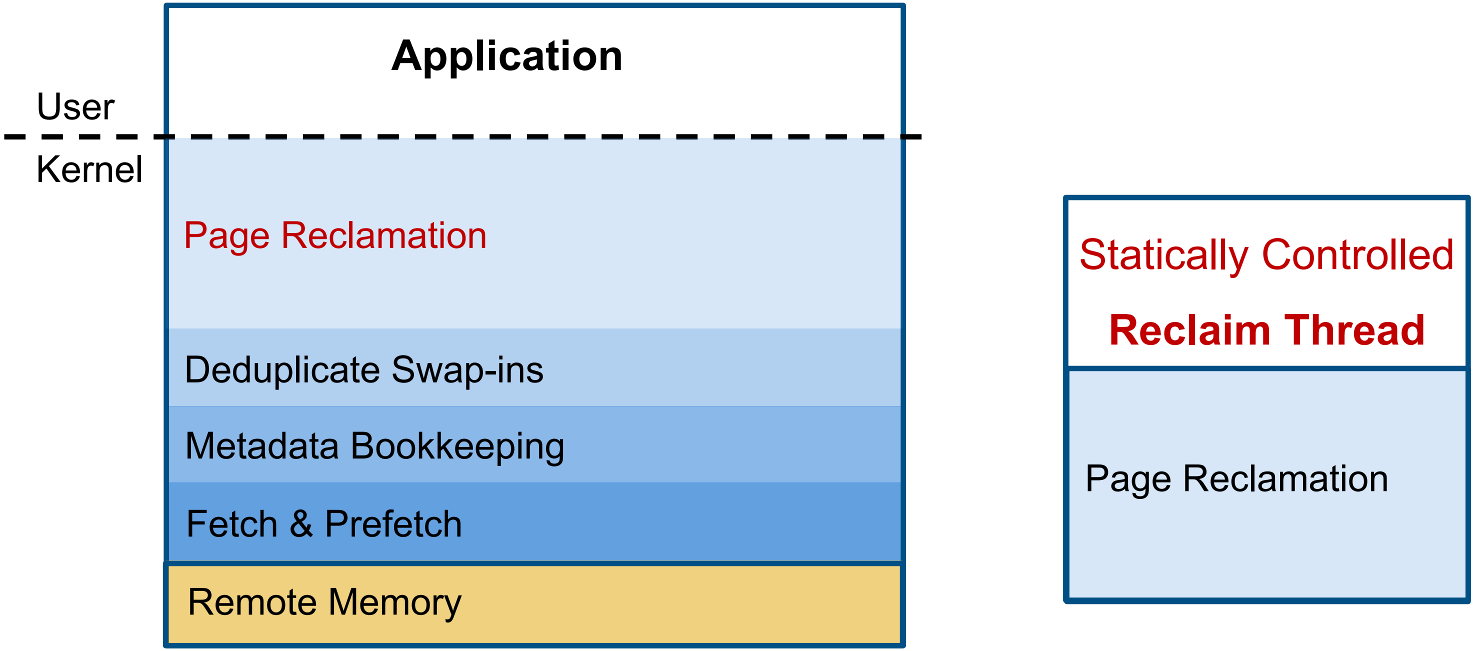
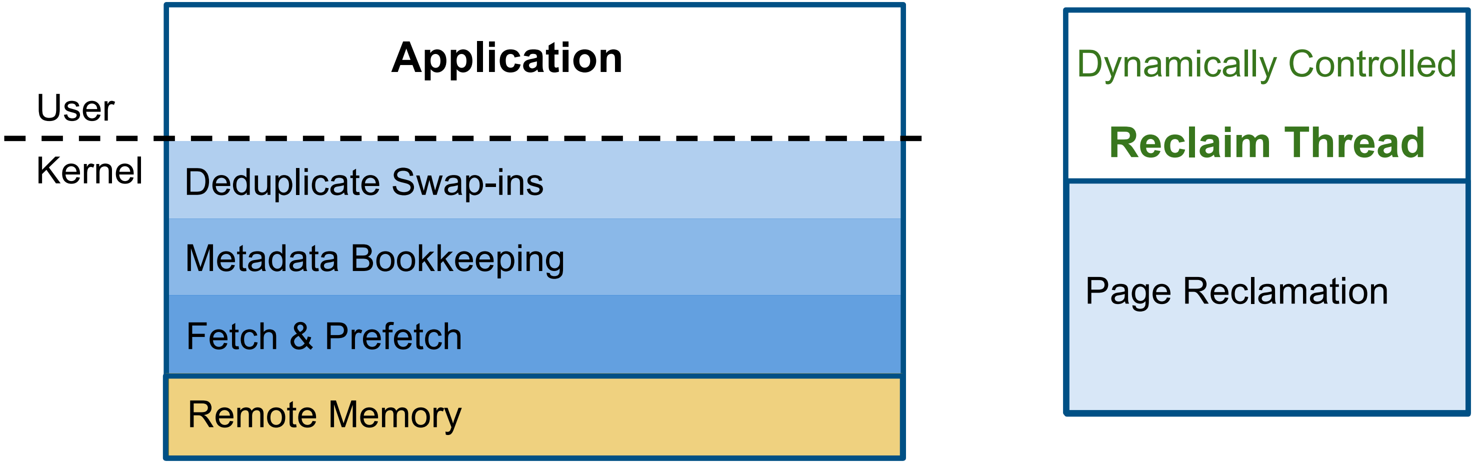


Must Have Controlled Asynchrony

- **When** to start reclamation?
- **How** many cores for reclamation?



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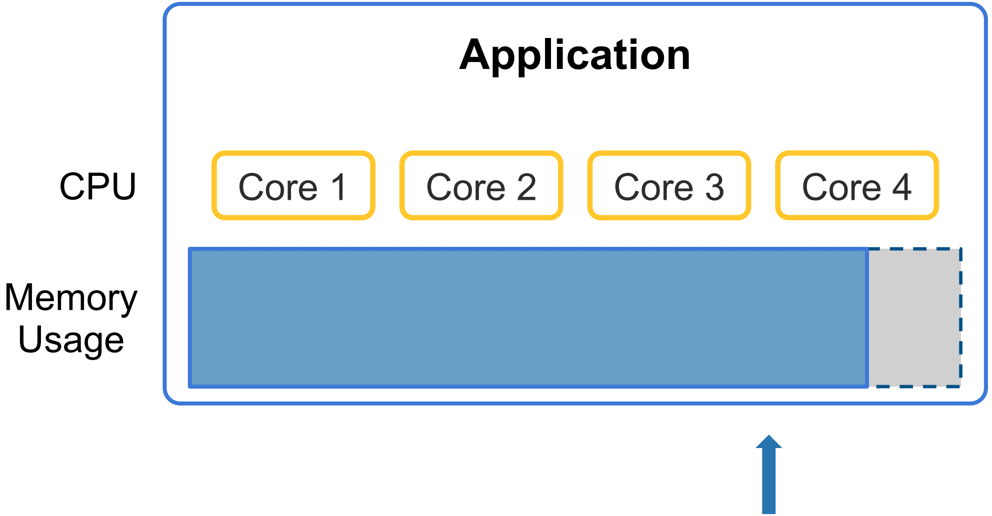
Challenge #1: When To Start Reclamation



When to start reclamation?

