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Rearchitecting Linux Storage Stack for μs Latency and High Throughput




Jaehyun Hwang *Cornell University*

Midhul Vuppalapati *Cornell University*

Simon Peter *UT Austin*

Rachit Agarwal *Cornell University*

Widespread belief: Linux can't achieve *μs*-scale latency & high throughput

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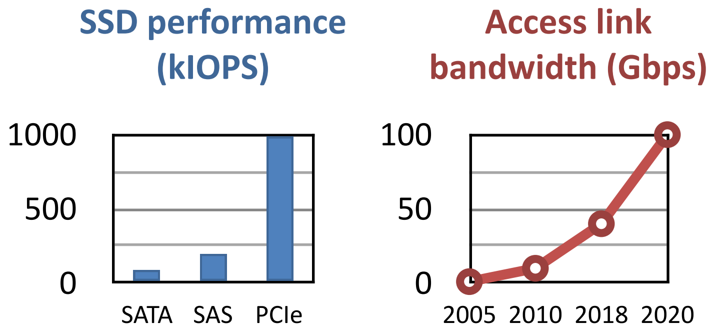
1. Adoption of high performance H/W, but stagnant single-core capacity



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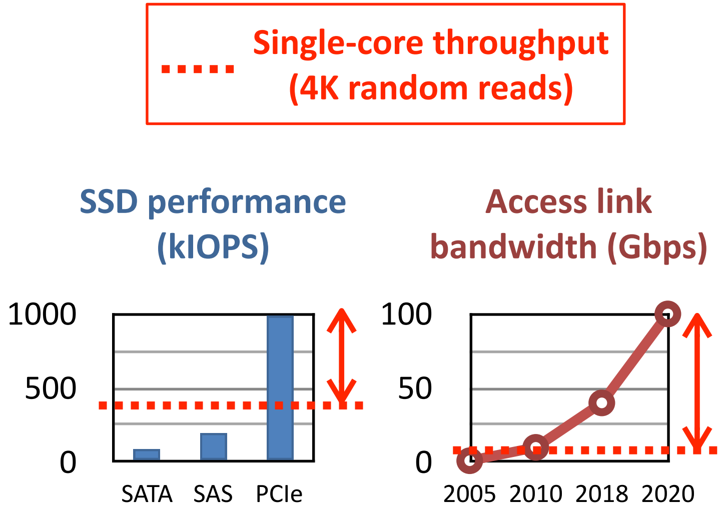

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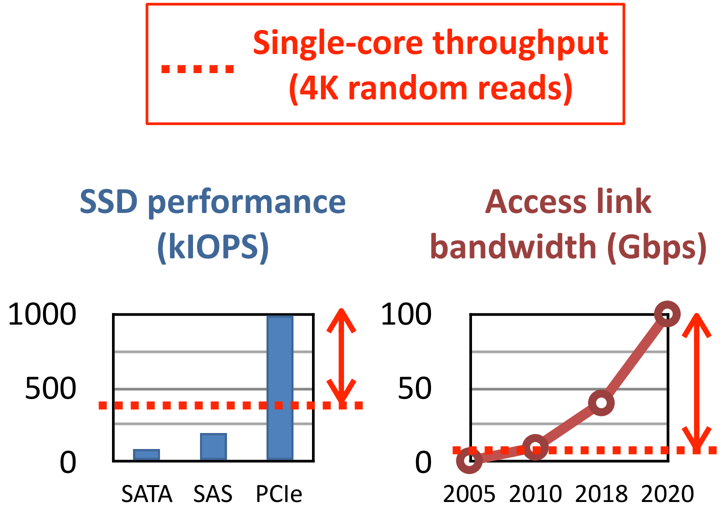

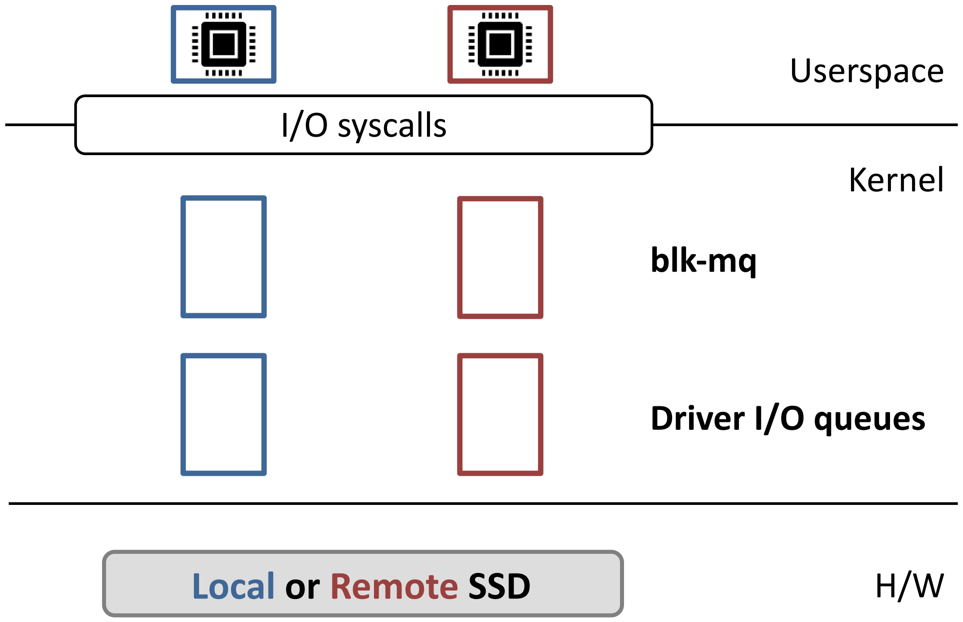

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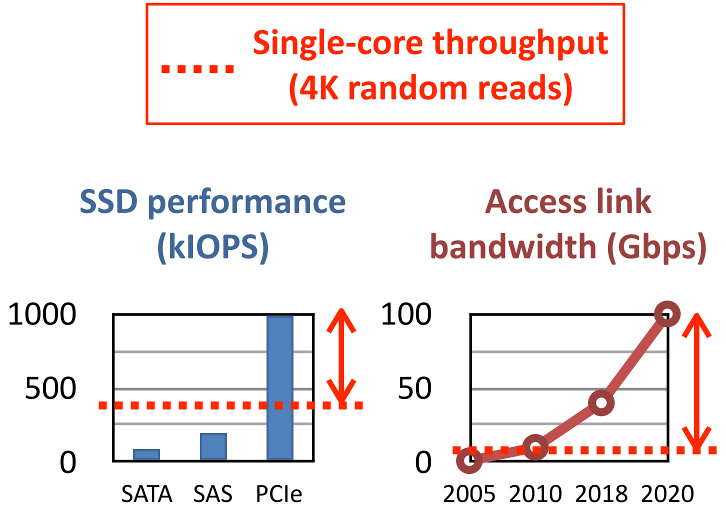

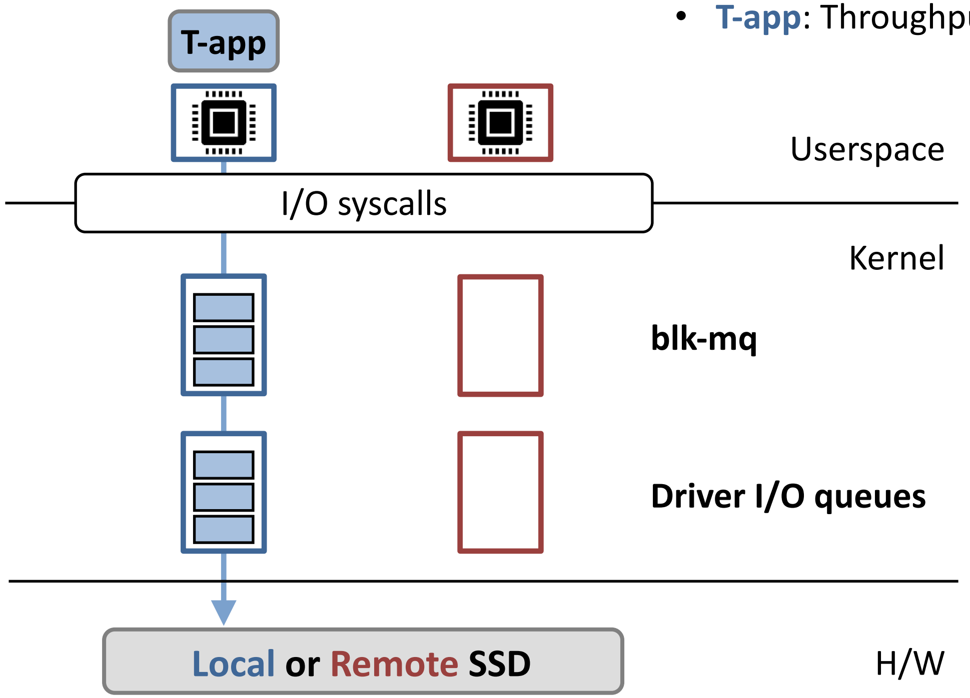

- **T-app**: Throughput-bound app

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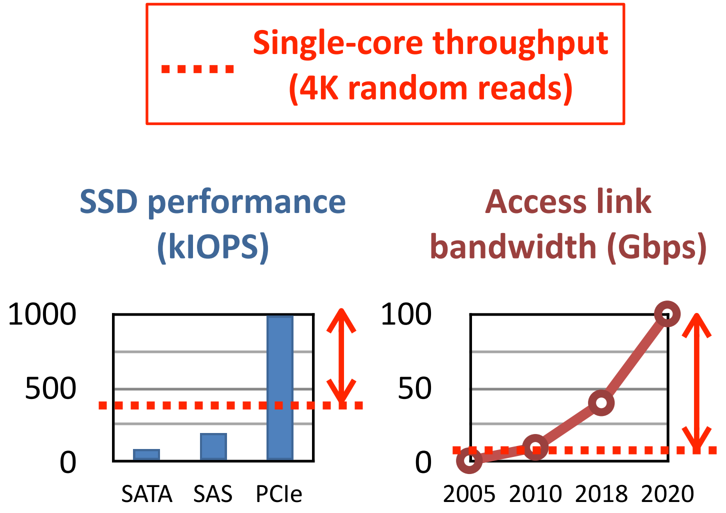

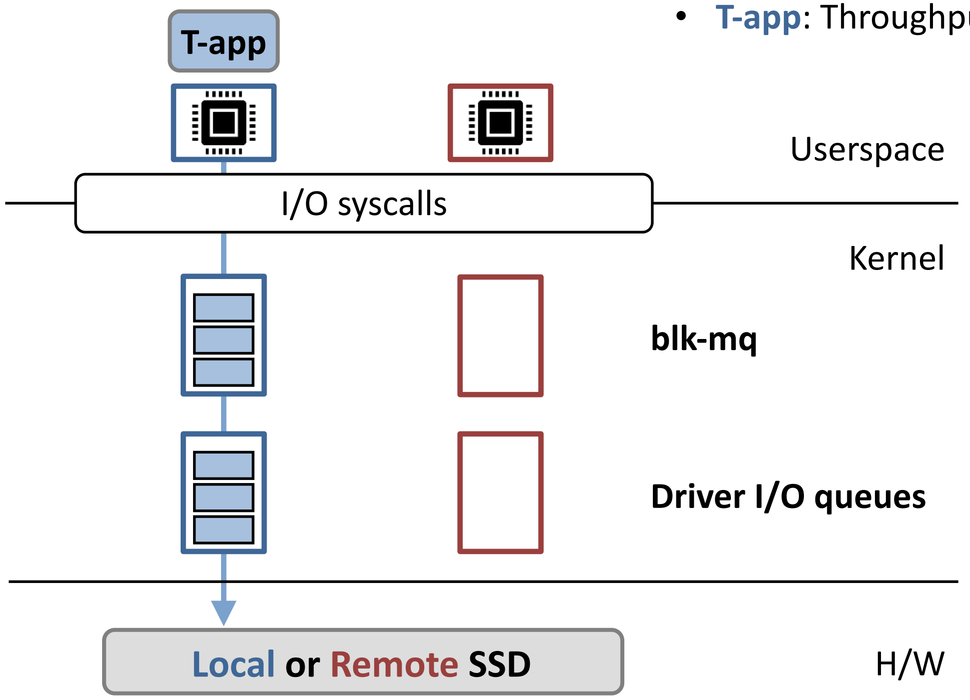

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Static data path ⇢ hard to utilize all cores

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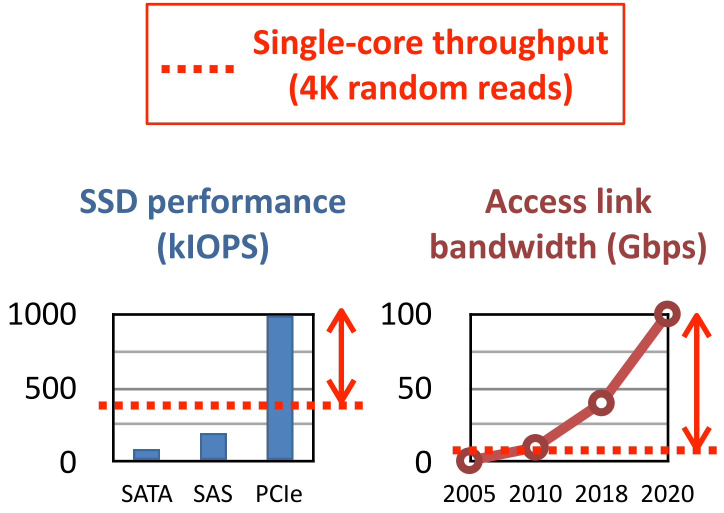

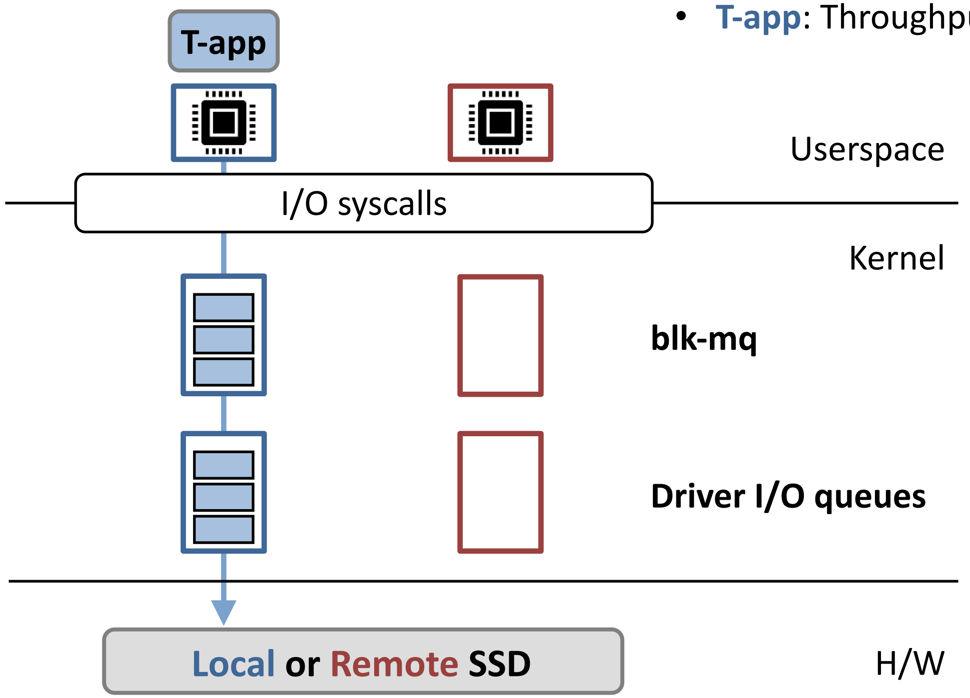

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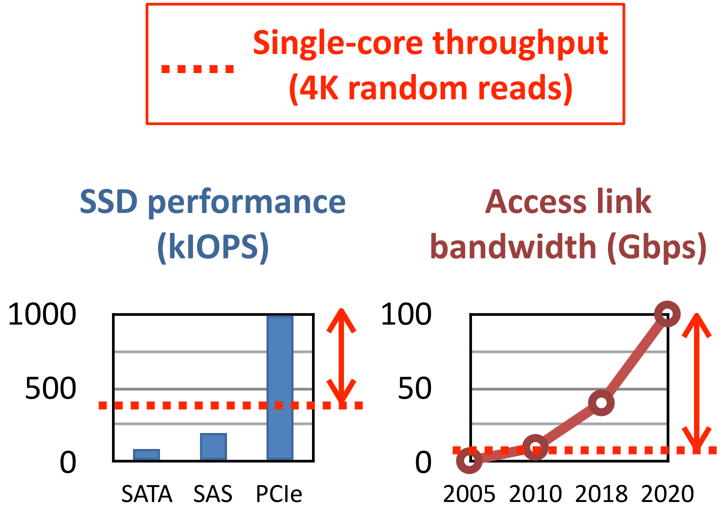