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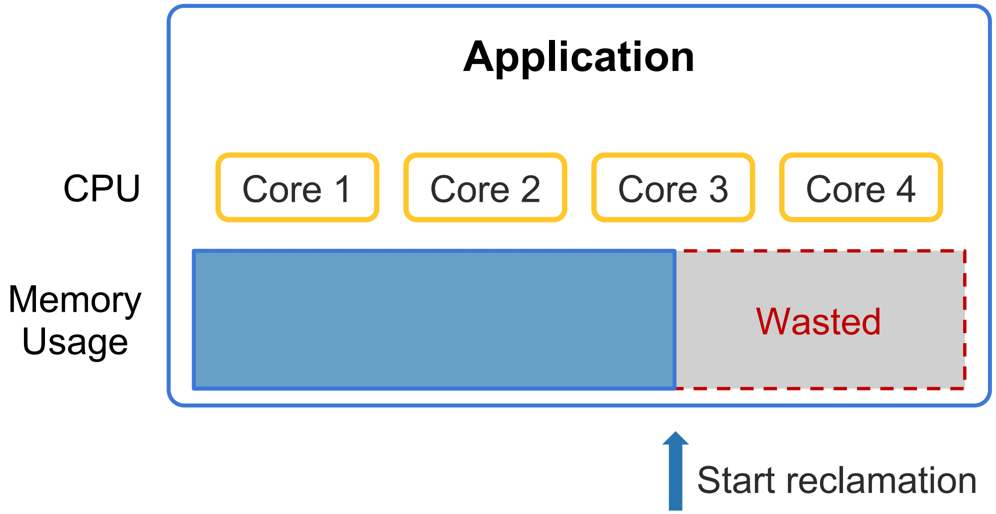
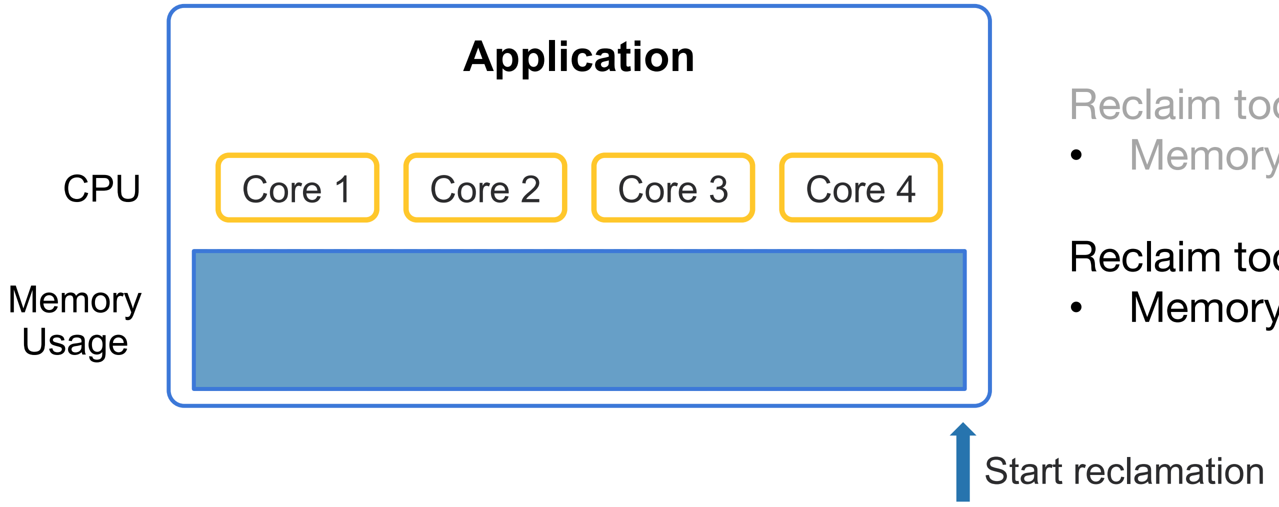


Reclaim too early:

- Memory underutilization

Challenge #1: When To Start Reclamation



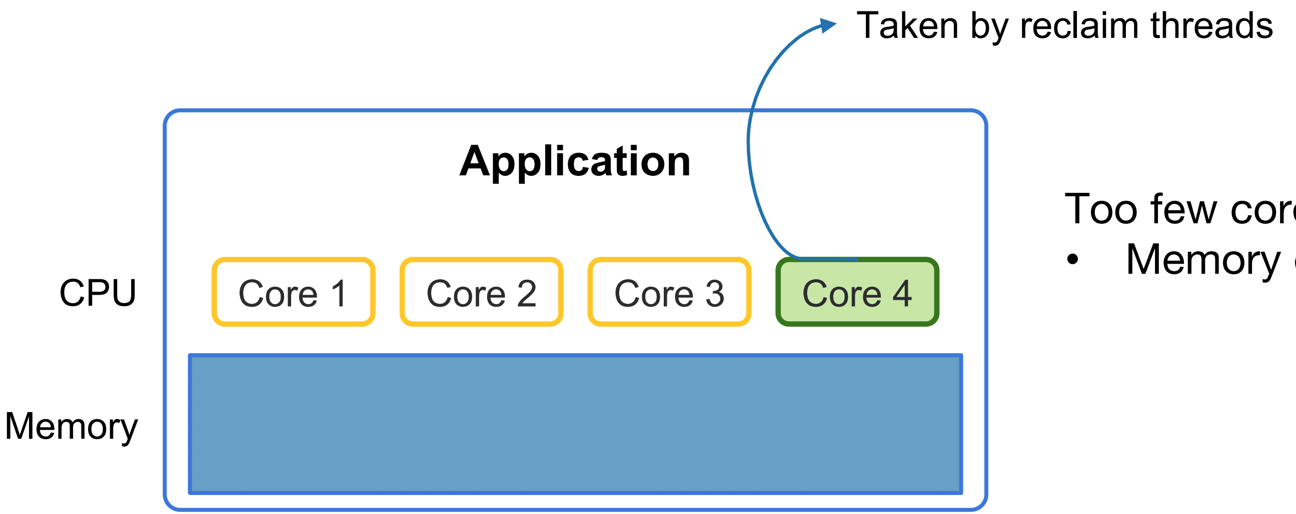
Reclaim too early:

- Memory underutilization

Reclaim too late:

- Memory exhaustion

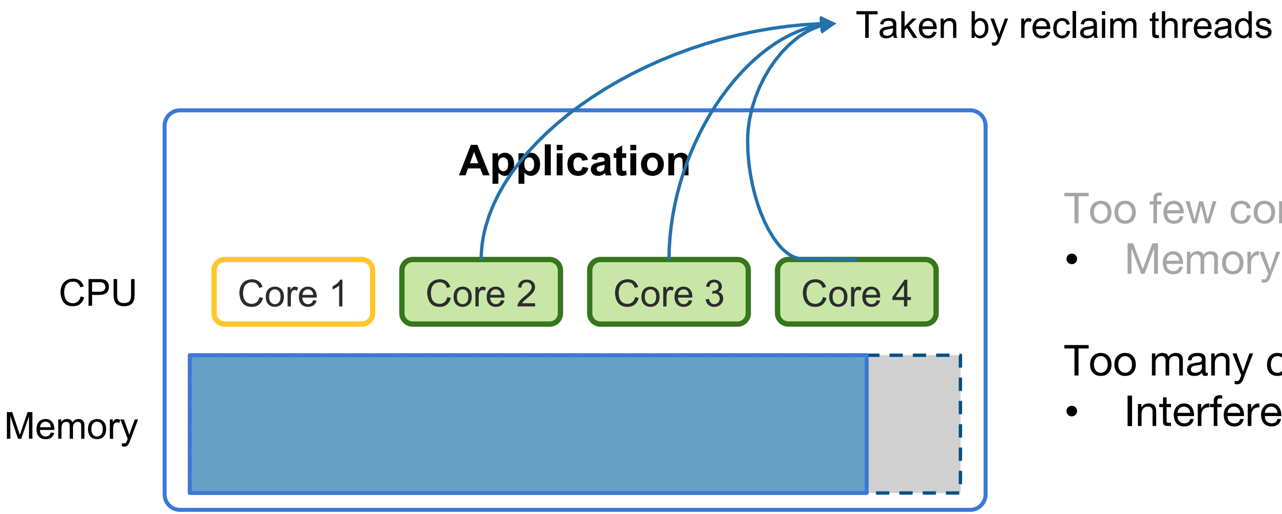
Challenge #2: How Many Cores For Reclamation



Too few cores:

- Memory exhaustion

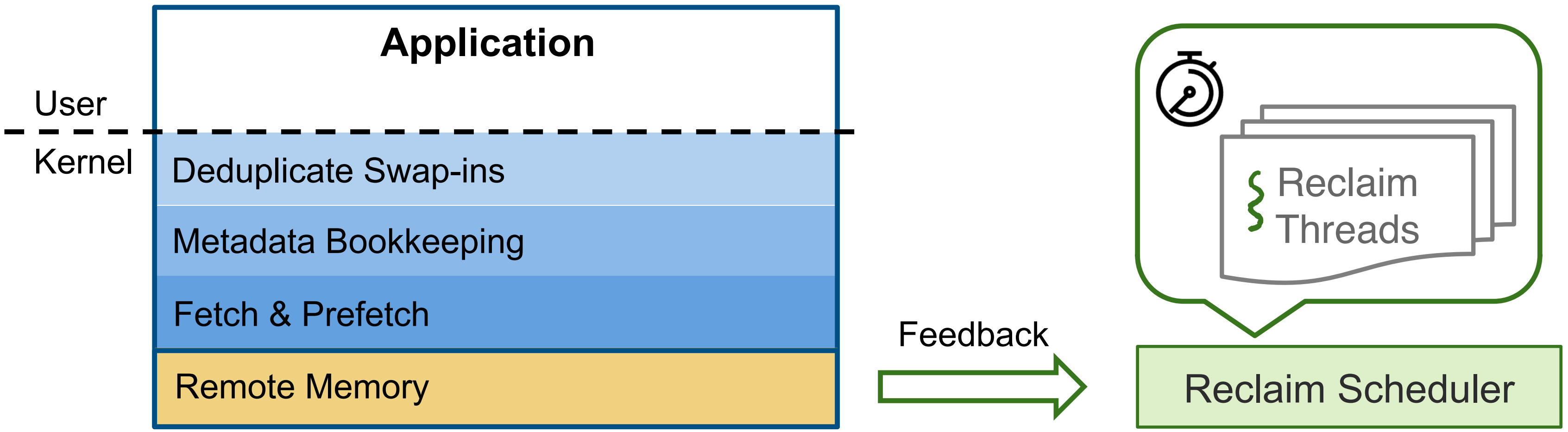
Challenge #2: How Many Cores For Reclamation



Too few cores:
- Memory exhaustion

Too many cores:
- Interfere user threads

Hermit Design: Feedback-Directed Asynchrony



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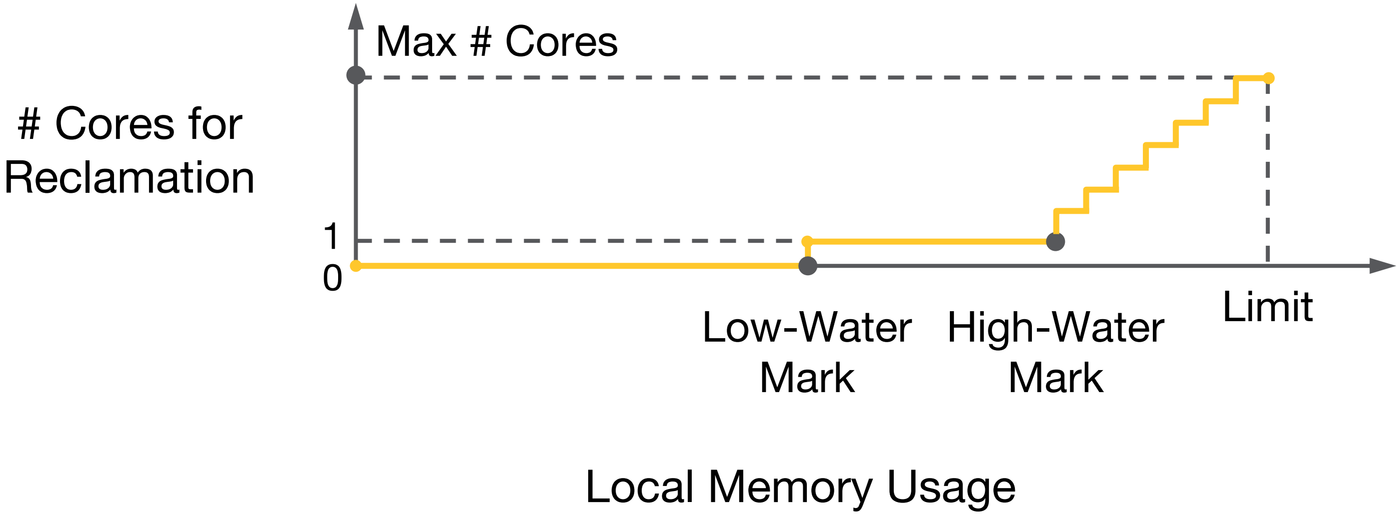
Hermit's Adaptive Reclaim Scheduling



Hermit's Adaptive Reclaim Scheduling

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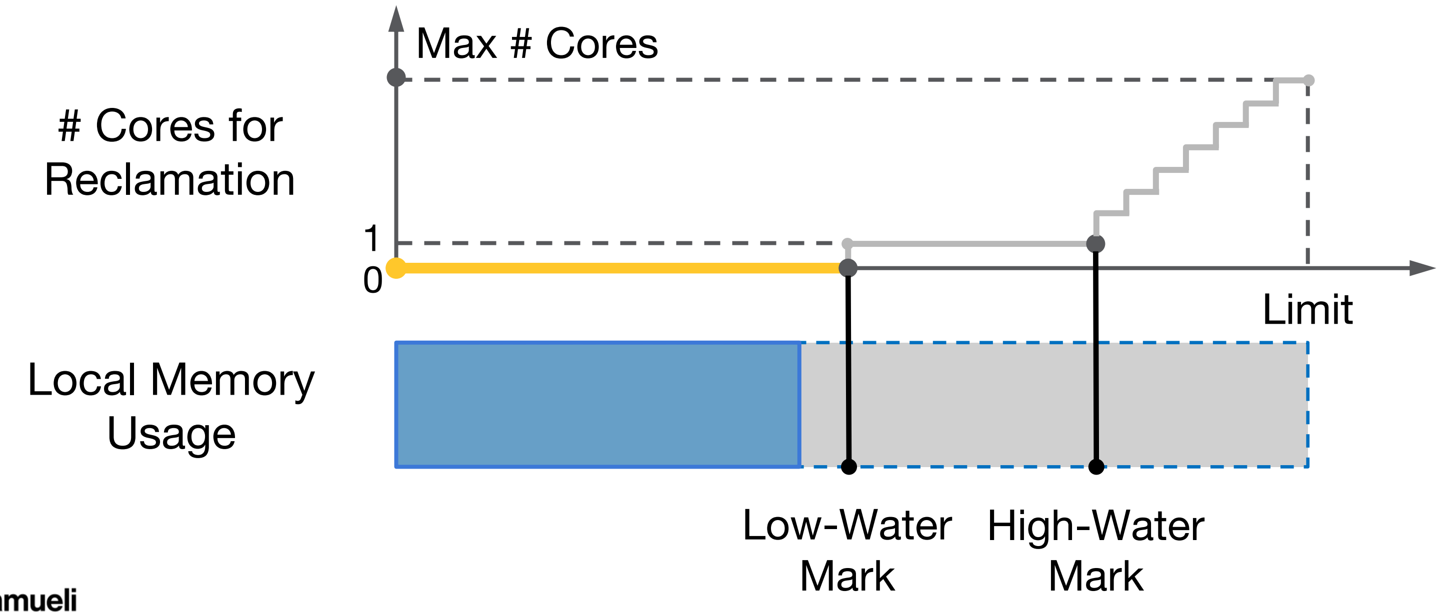