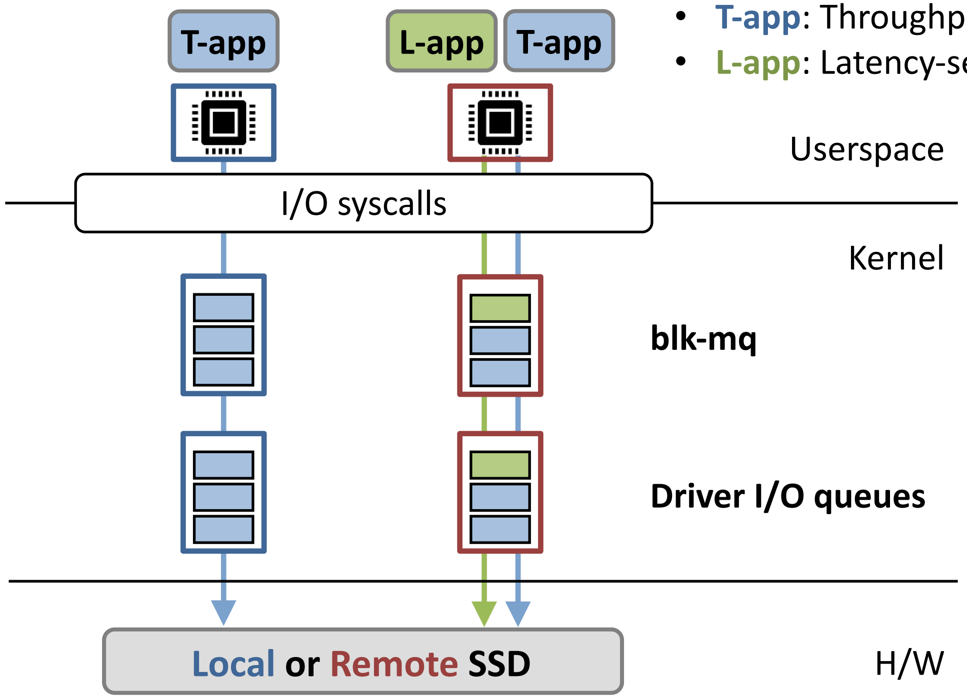

- T-app: Throughput-bound app
- L-app: Latency-sensitive app

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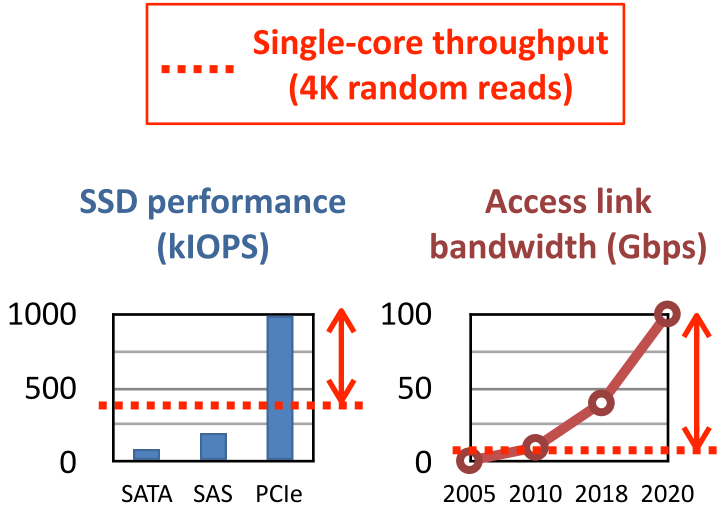

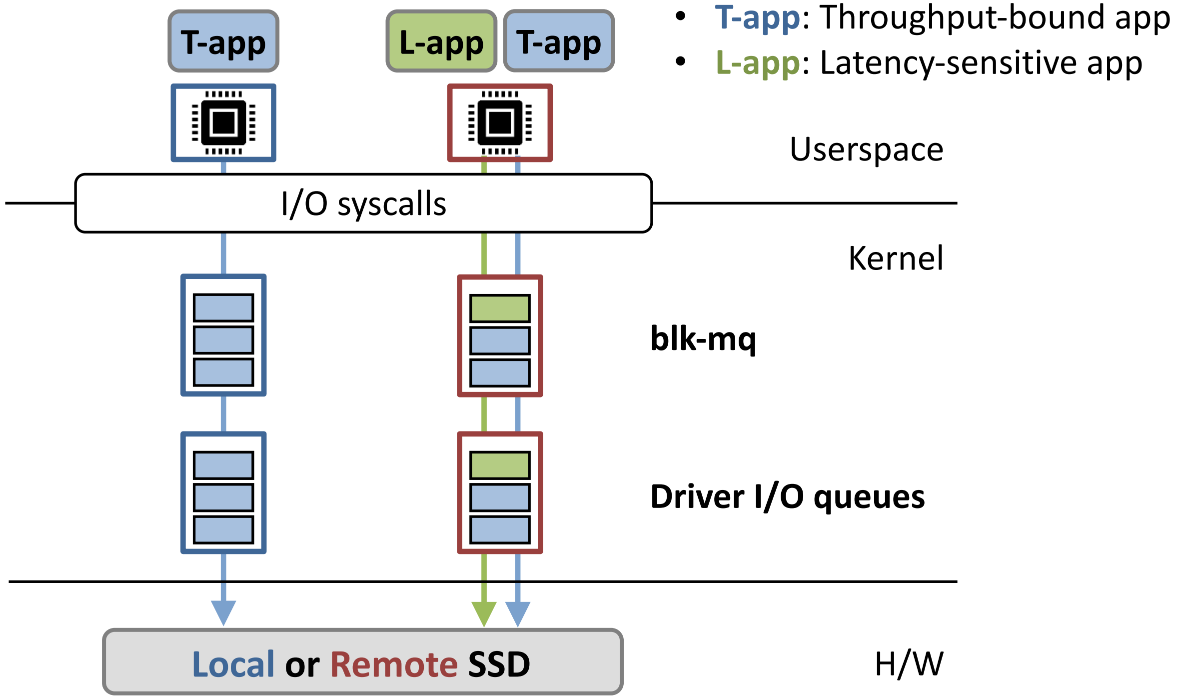

Static data path ⇢ hard to utilize all cores

High latency due to HoL blocking

Performance of Existing Storage Stacks

Applications accessing in-memory data in remote servers (single-core case)

L-app: 4KB, **T-app**: 64–128KB

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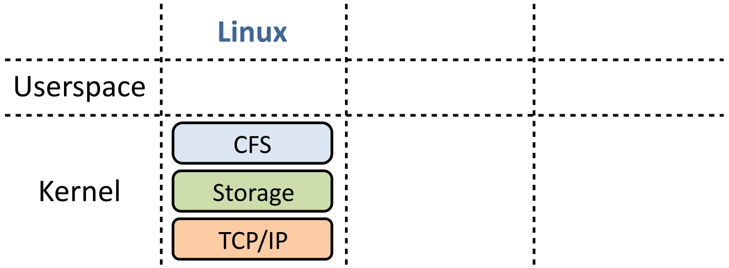

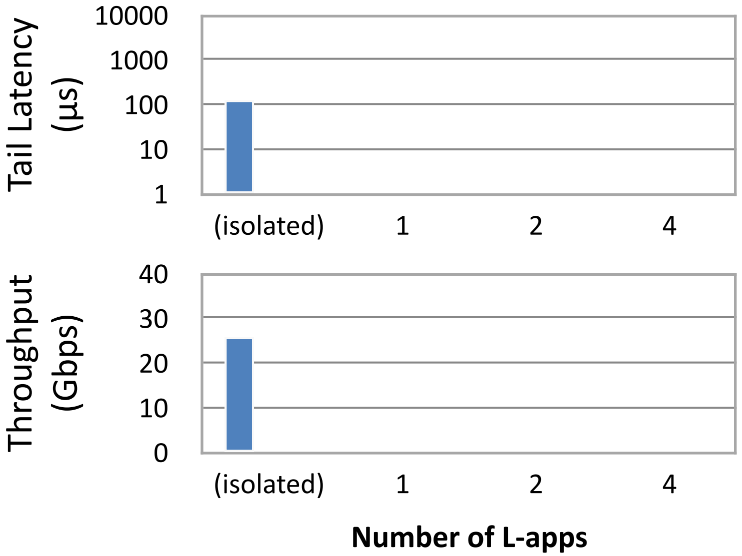

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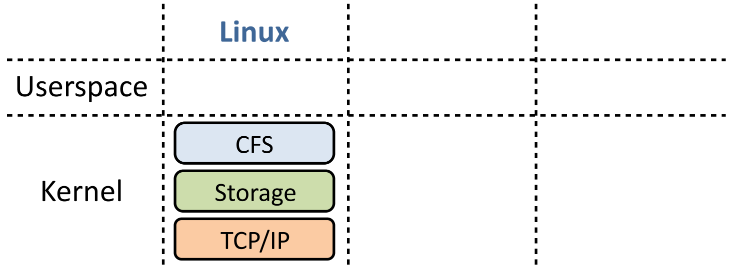

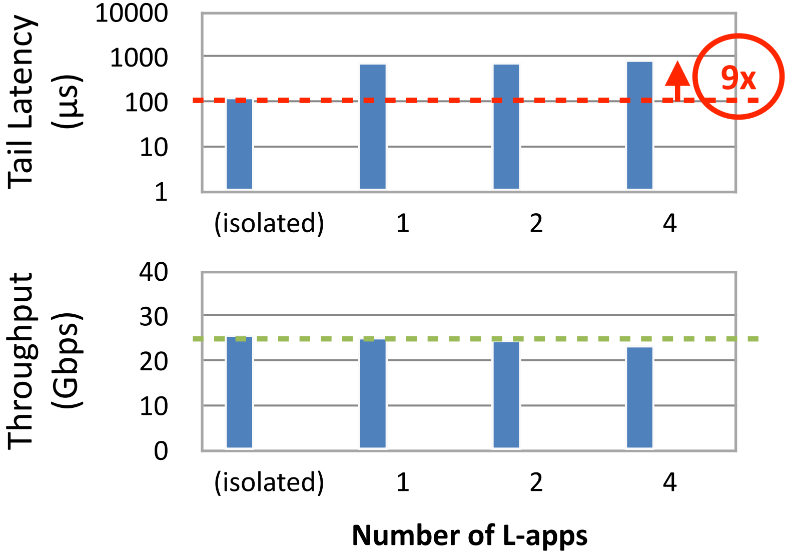

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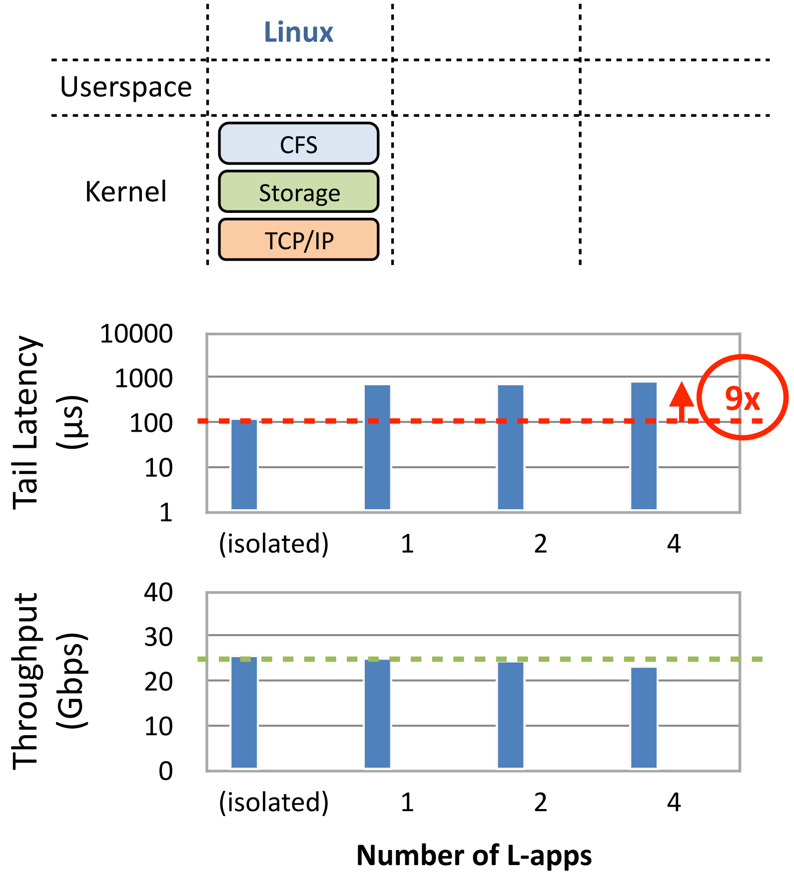

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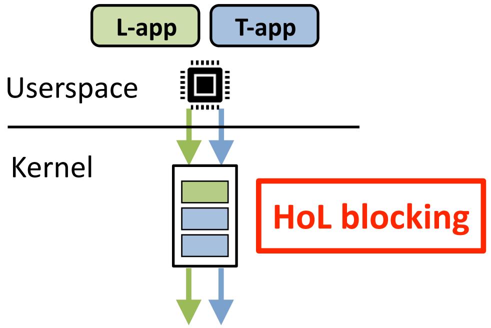

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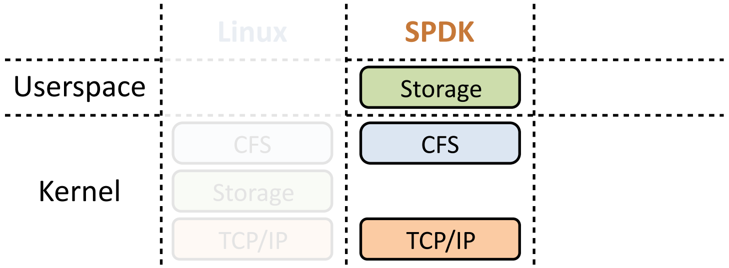

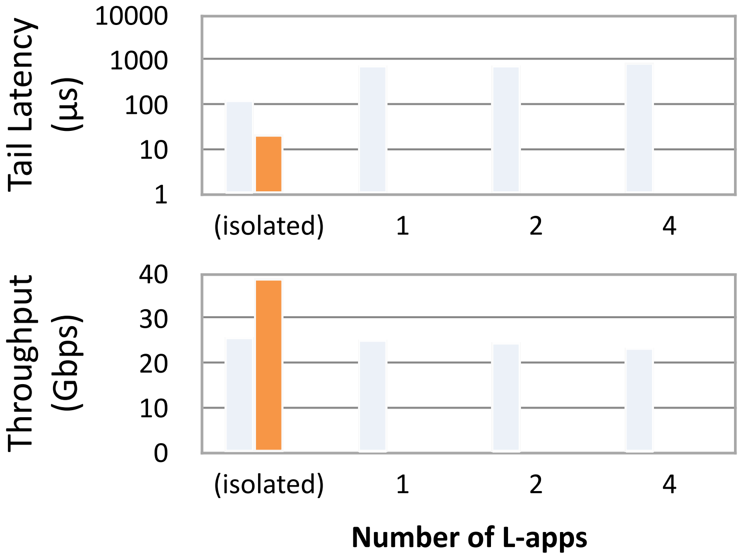

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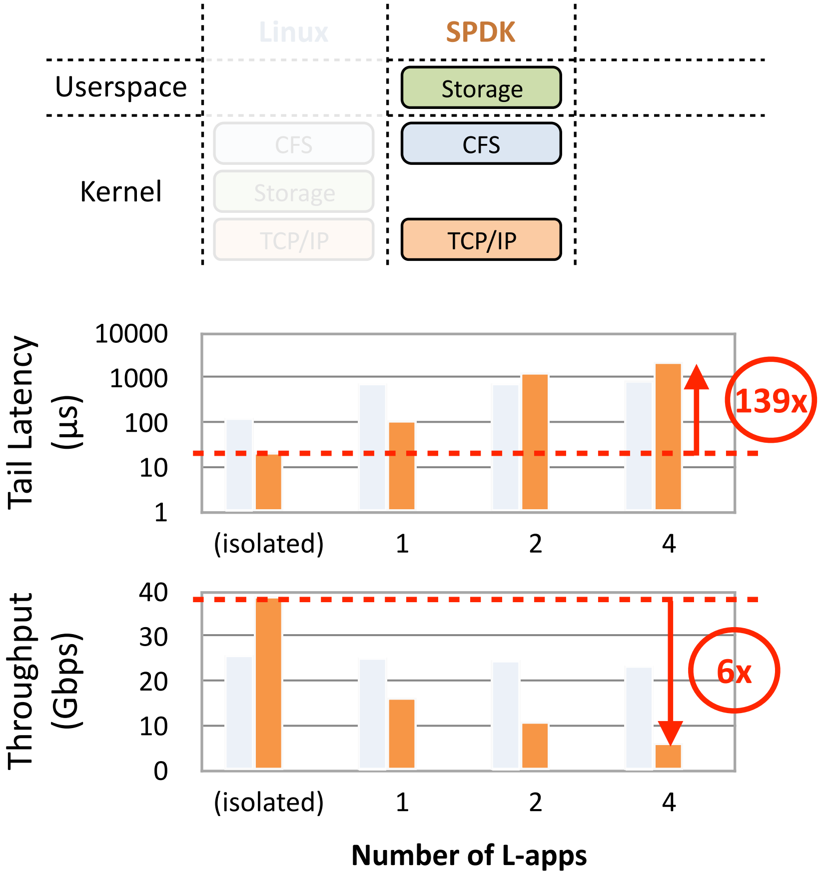