Hermit’s Adaptive Reclaim Scheduling

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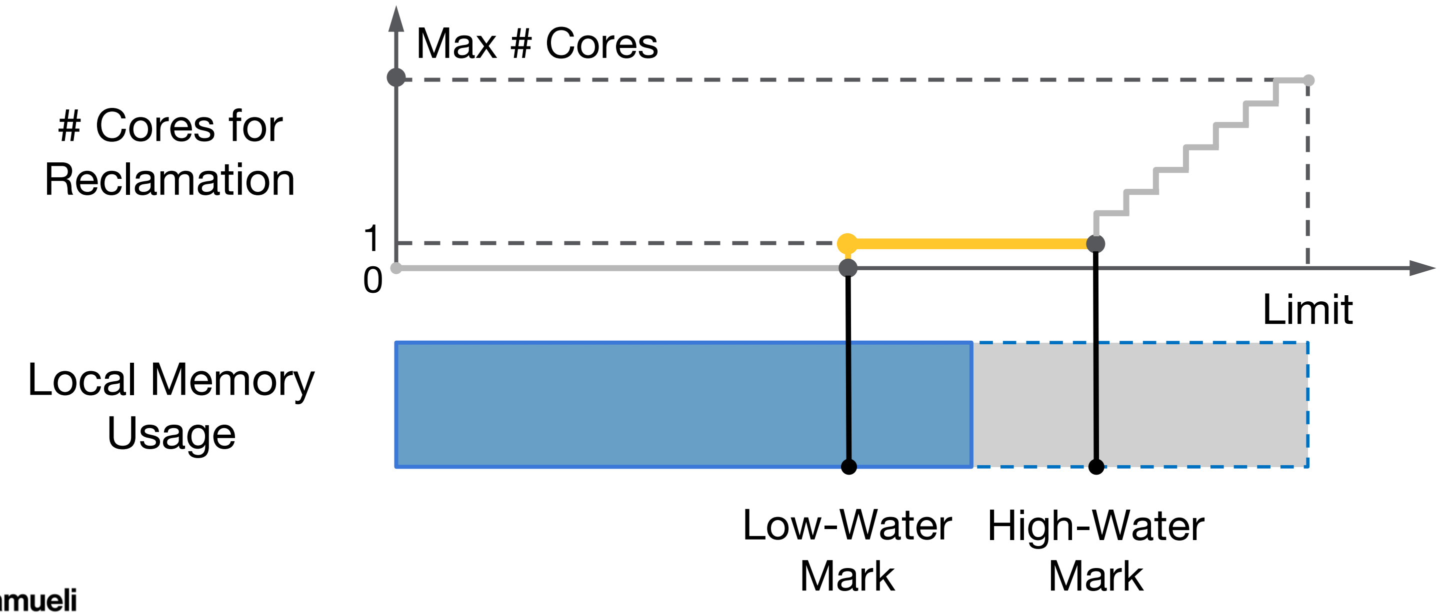

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Hermit's Adaptive Reclaim Scheduling

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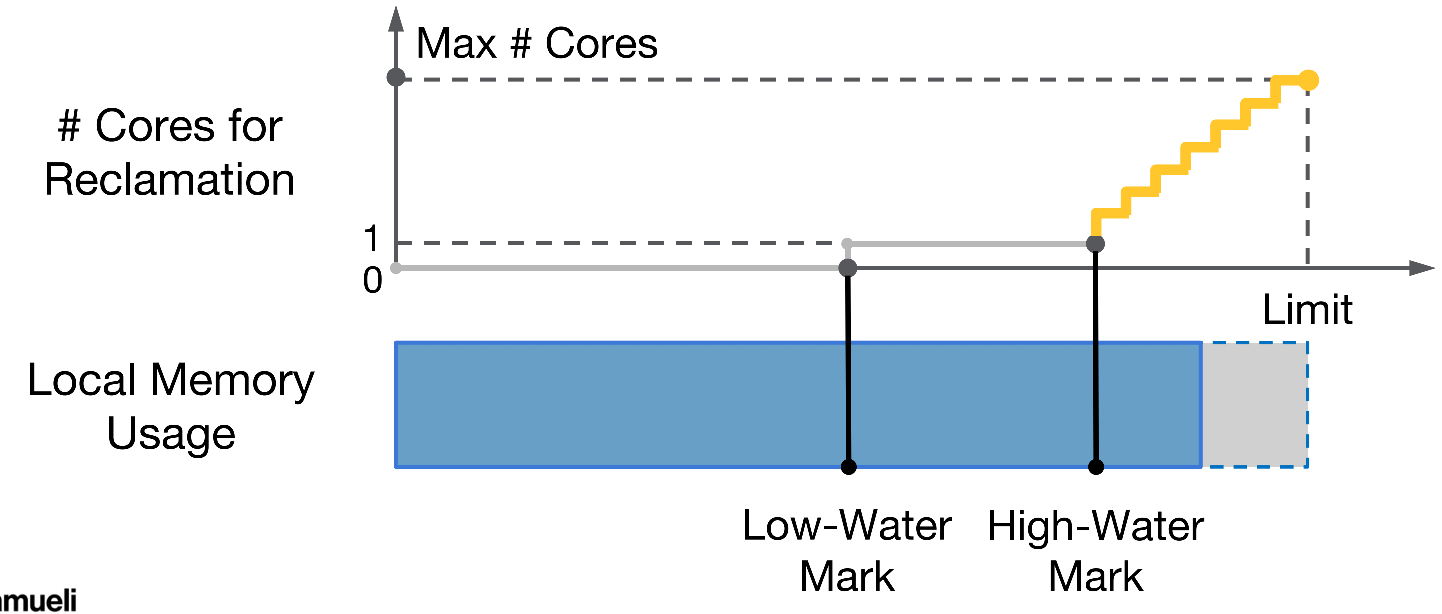

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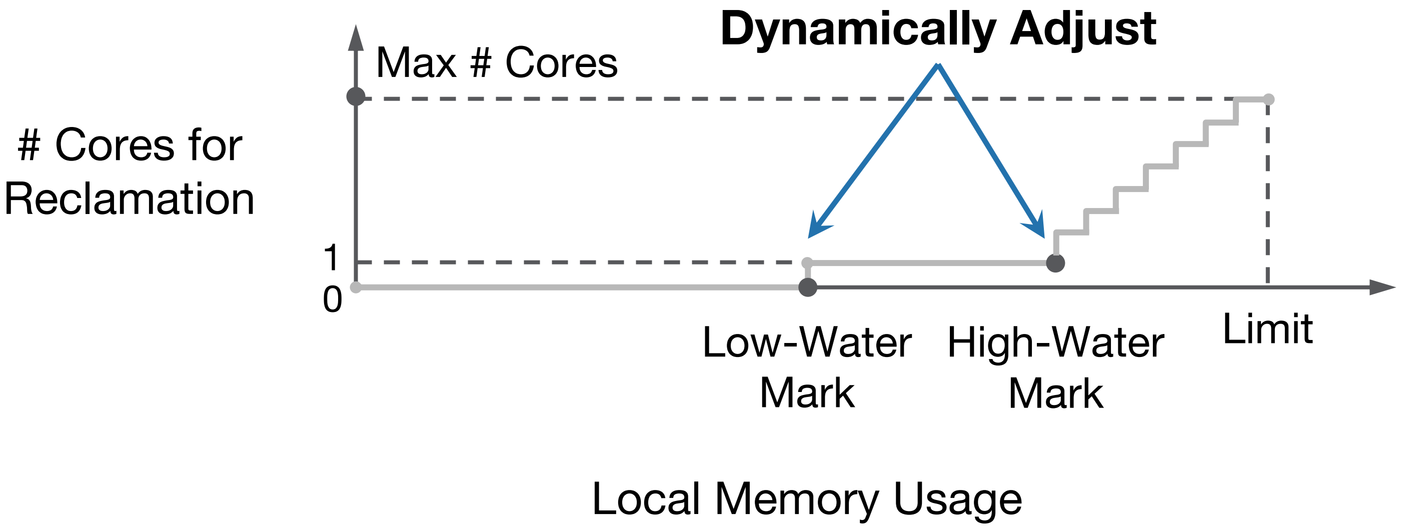

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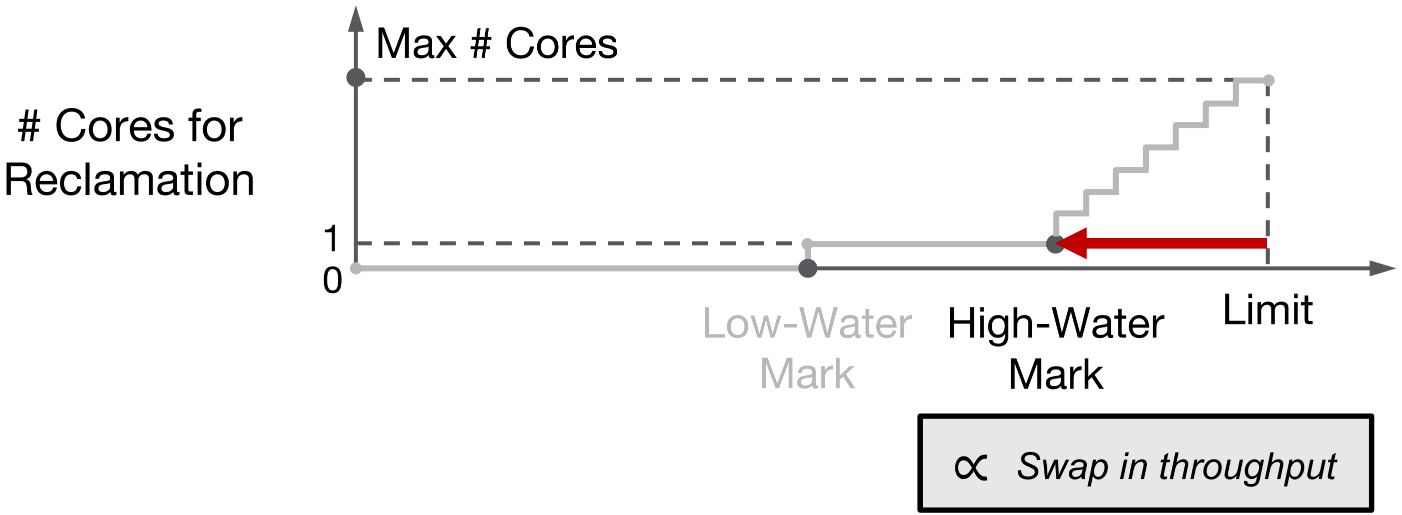
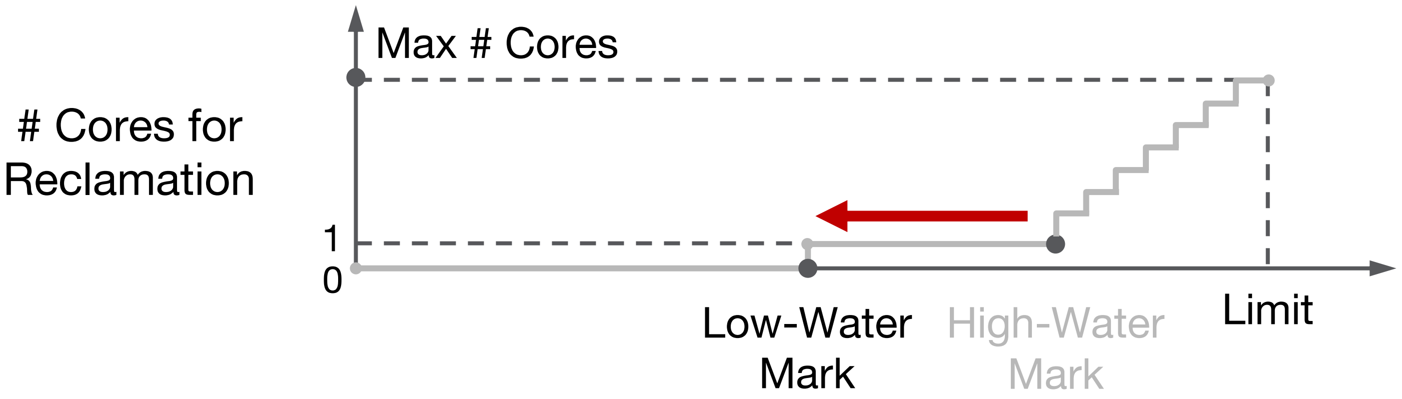