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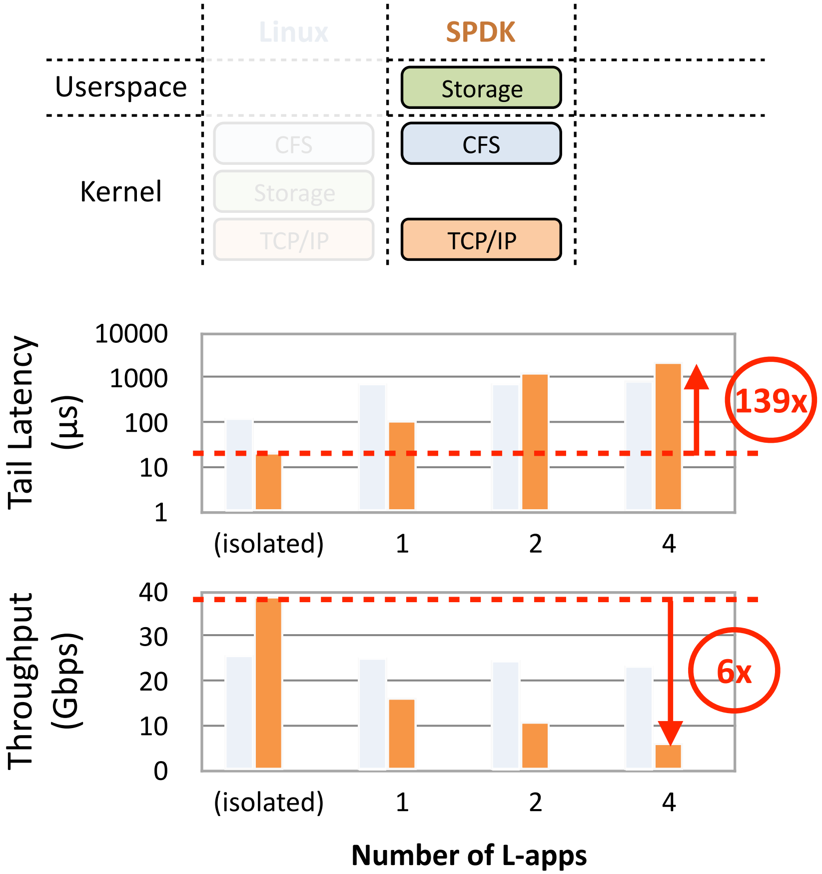

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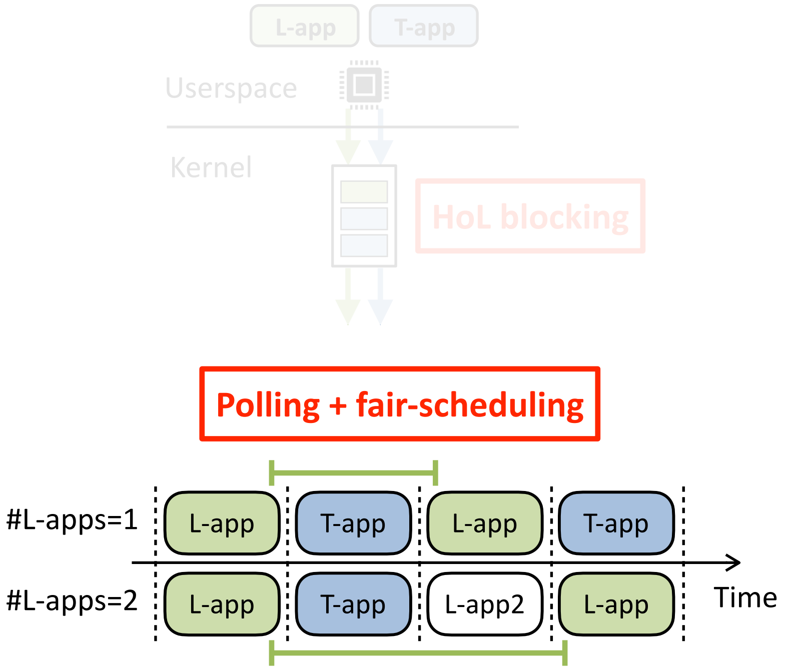

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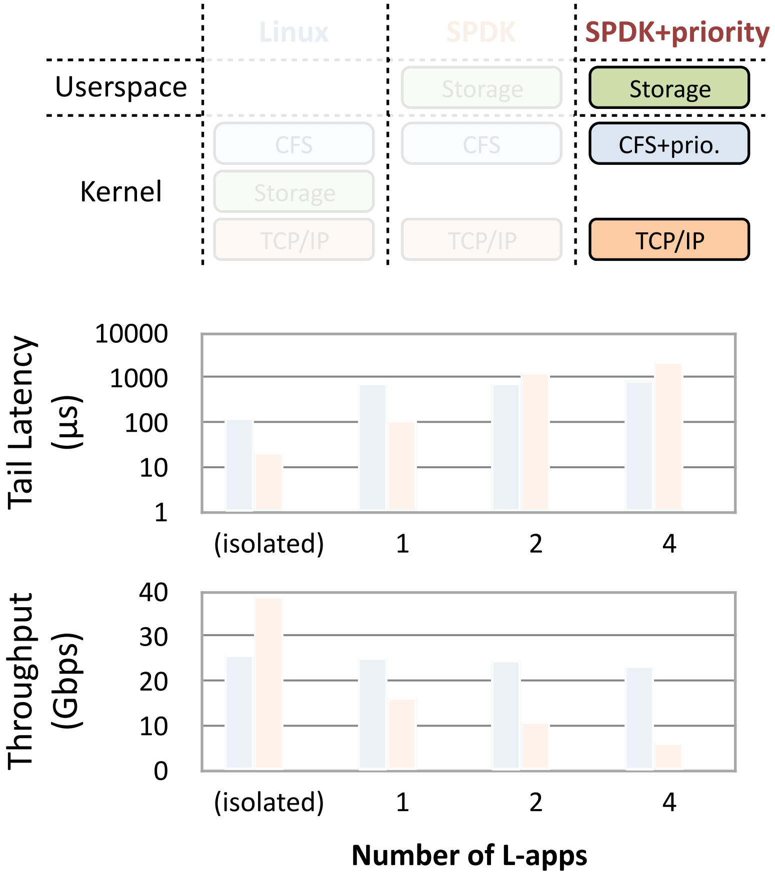

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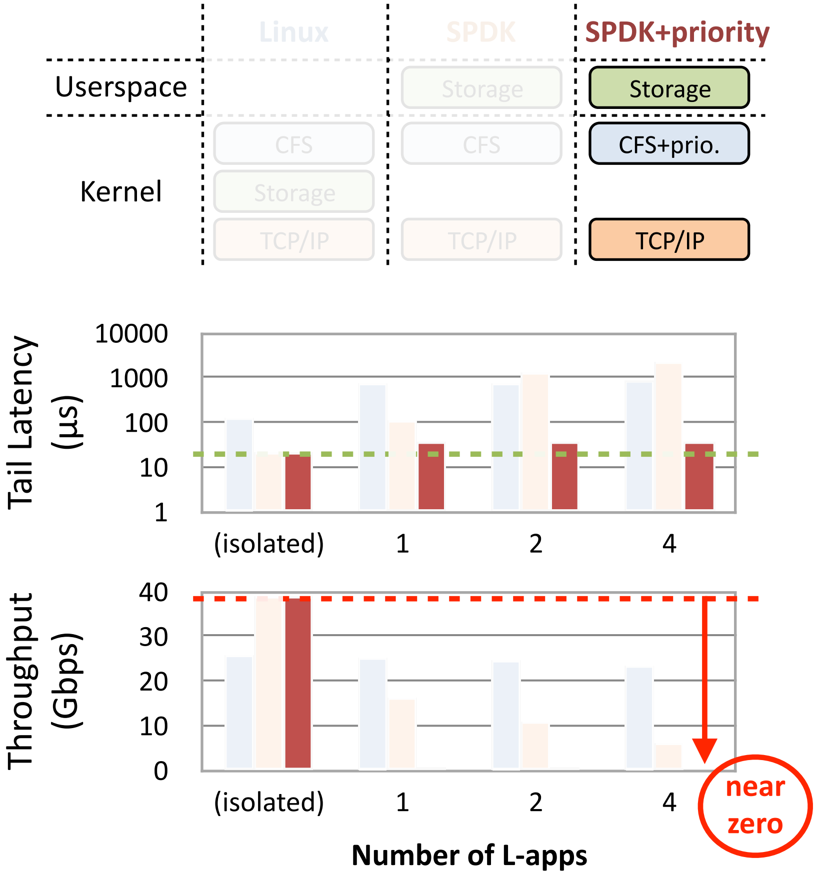

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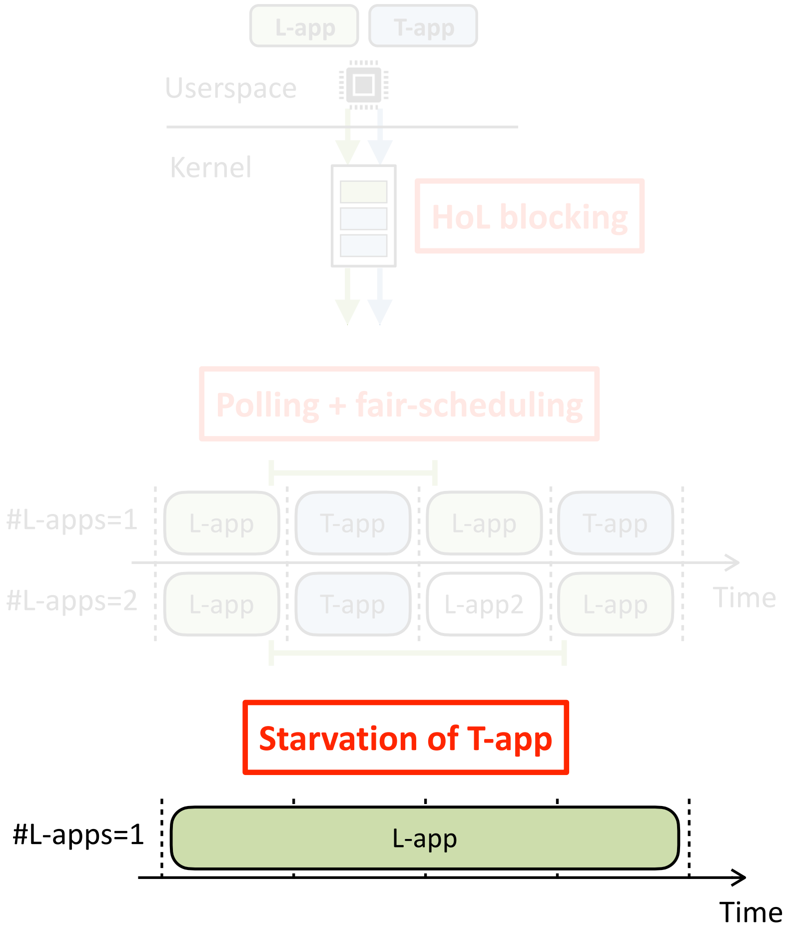

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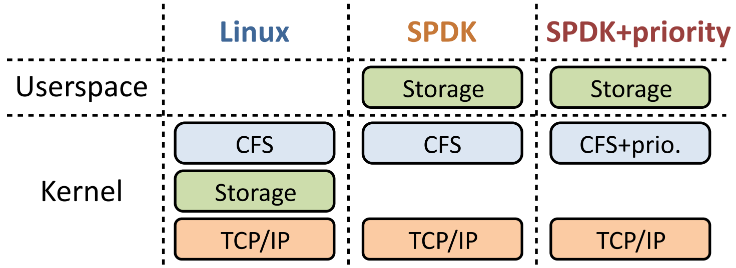

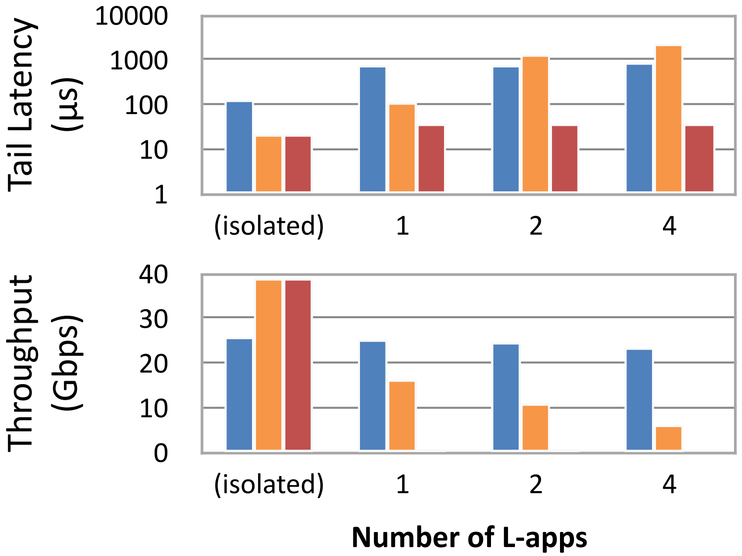

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Low latency or high throughput, but not both

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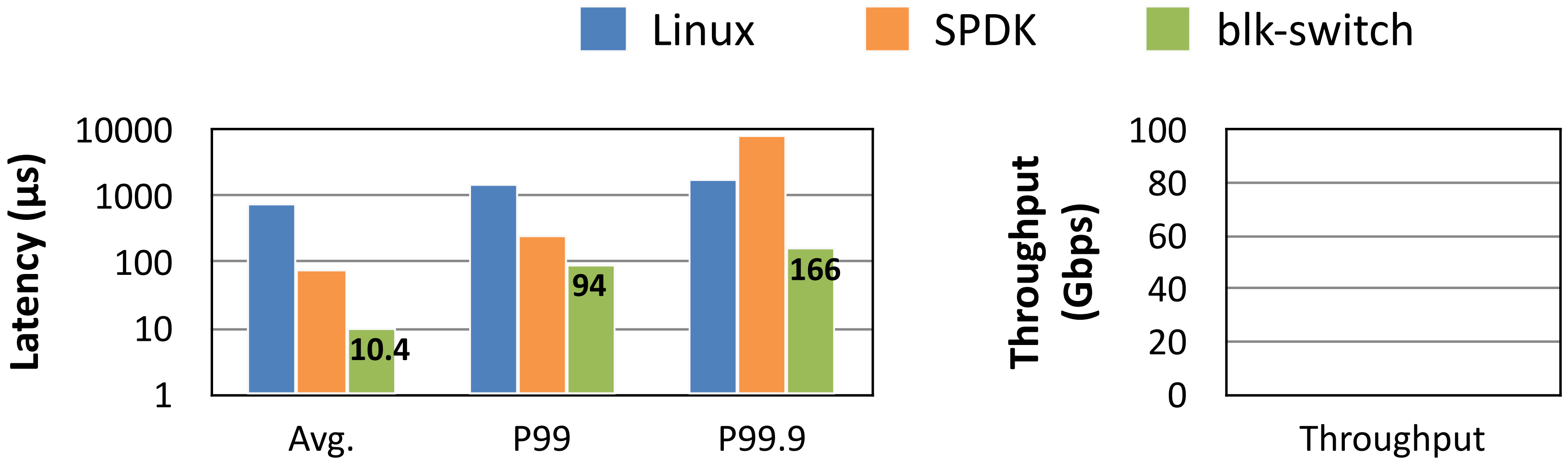

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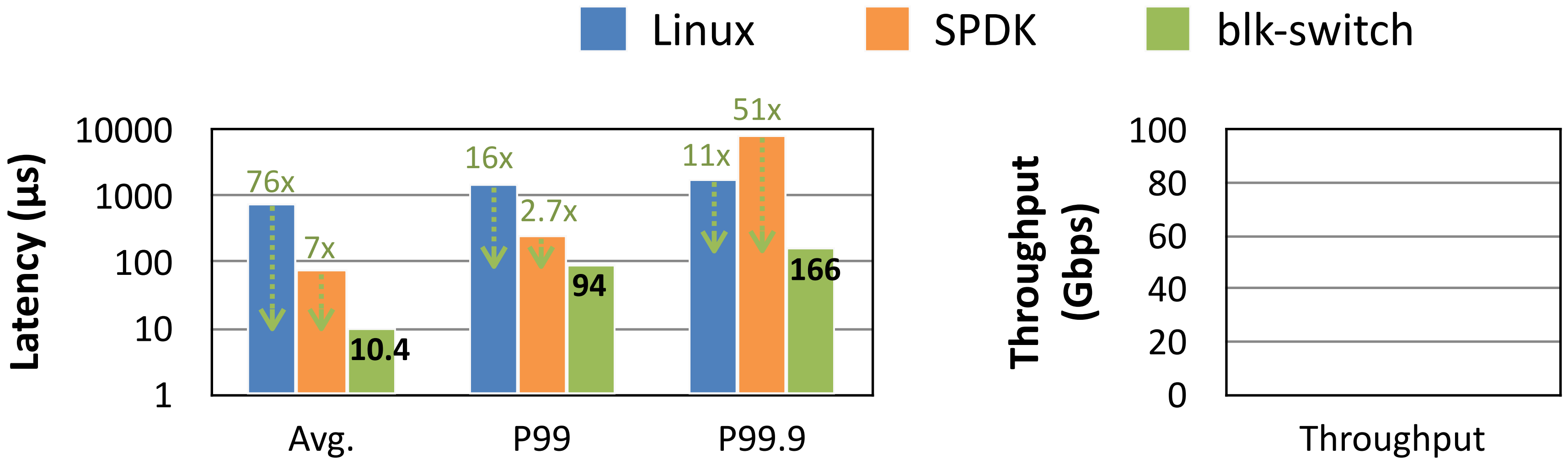