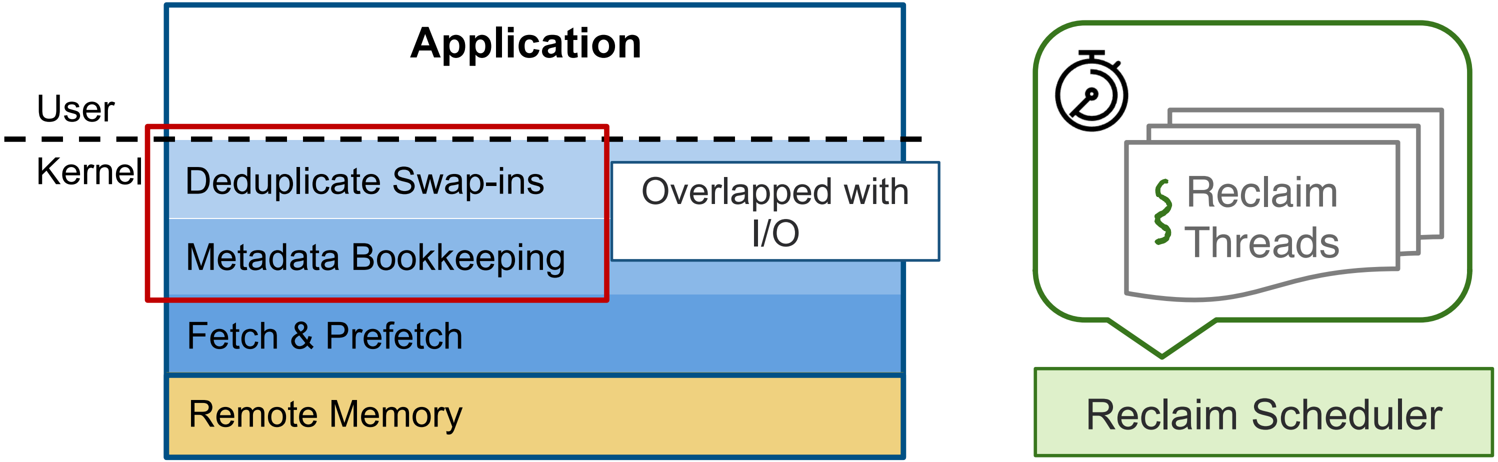
Hermit's Adaptive Reclaim Scheduling

***Page Turnaround (PT)*: how long a swapped-out page remains untouched**



When PT remains high

Hermit Achieves Low Latency



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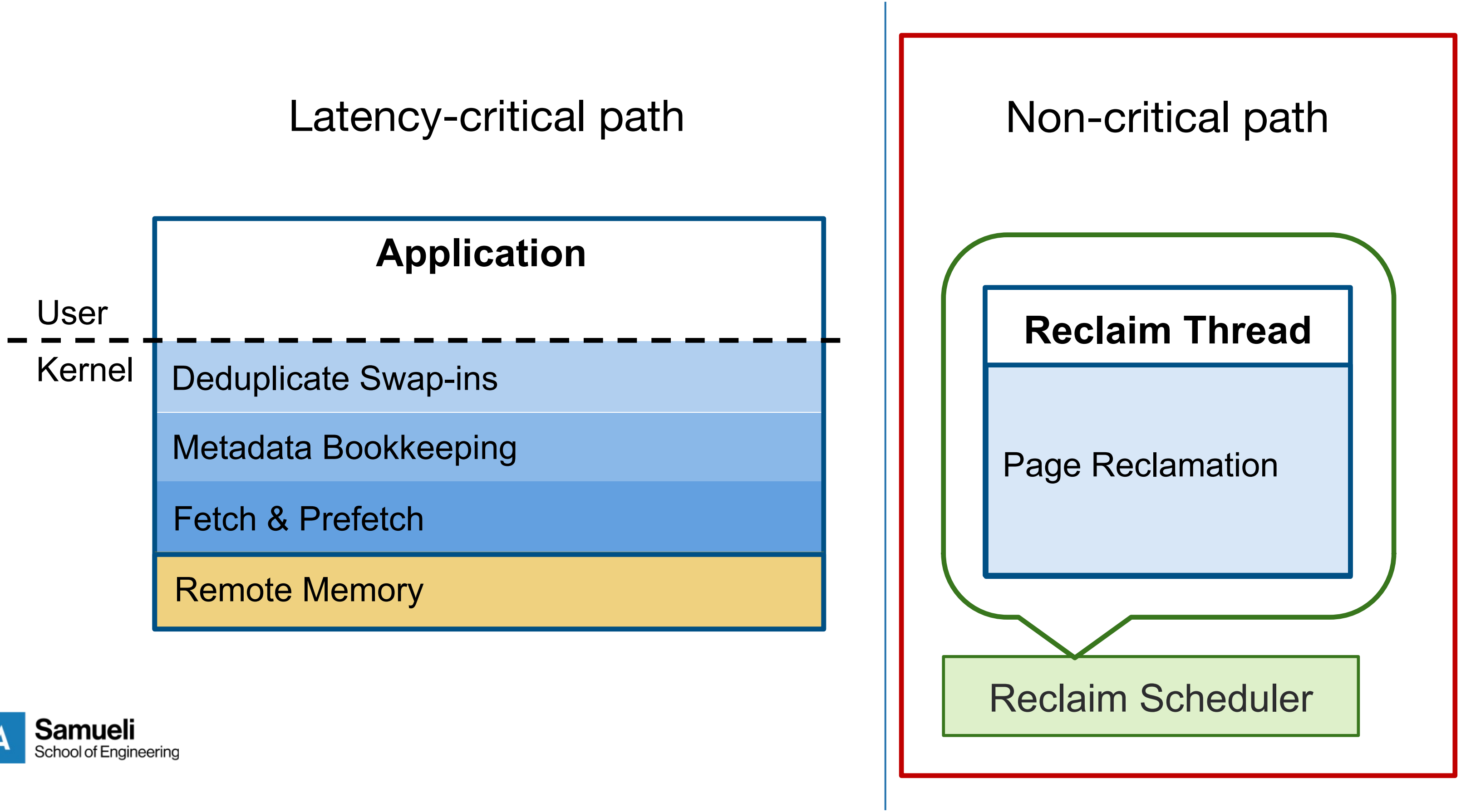
How To Improve Throughput?



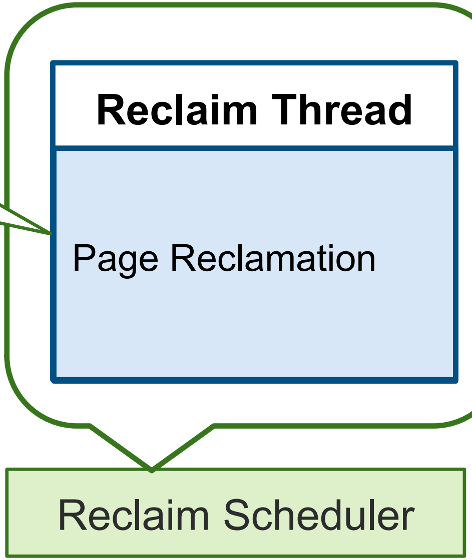
Aggressive Batching For Async. Reclamation

Batched operations for a group of pages:

- *TLB Shootdown*
- *Page I/O Write*
- *`cgroup` Accounting*
- *etc.*

2.9x more CPU efficient

Non-critical path



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Evaluation

Evaluated 6 real-world cloud applications with varying local memory ratios

- **Latency-Critical**: Memcached, SocialNet, Gdnsd
- **Batch-Processing**: Spark, XGBoost, Cassandra

State of the art: Fastswap [EuroSys'20]

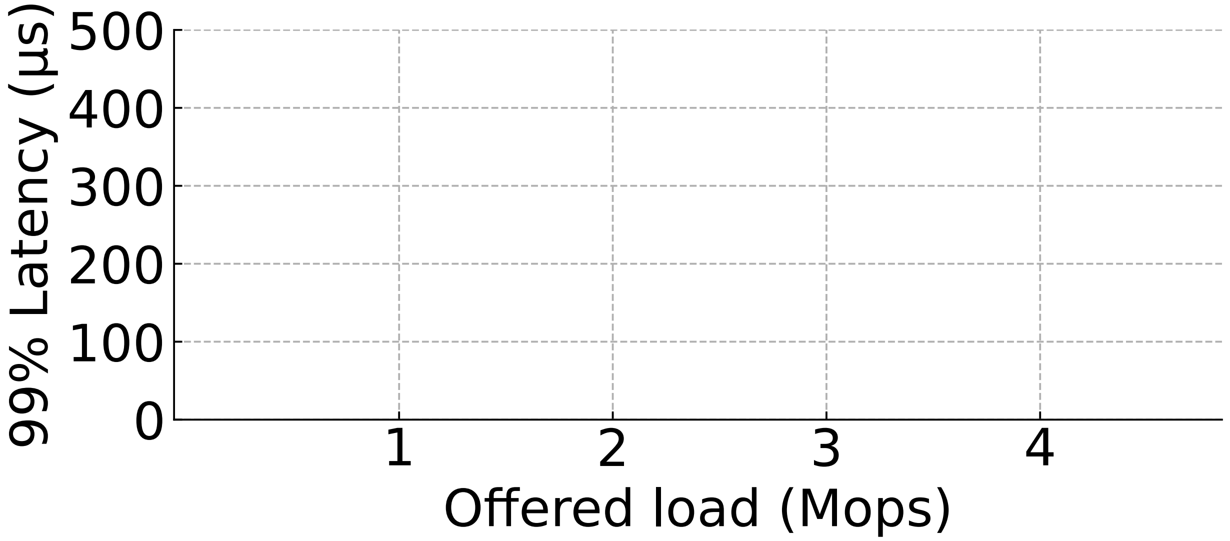
- Offload page reclamation to a single dedicated core

➢ How does Hermit maintain low end-to-end tail latency?

➢ How does Hermit improve application throughput?

Low Tail Latency

Memcached with Facebook USR workload.