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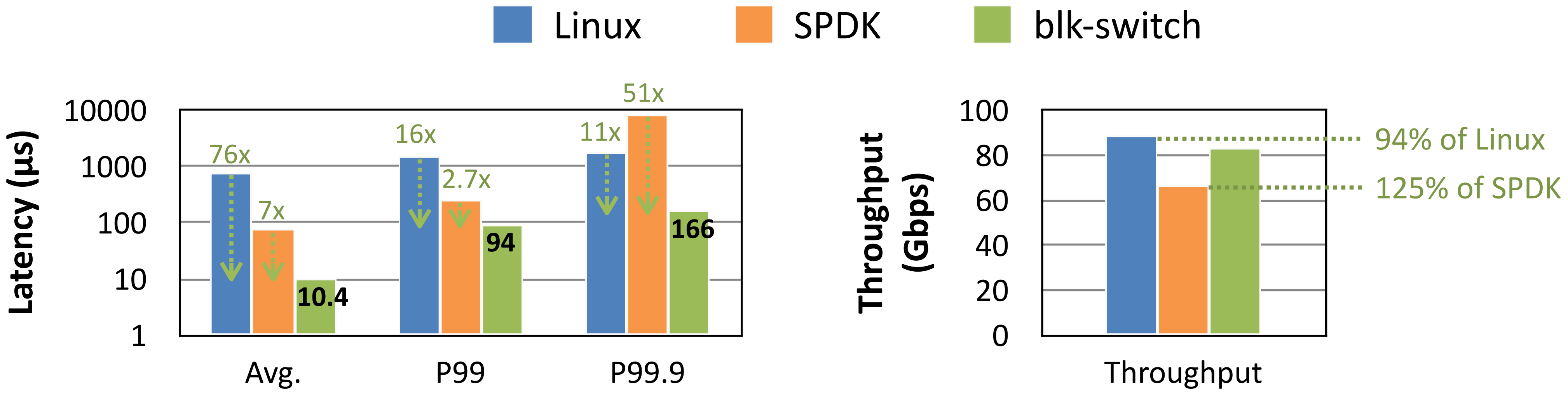

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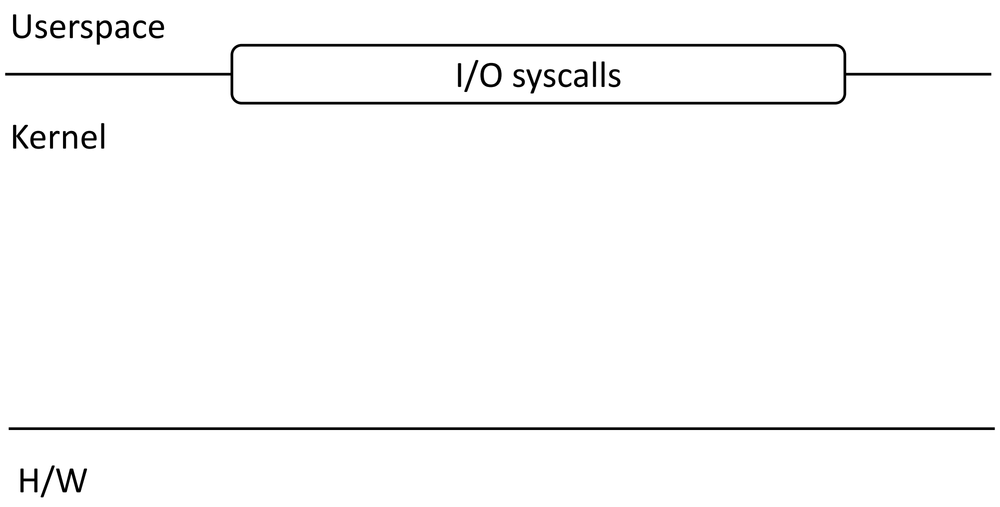

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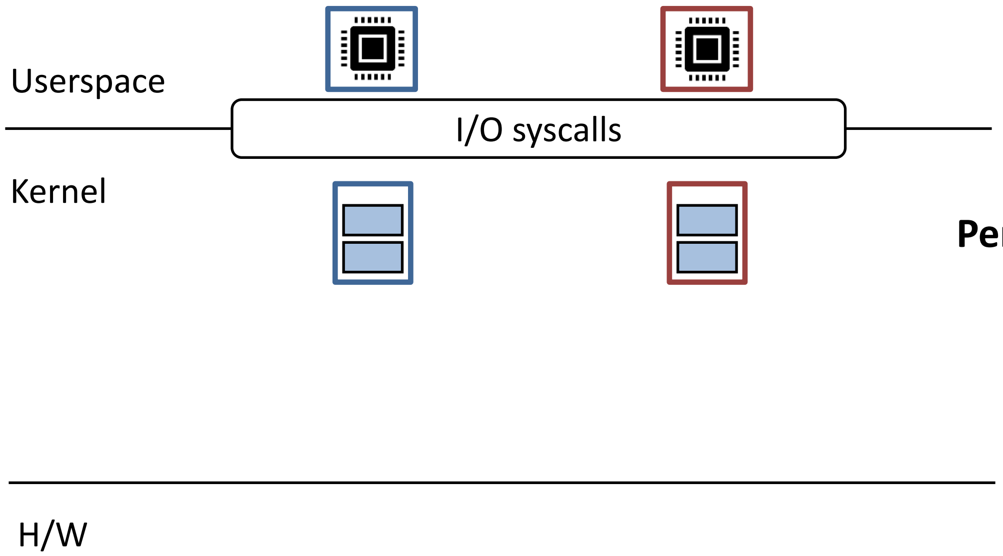

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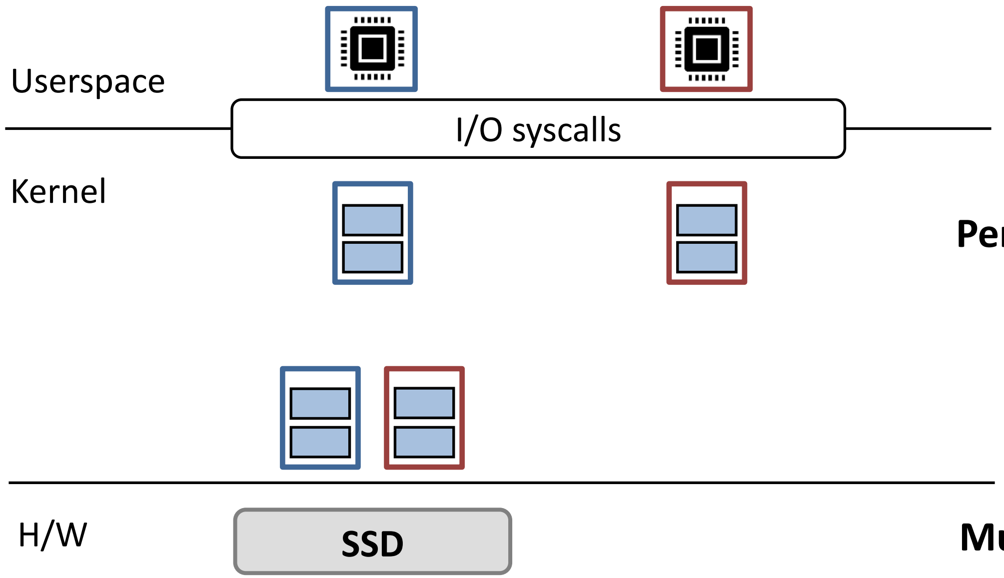

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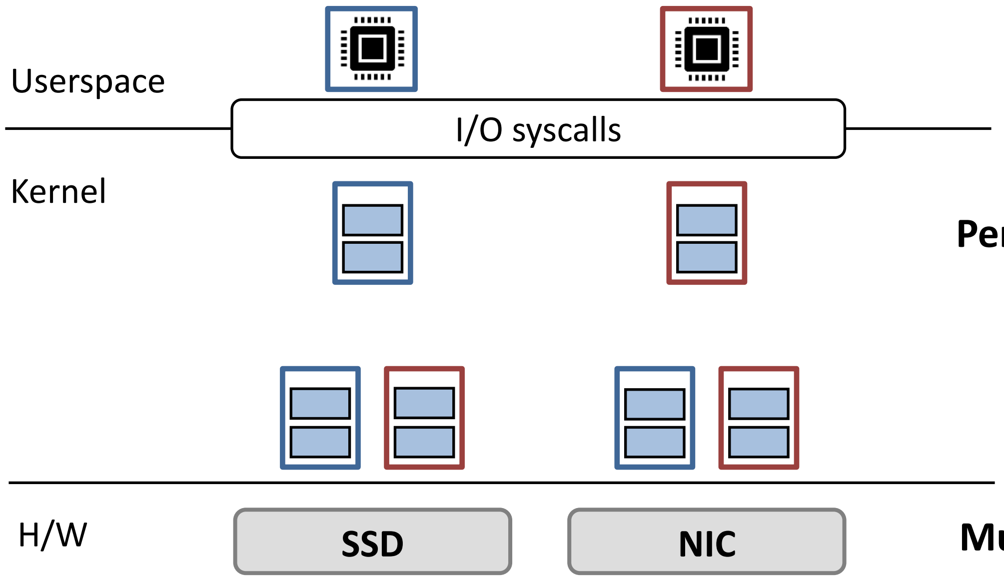

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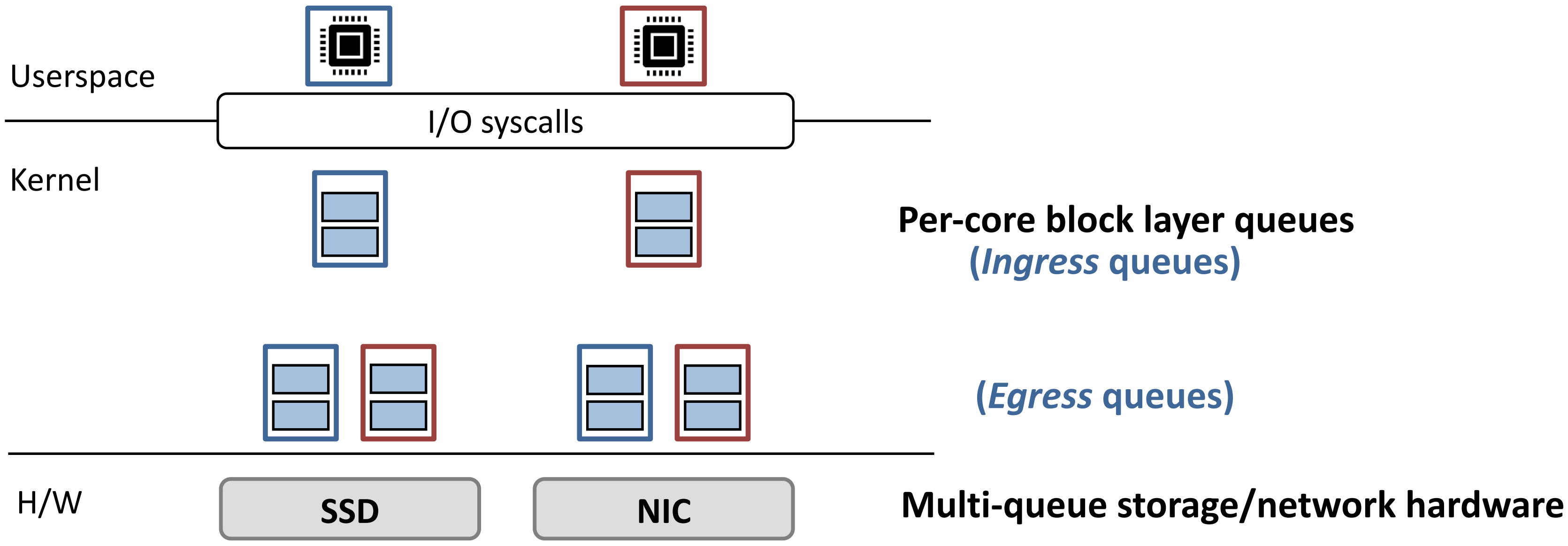

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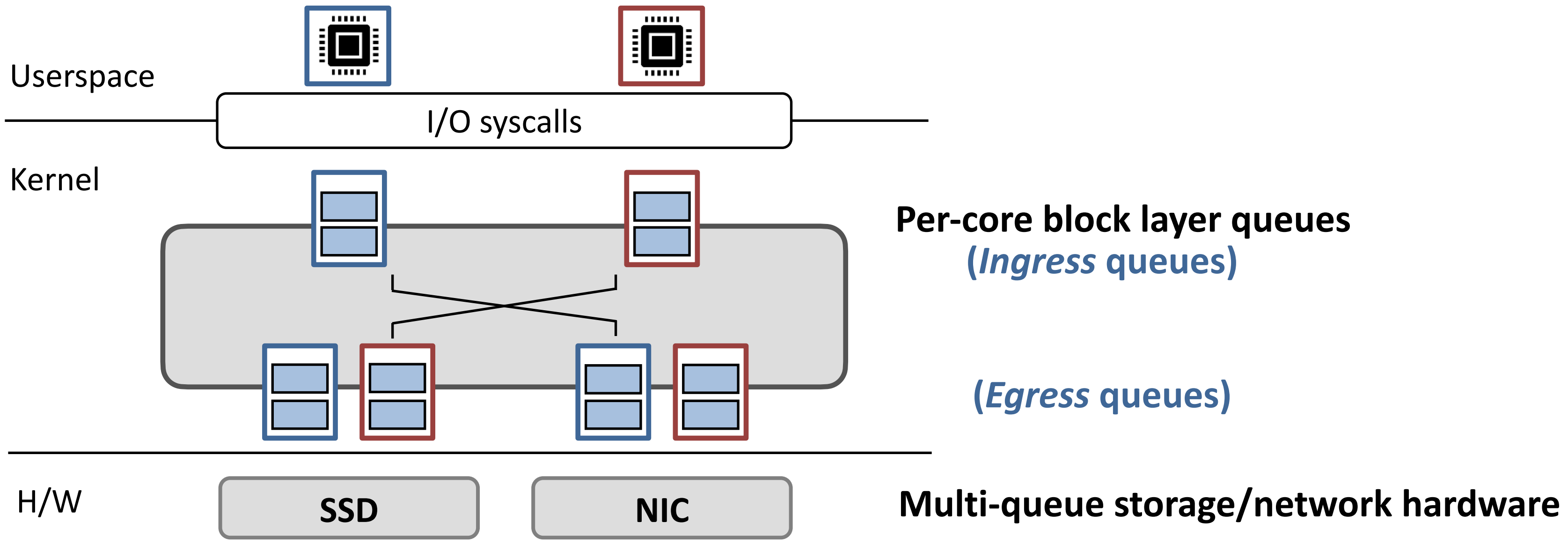

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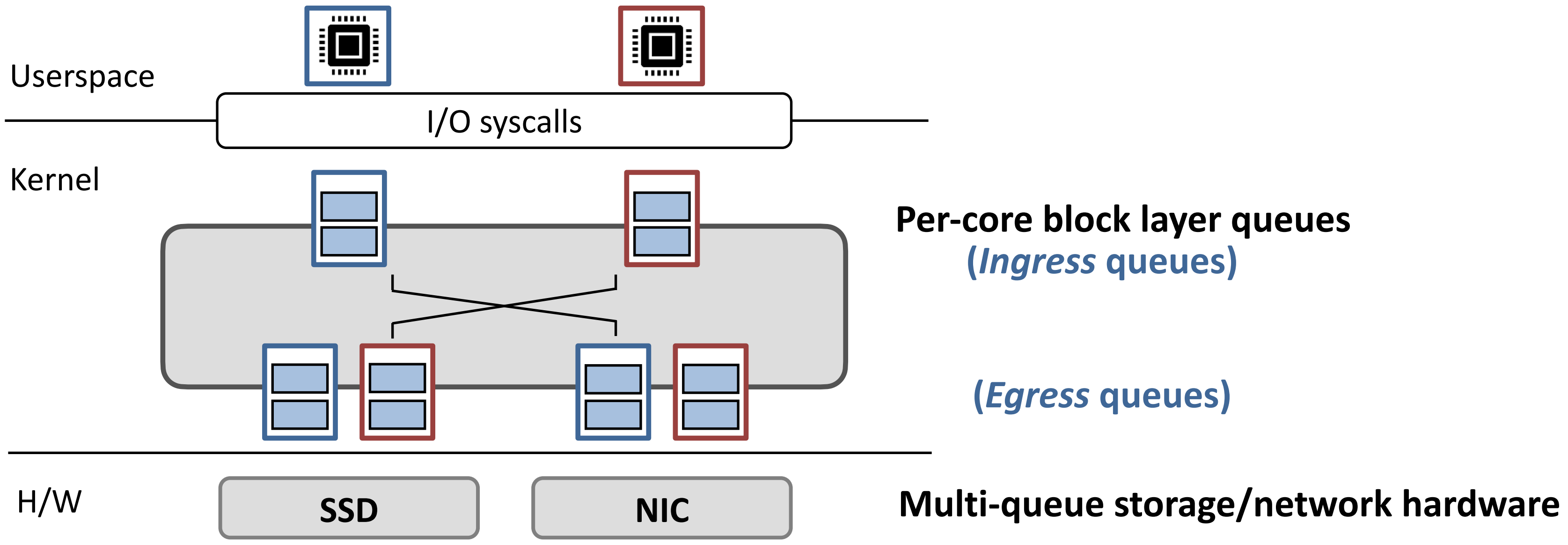