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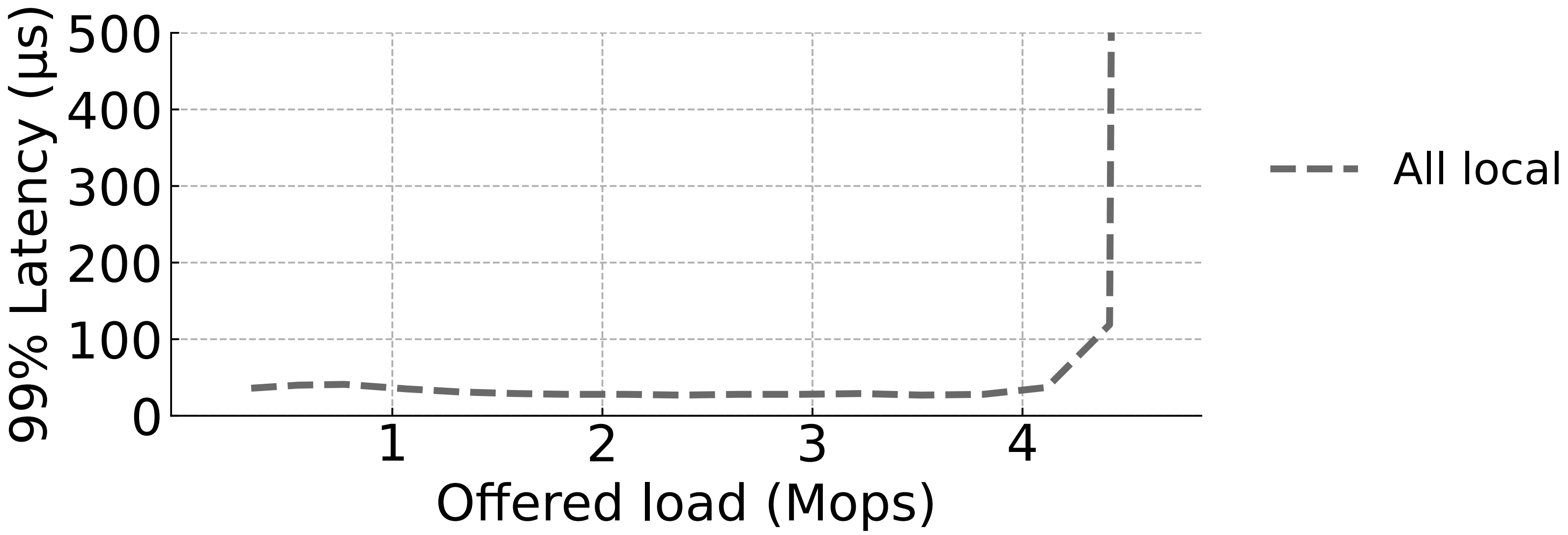
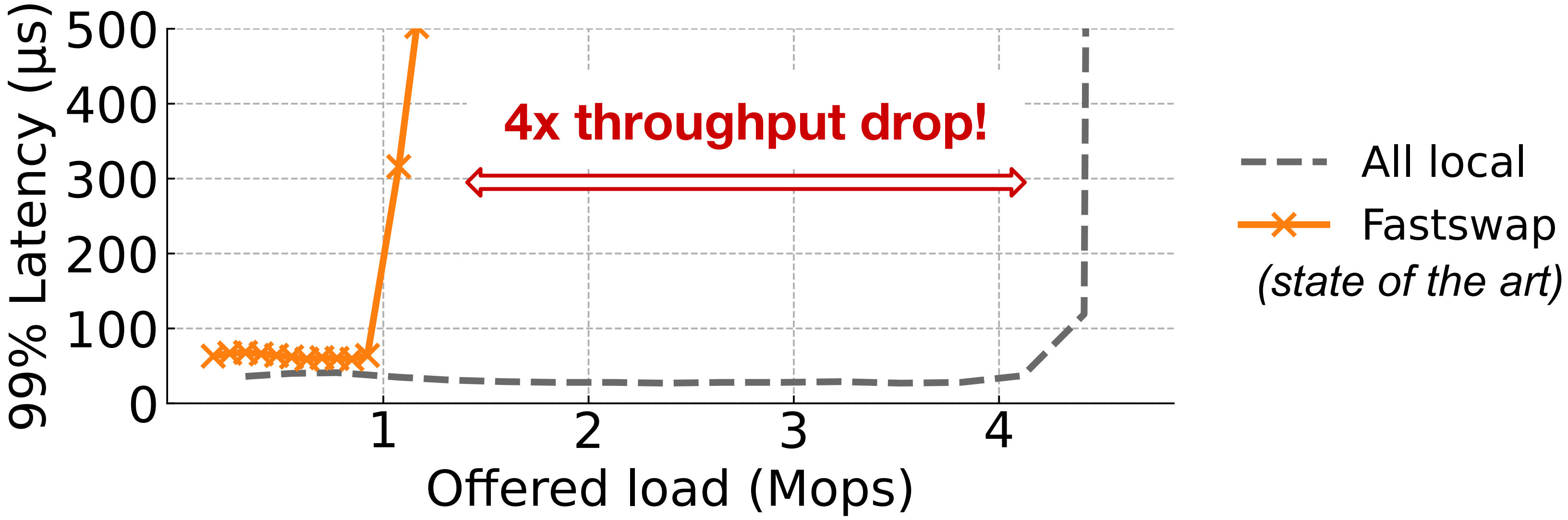


Low Tail Latency

Memcached with Facebook USR workload.

❖ Cache 70% of working set in local memory (i.e., 30% in remote memory).



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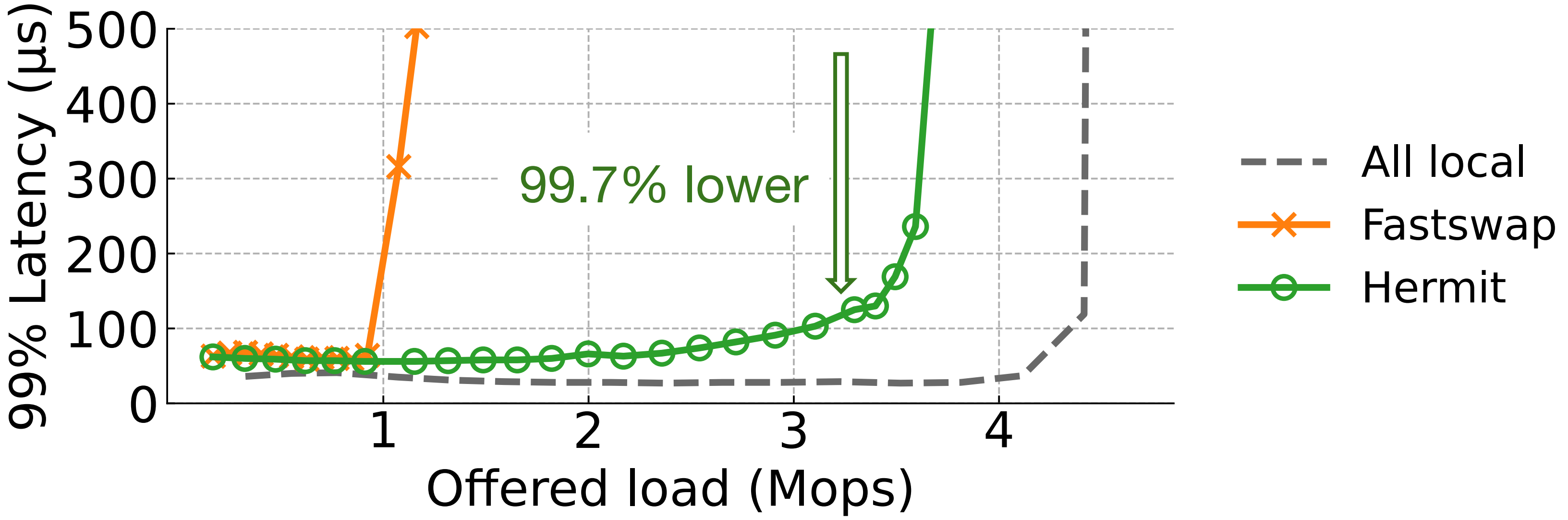