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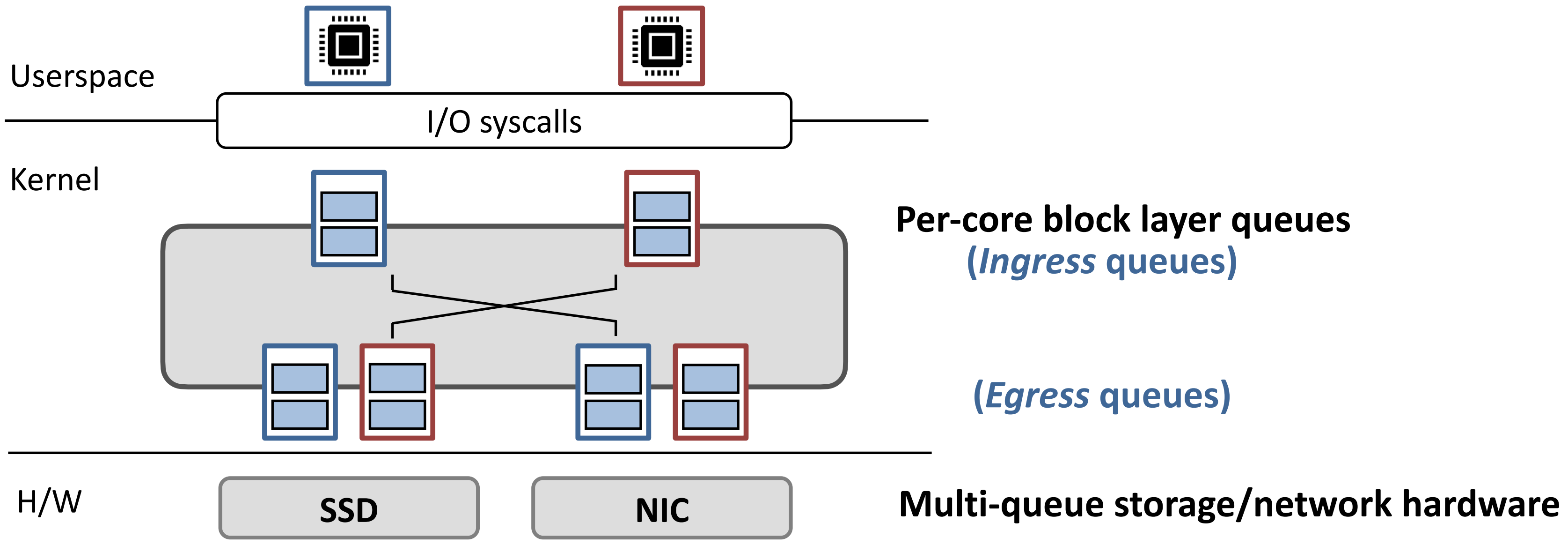

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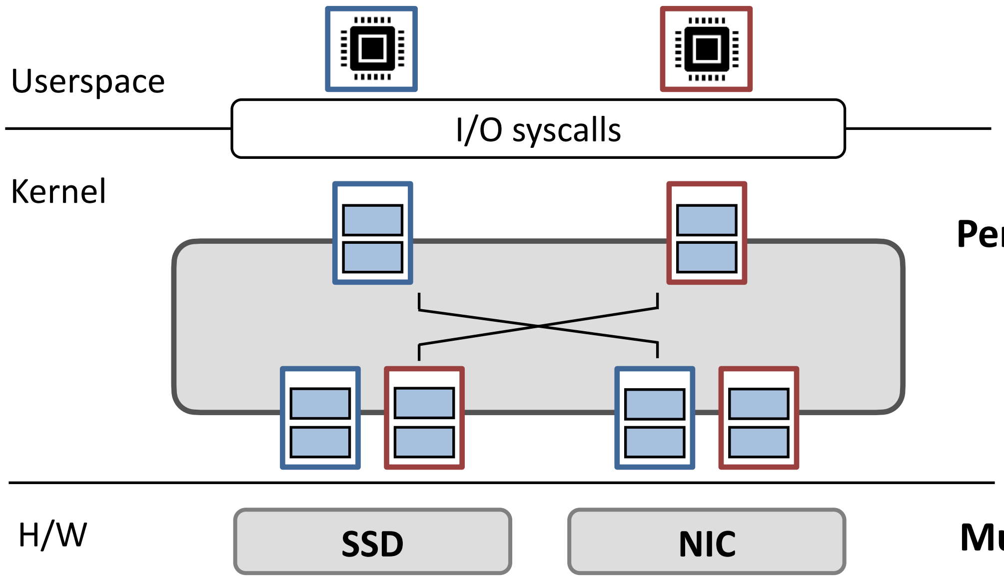

Per-core block layer queues
(*Ingress* queues)

(*Egress* queues)

Multi-queue storage/network hardware

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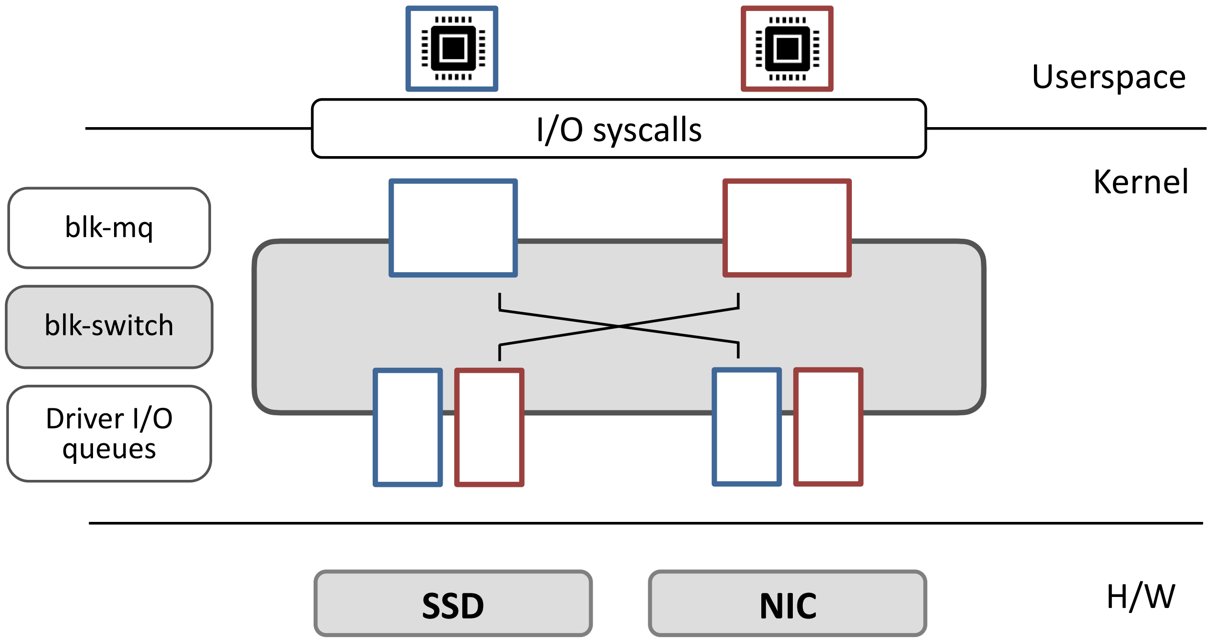
  - Enables decoupling request processing from application cores
  - Multi-egress queues, prioritization, and load balancing

A deeper dive into blk-switch architecture



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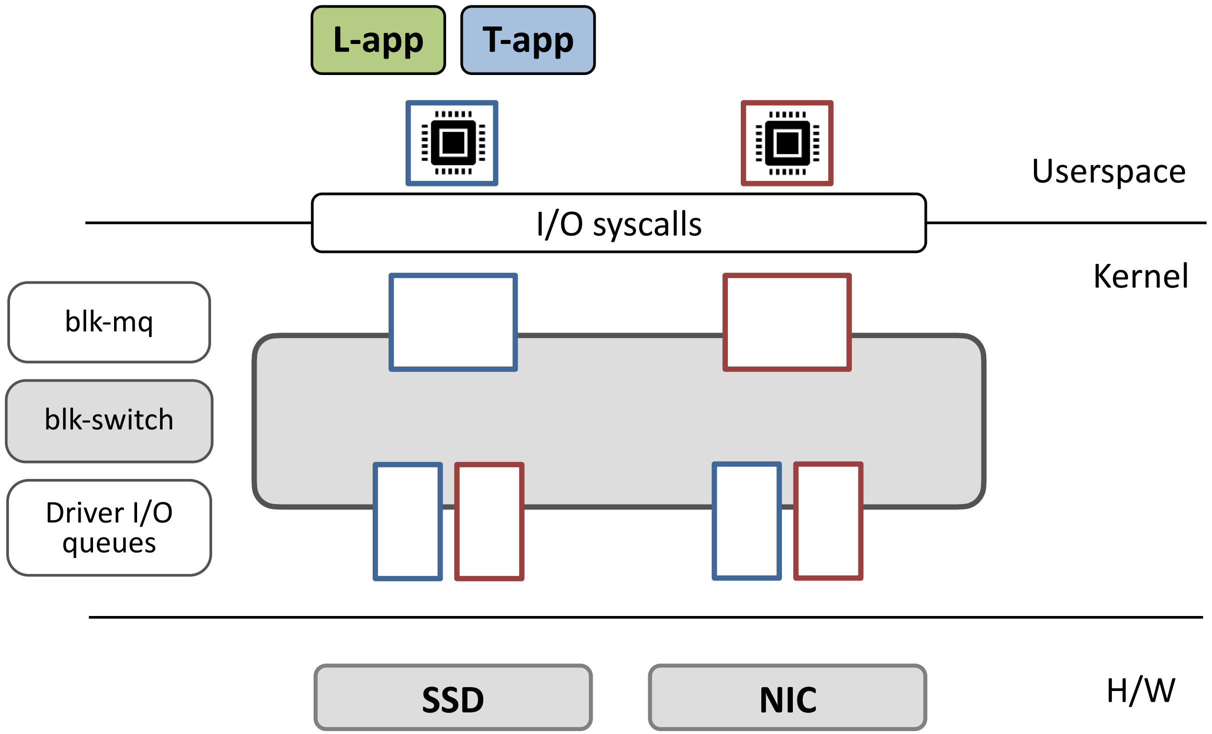

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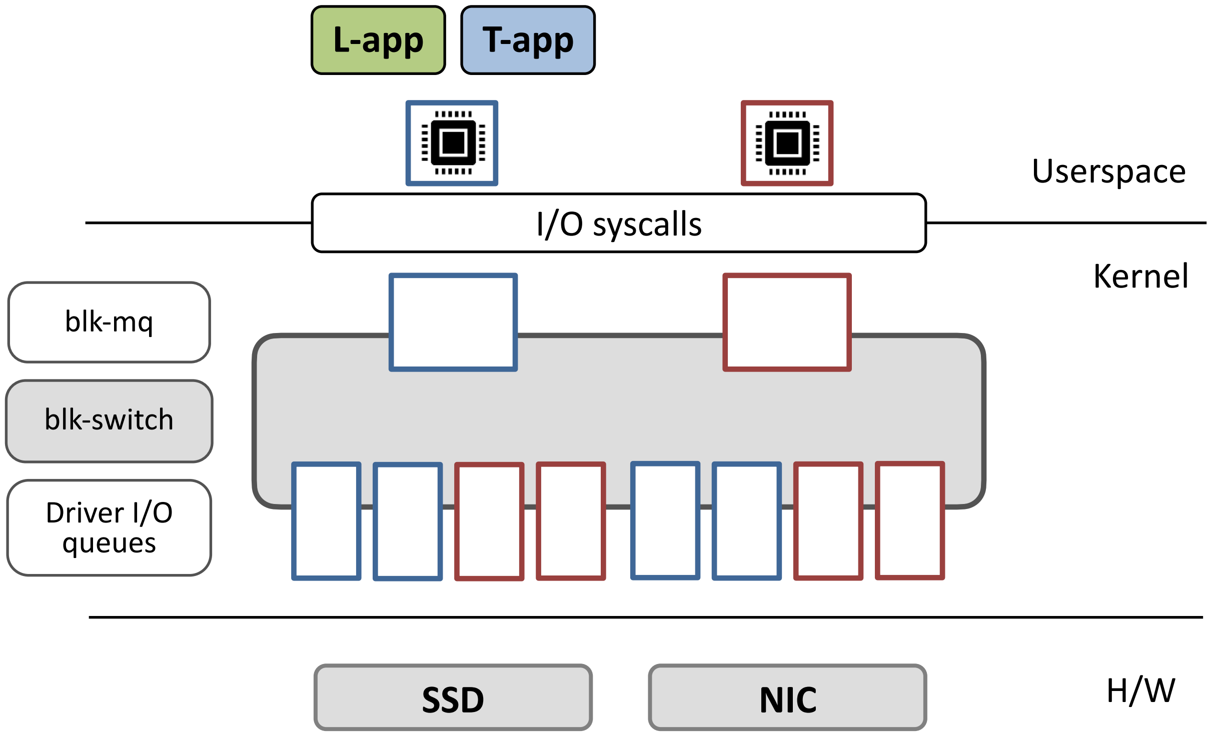

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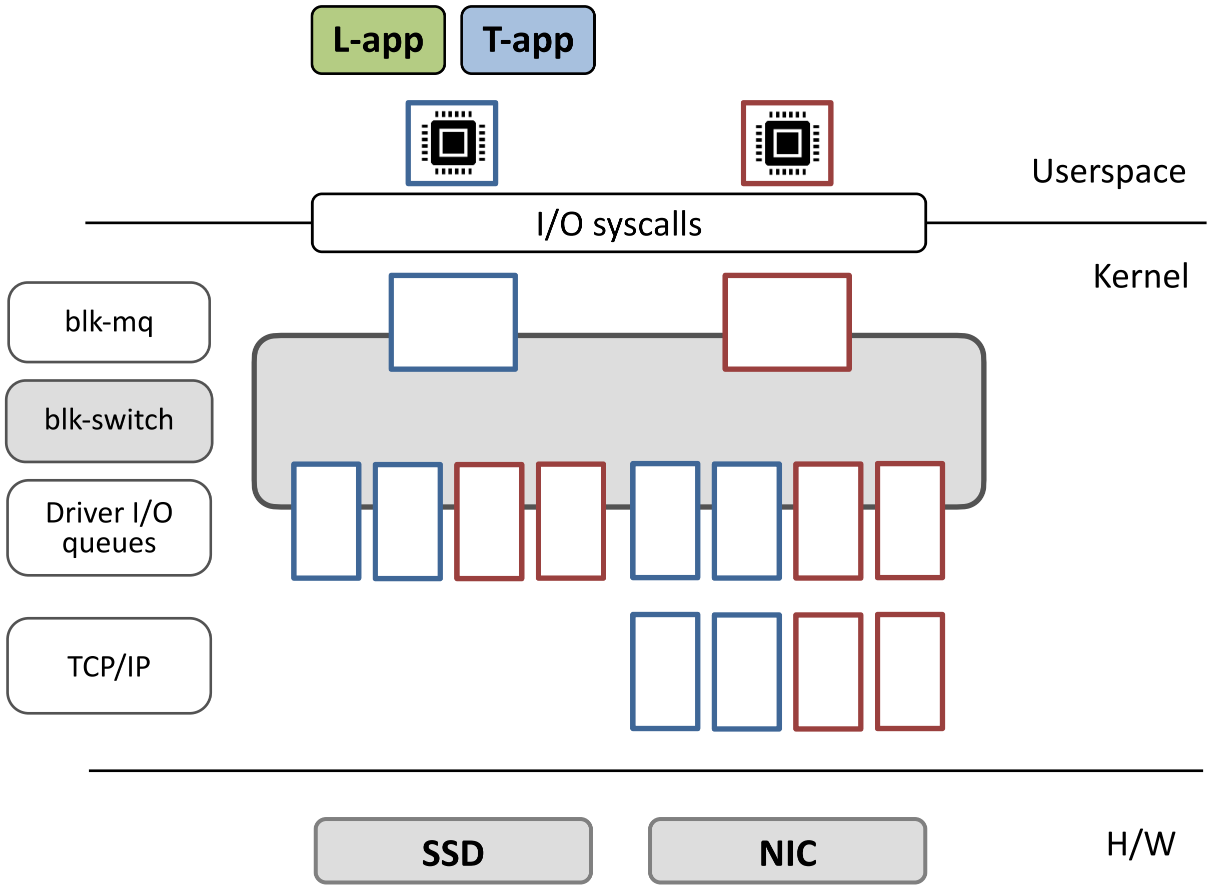

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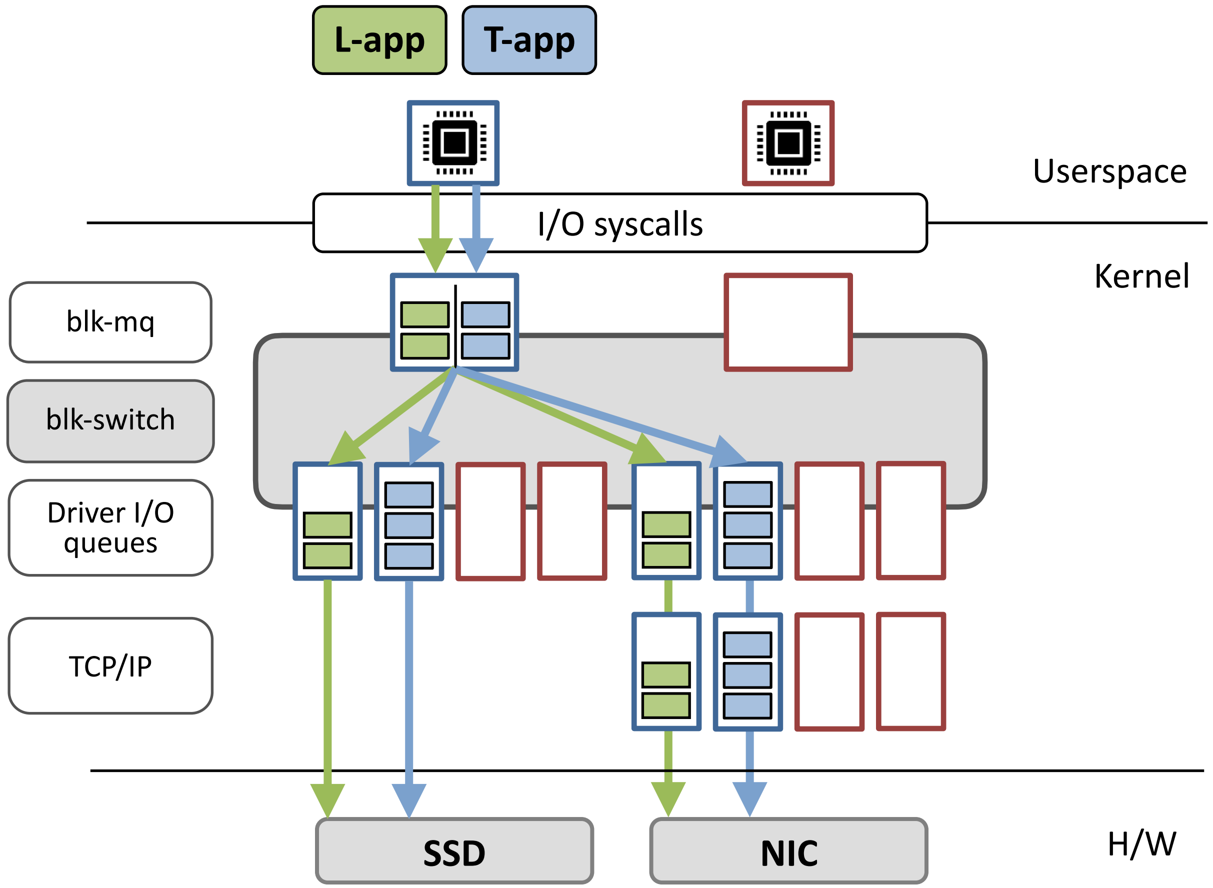

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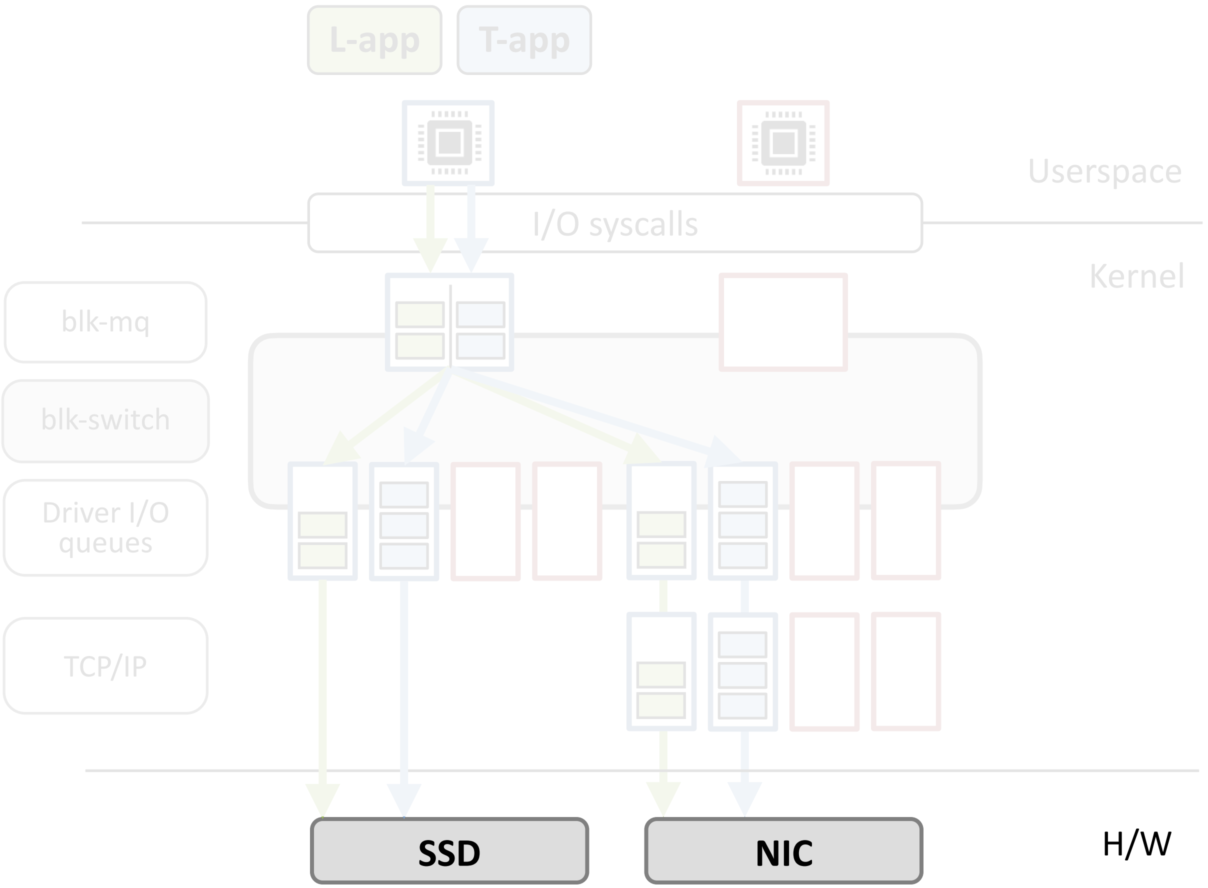

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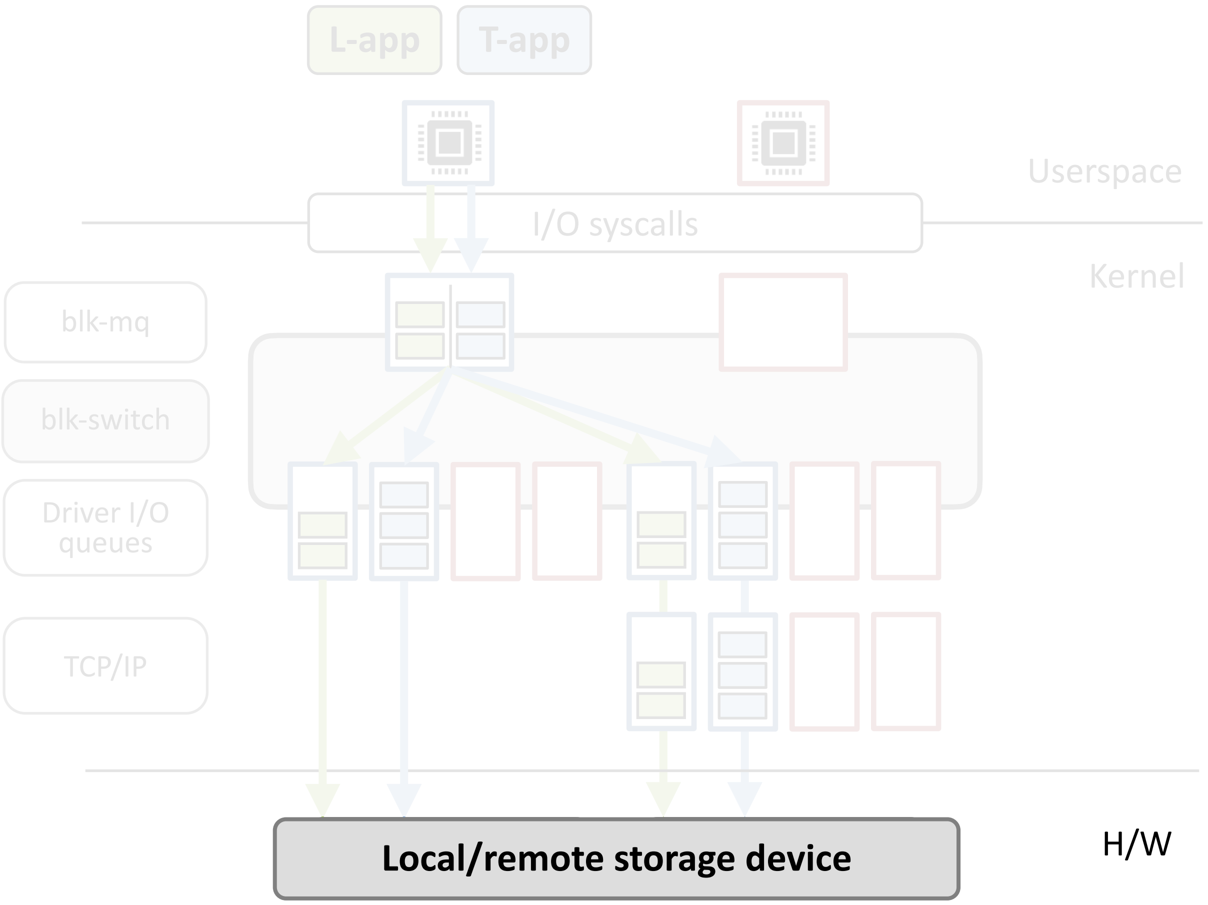

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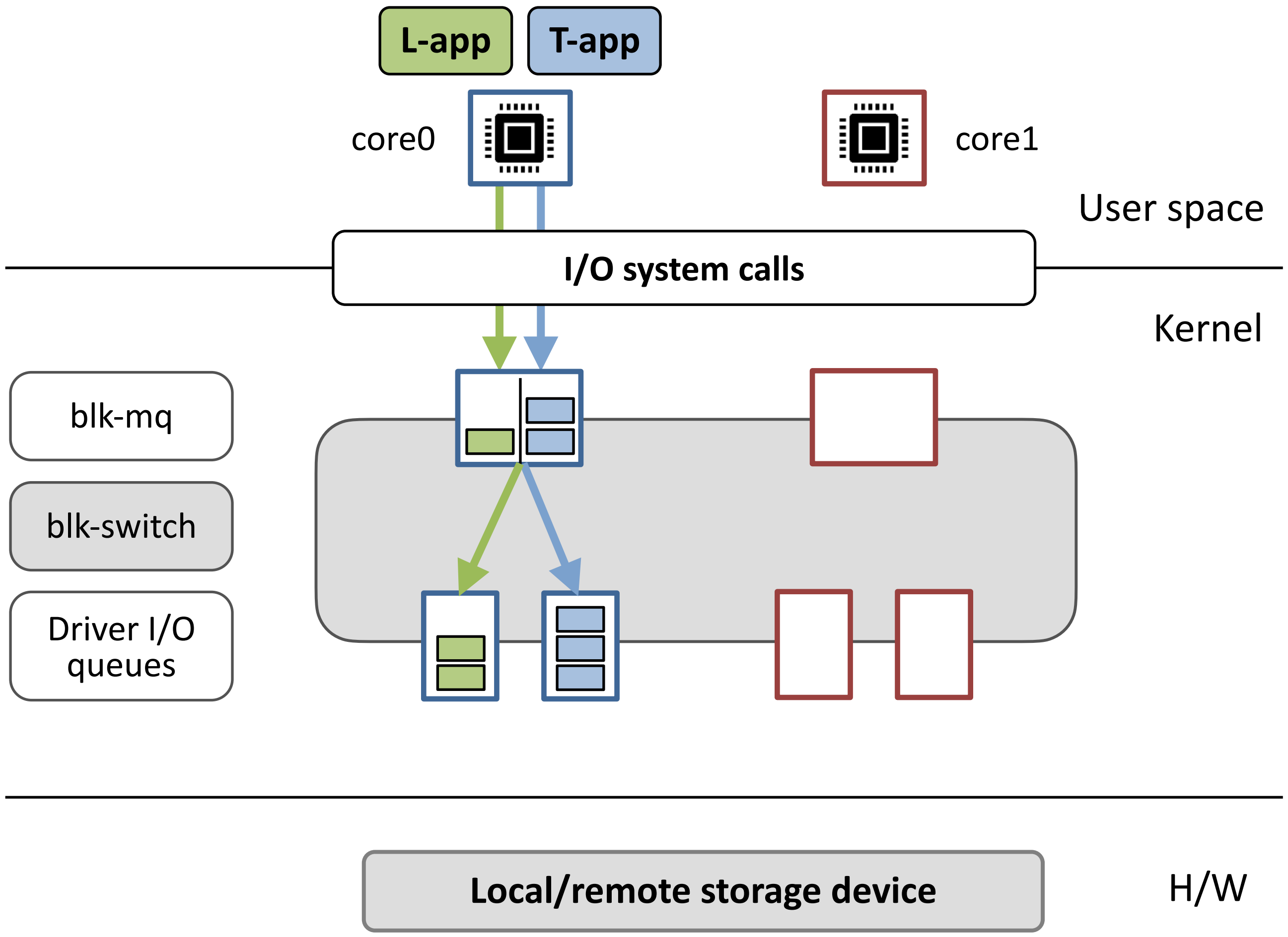

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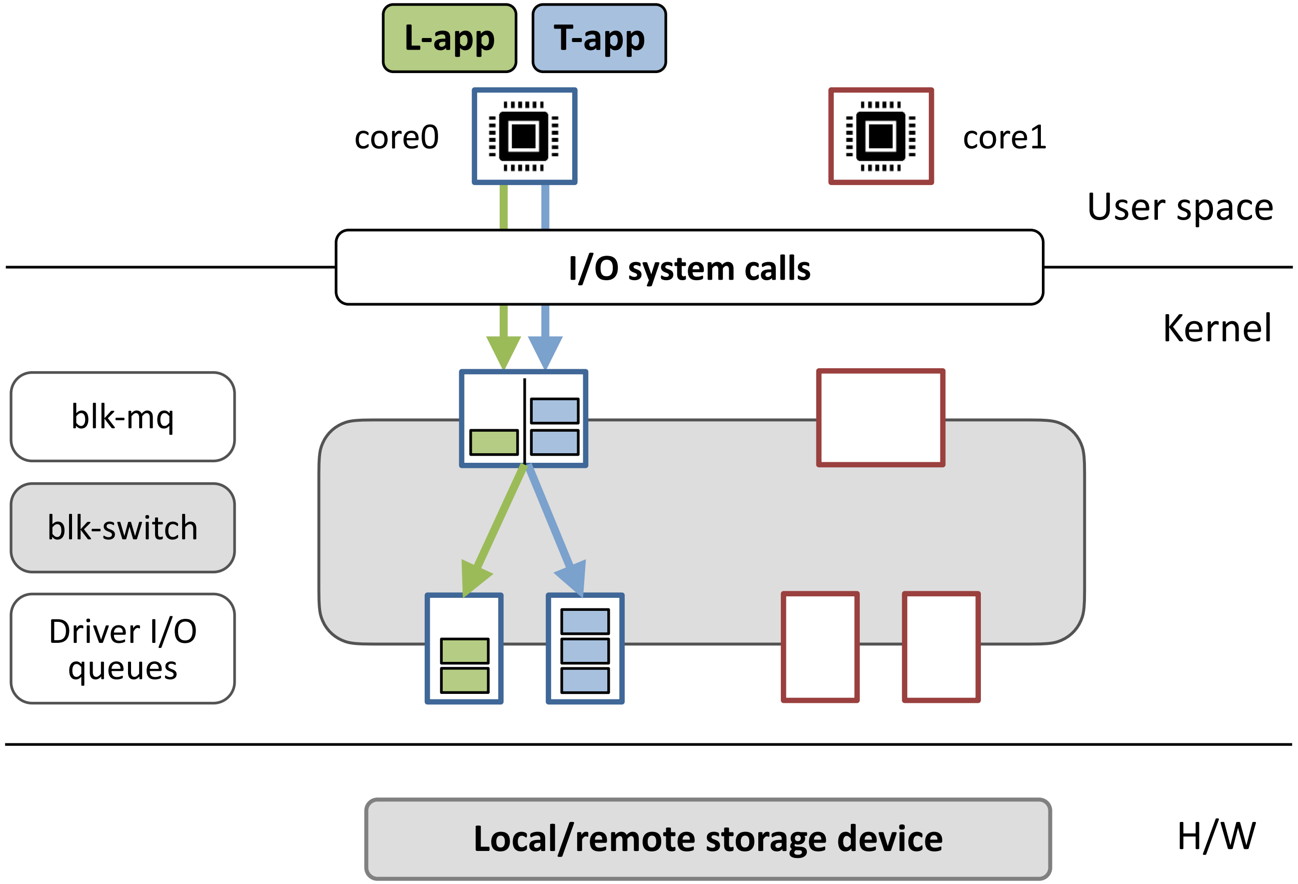