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High Throughput

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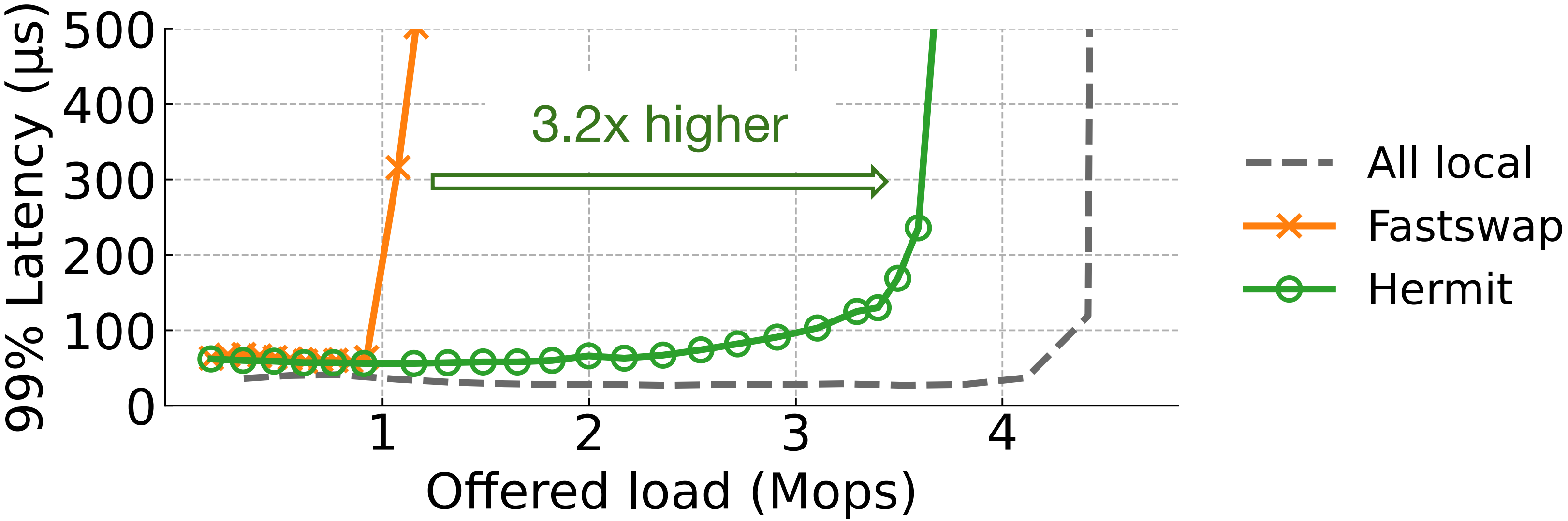

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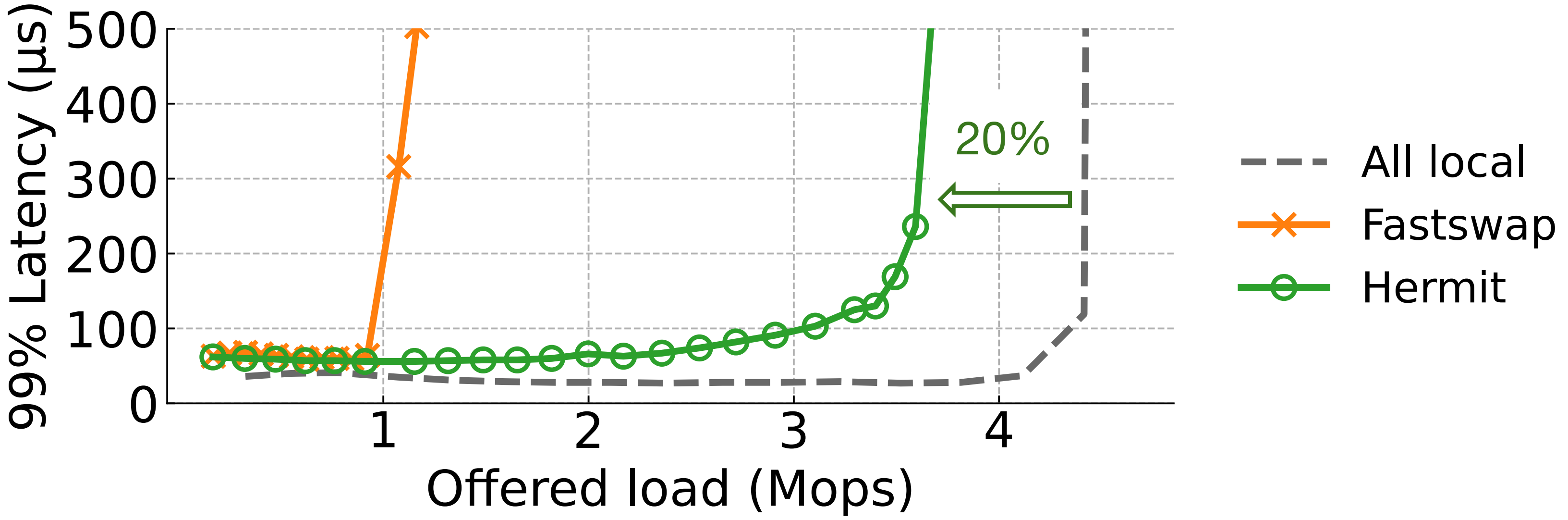

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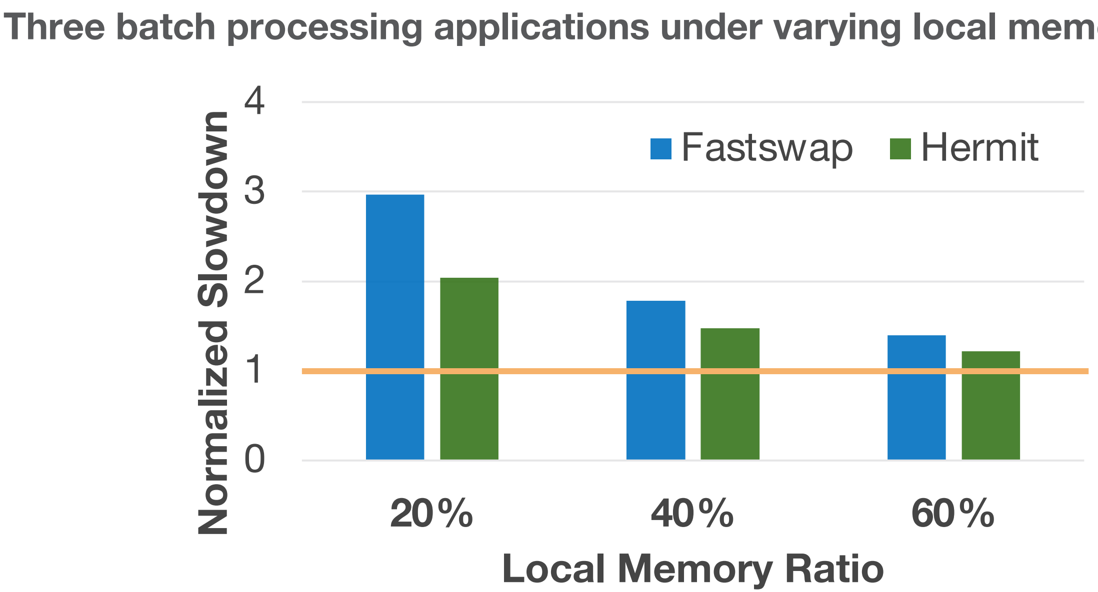
High Throughput For Batch Applications



Hermit offers 1.24x higher throughput (up to 1.87x)

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Conclusion

Low latency, high throughput, and transparency can be achieved simultaneously!

- ❖ Asynchrony reduces latency and improves throughput
- ❖ Feedback loop is critical to the effect of asynchrony
- ❖ Design can be generalized to other kernel components such as page migration for CXL-attached memory

- ❖ Hermit offers up to 99.7% lower latency and 1.24x higher throughput without changing a single line of user code

https://github.com/uclasystem/hermit

Thank You!

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