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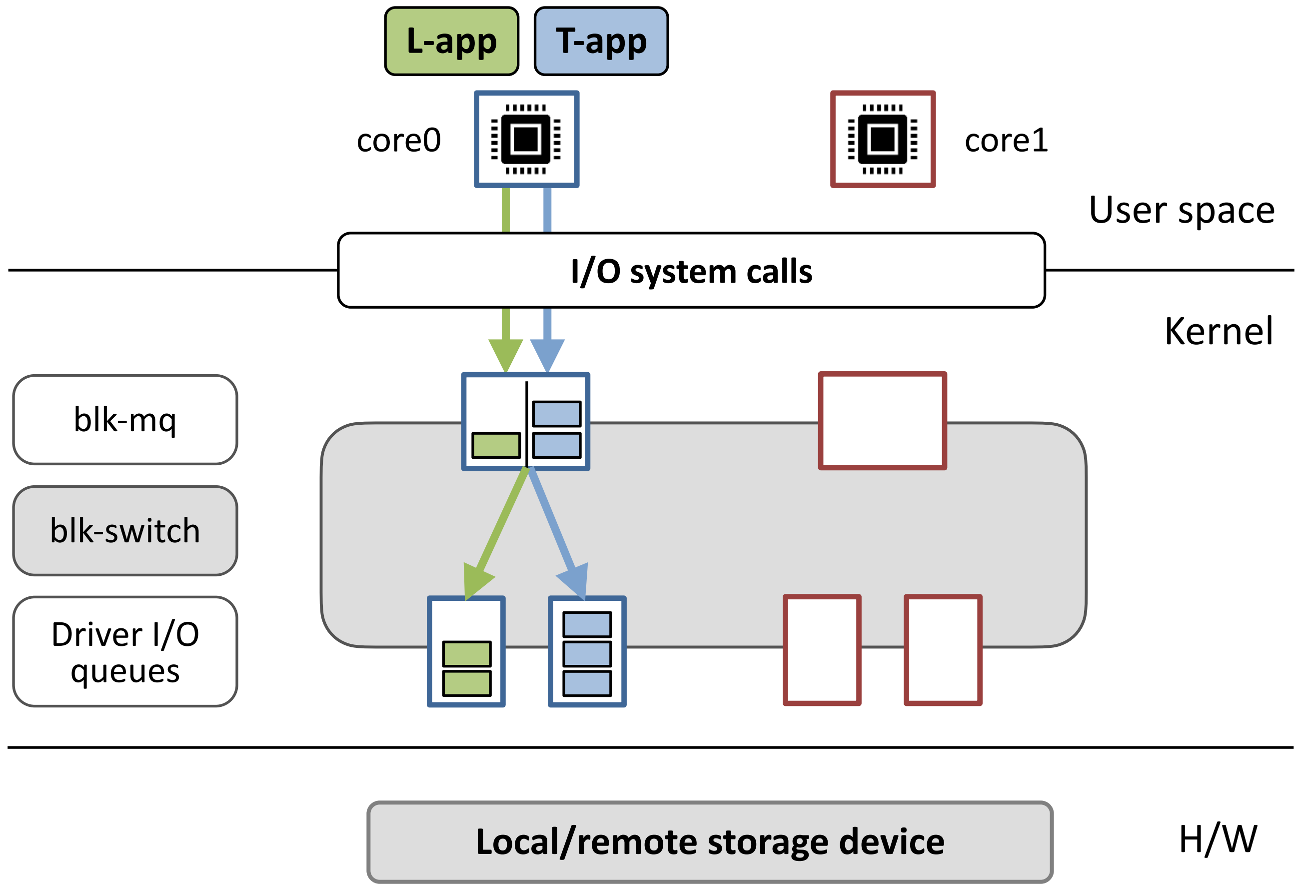

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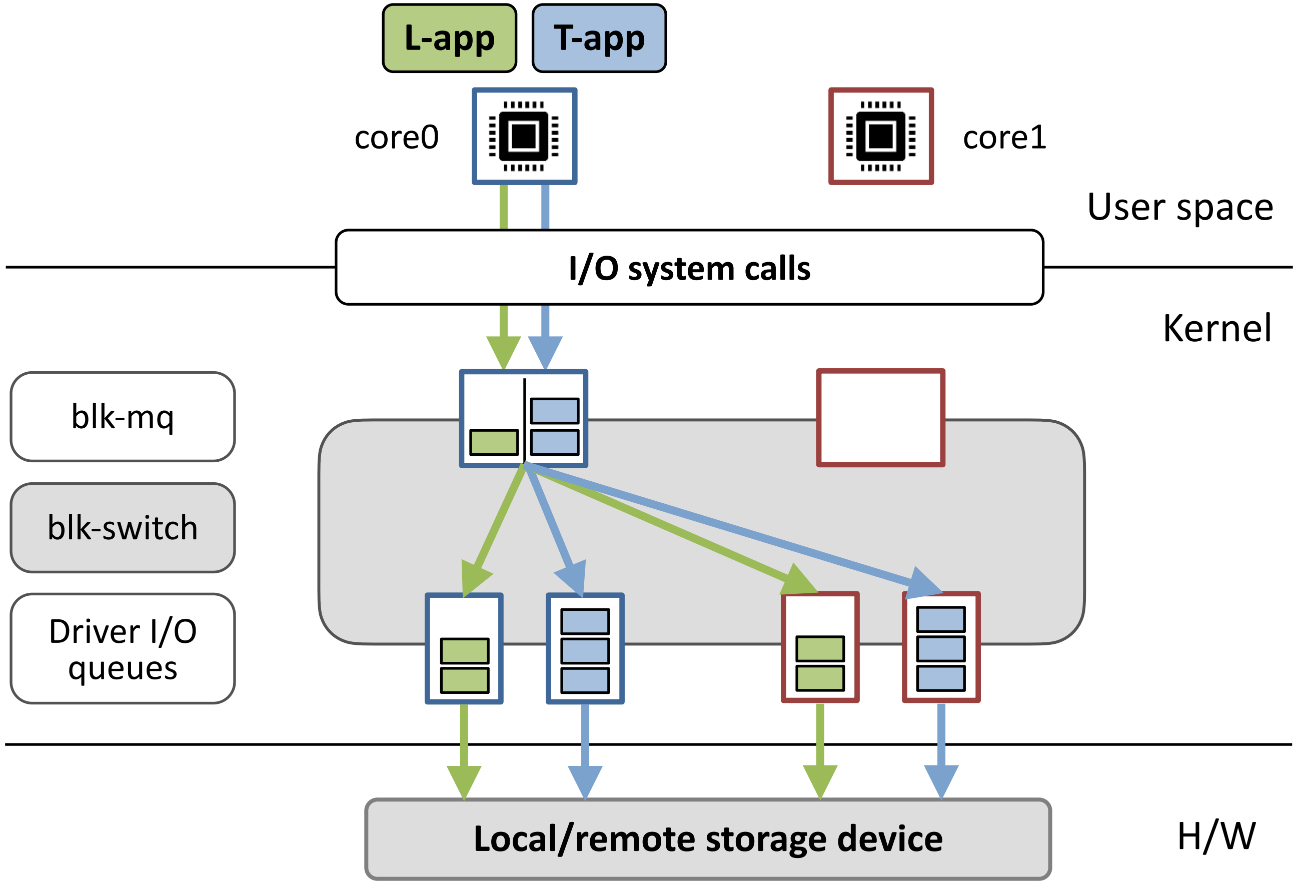

1. *Egress* queue per-(core, app-class)

2. *Flexible* mapping from ingress to egress queues

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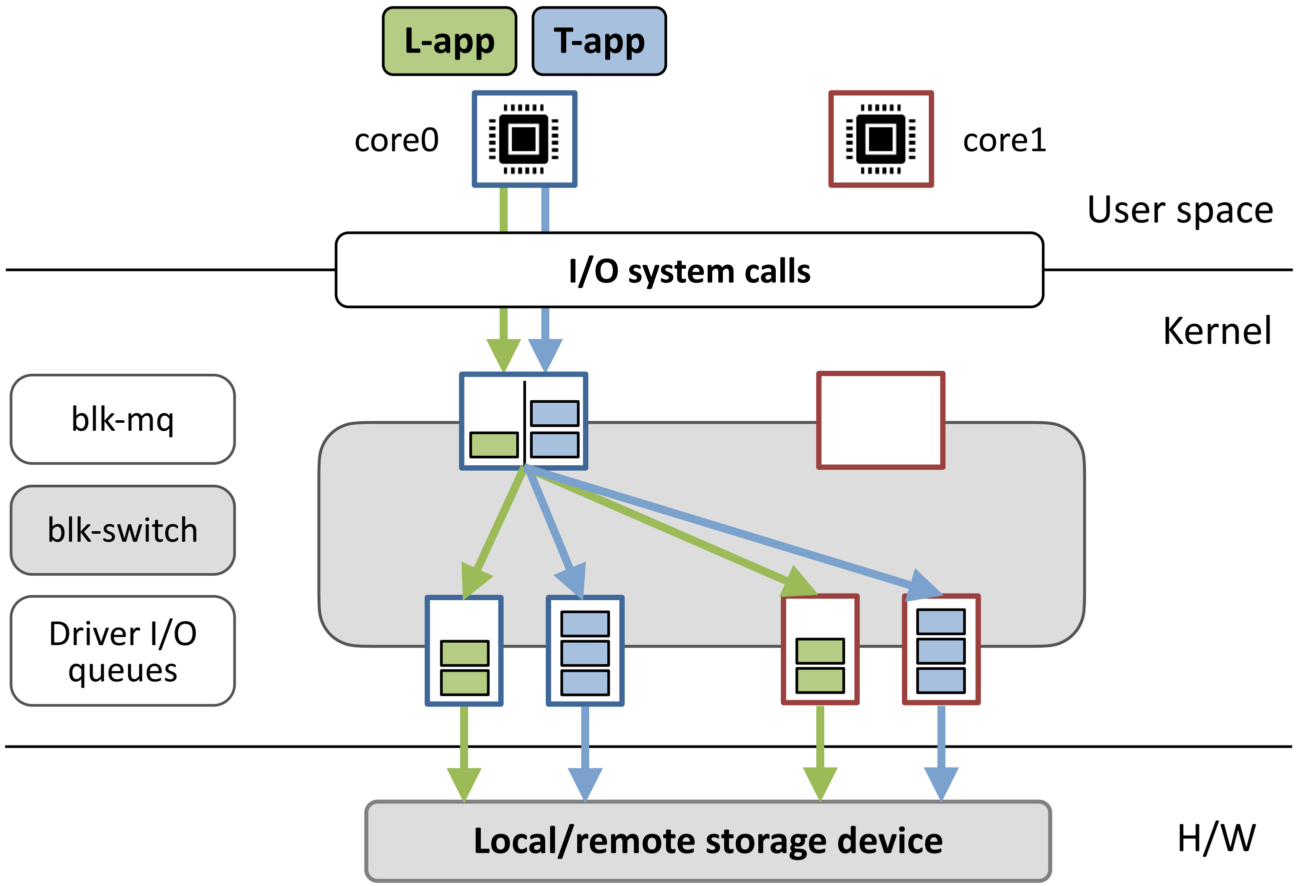

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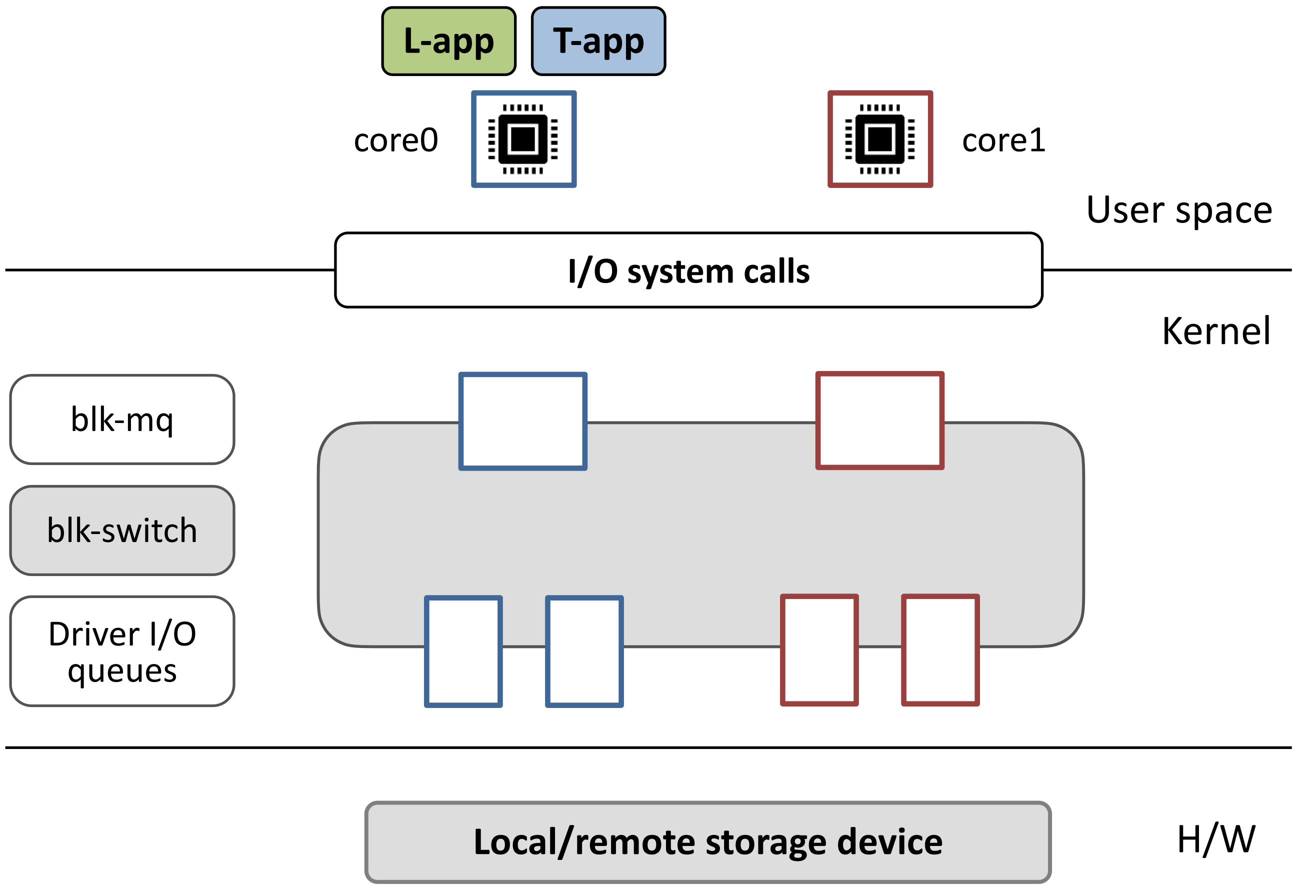
Decoupling request processing from application cores: “Static ⇢ Flexible”

blk-switch Prioritization



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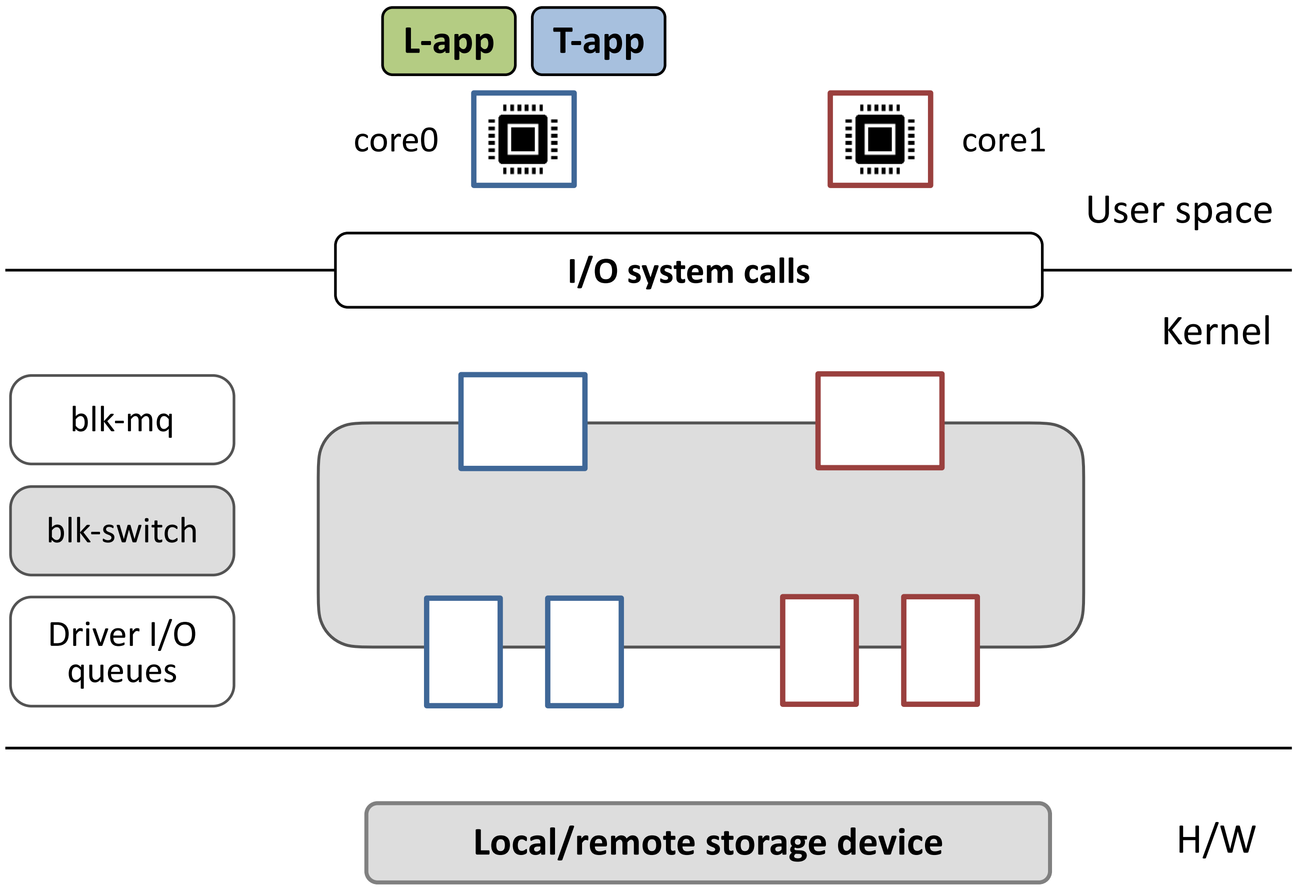

Prioritize **L-app request processing**

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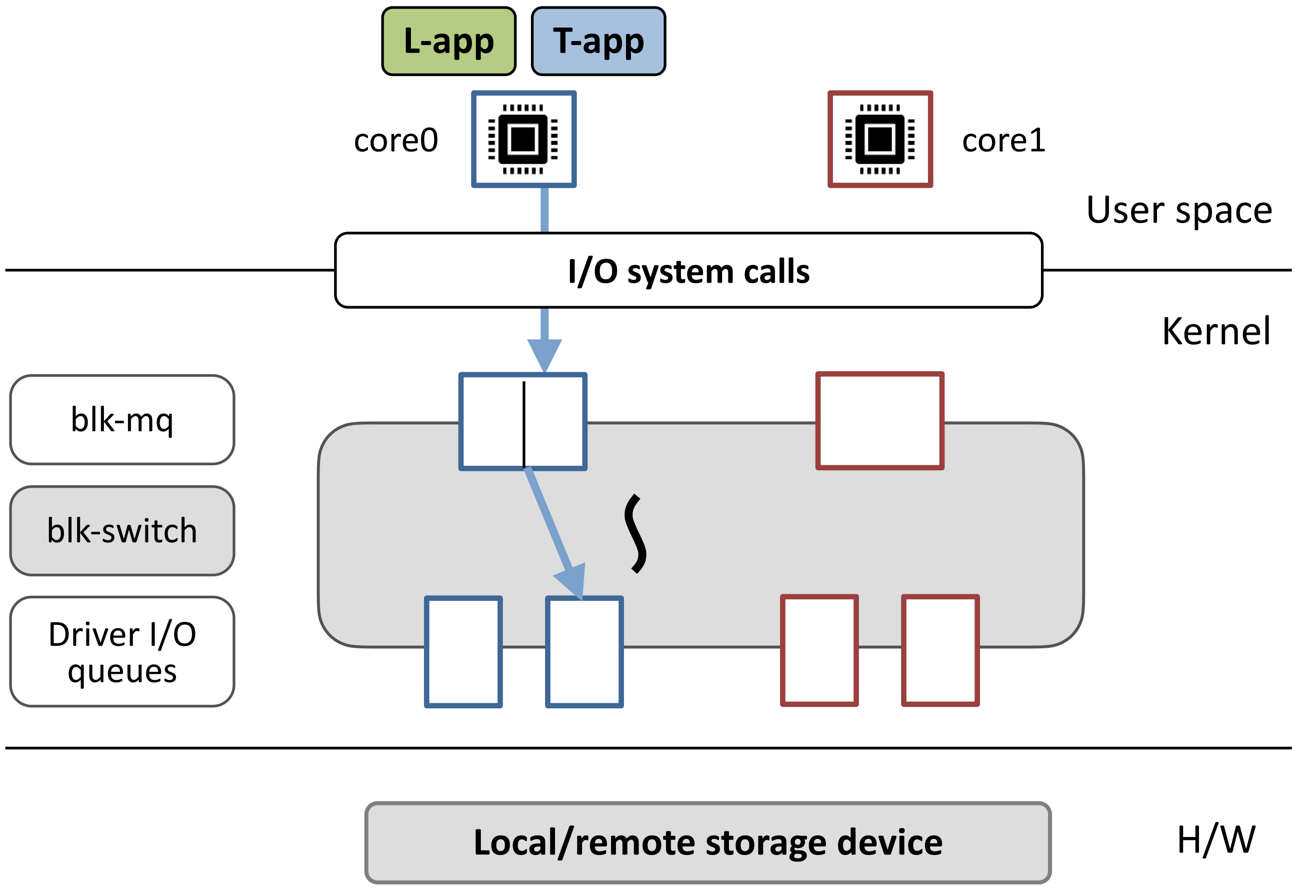

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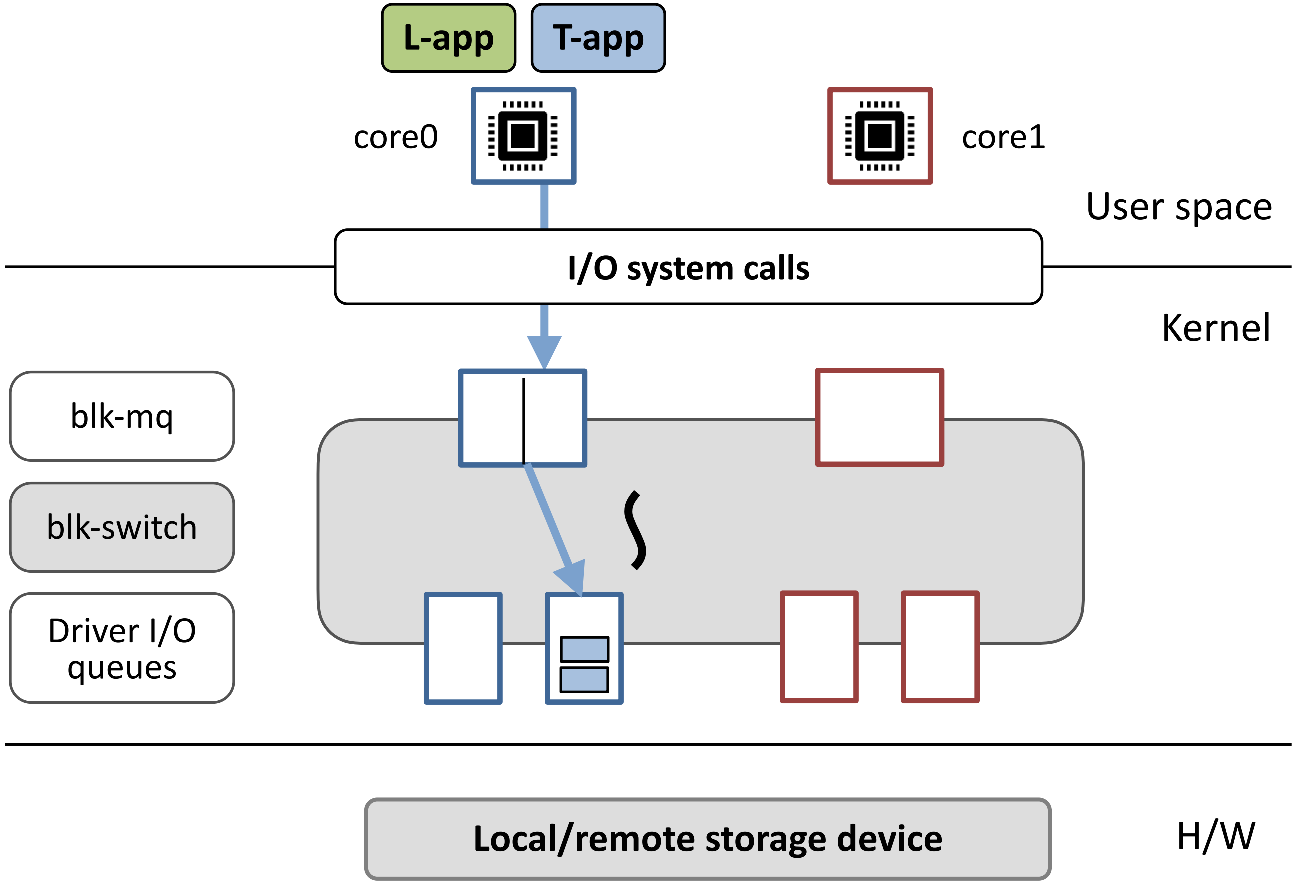

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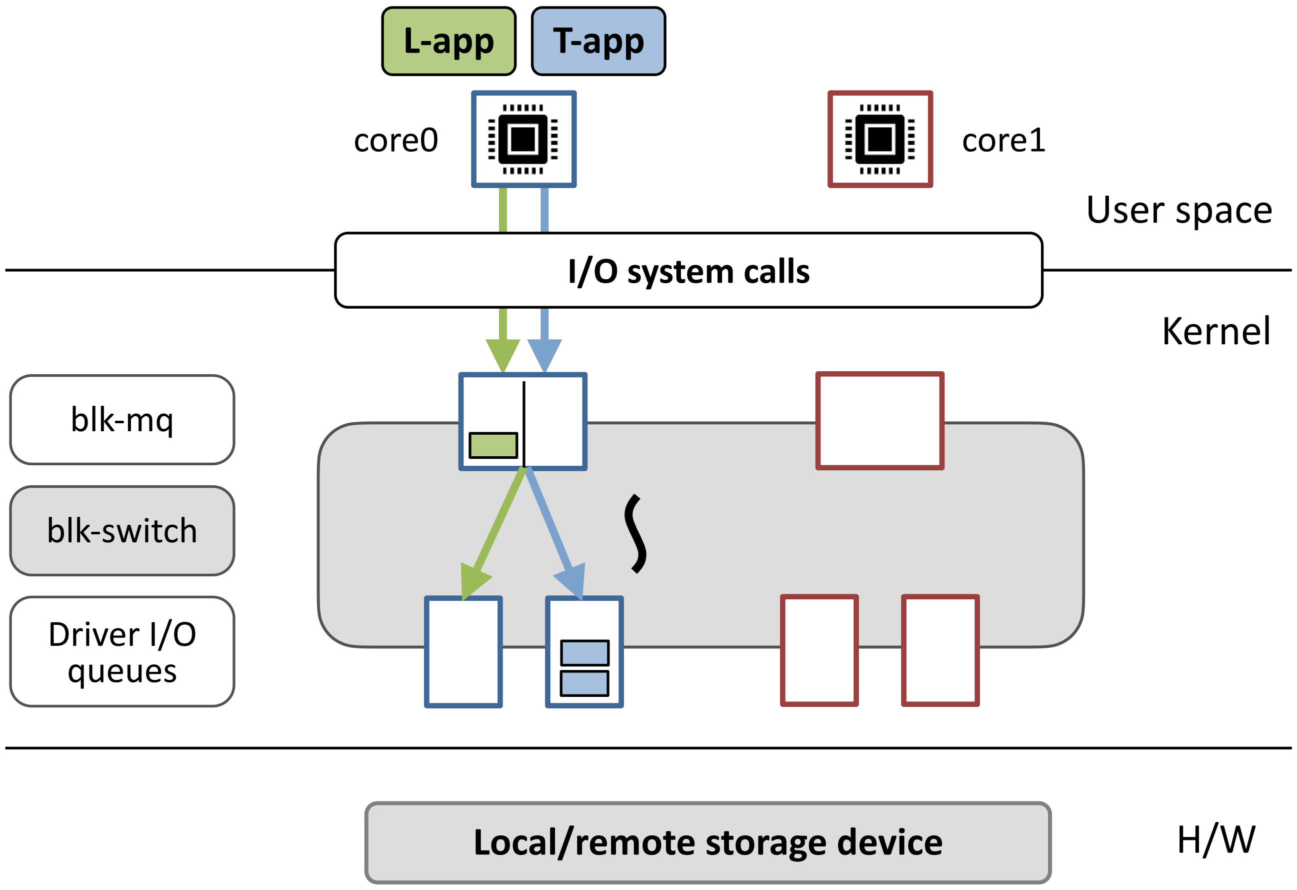

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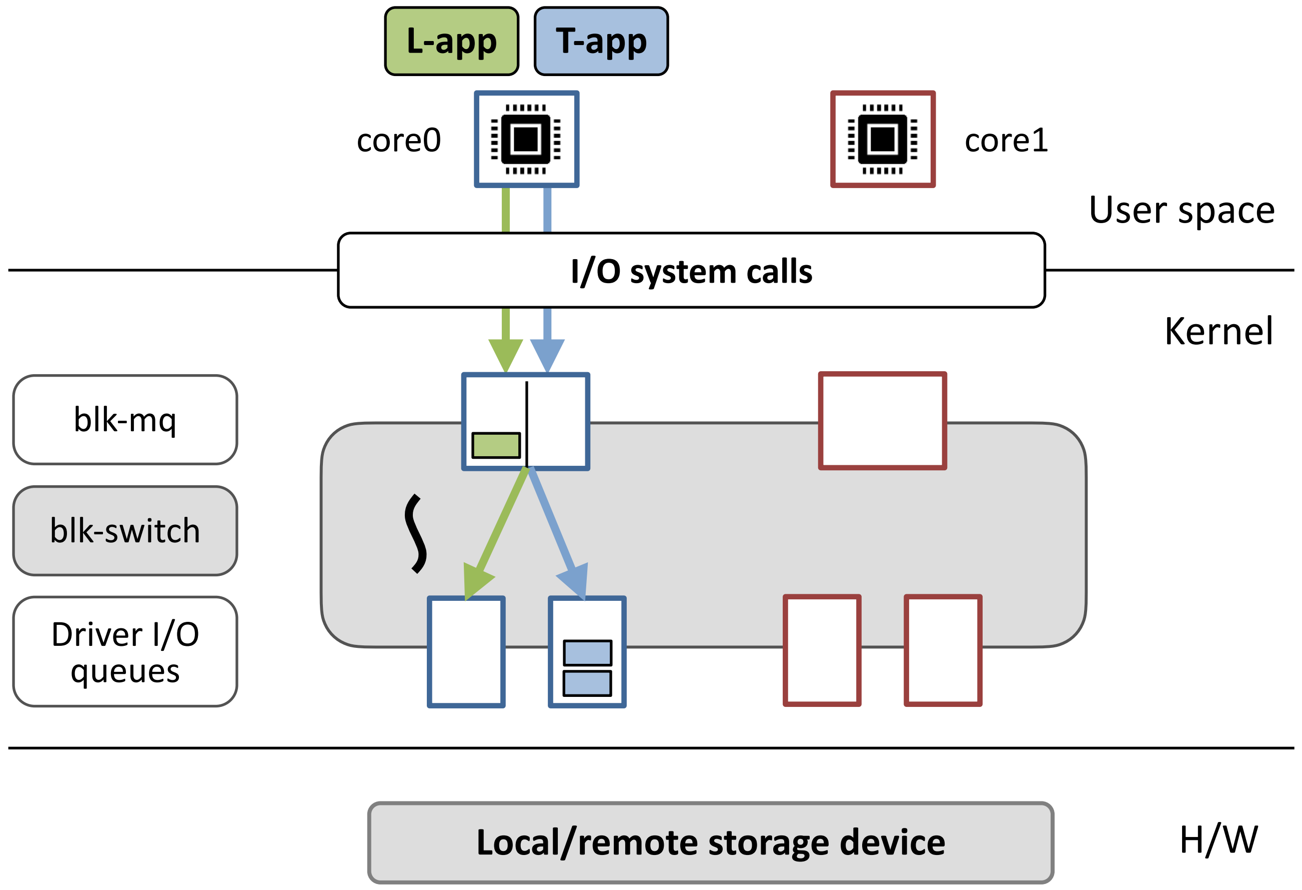

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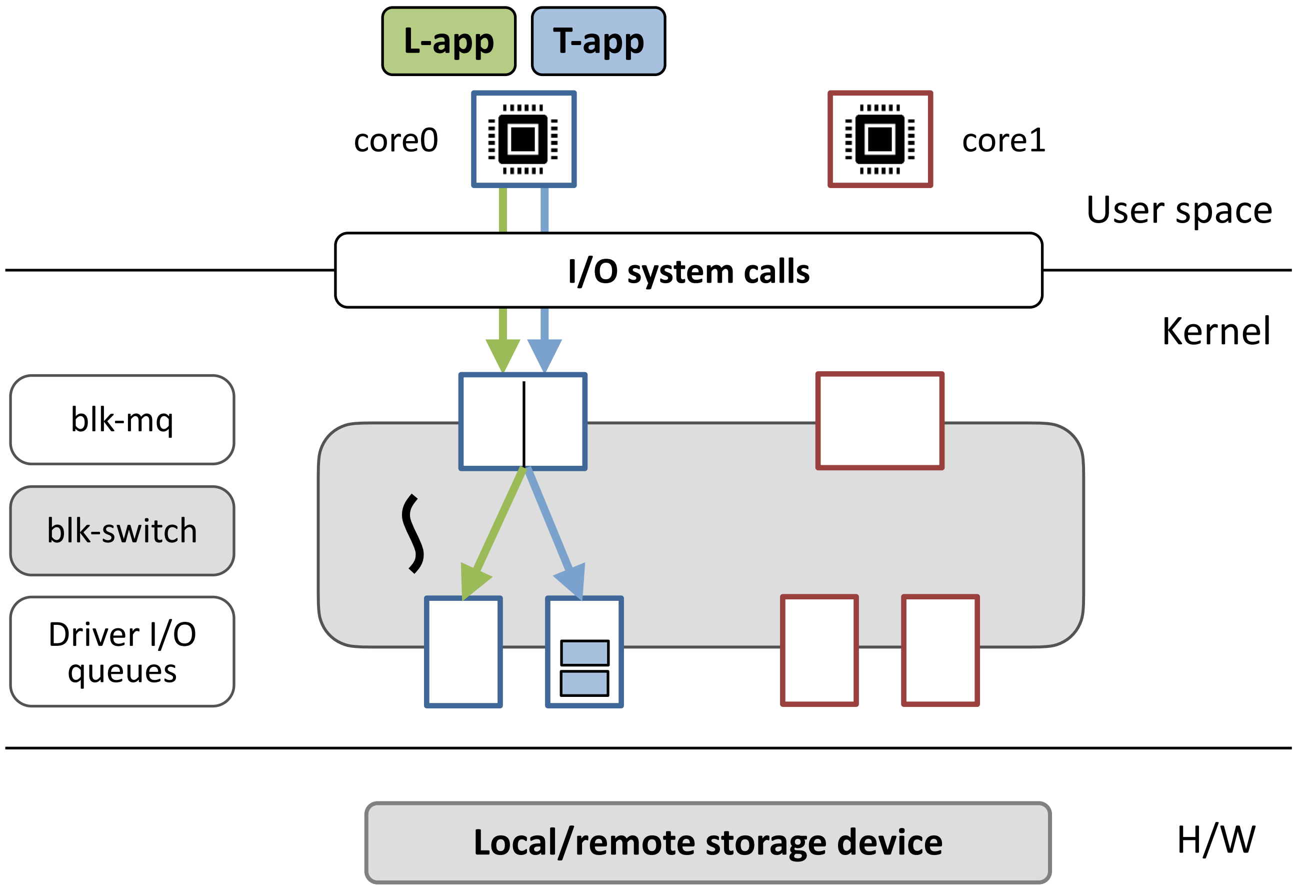

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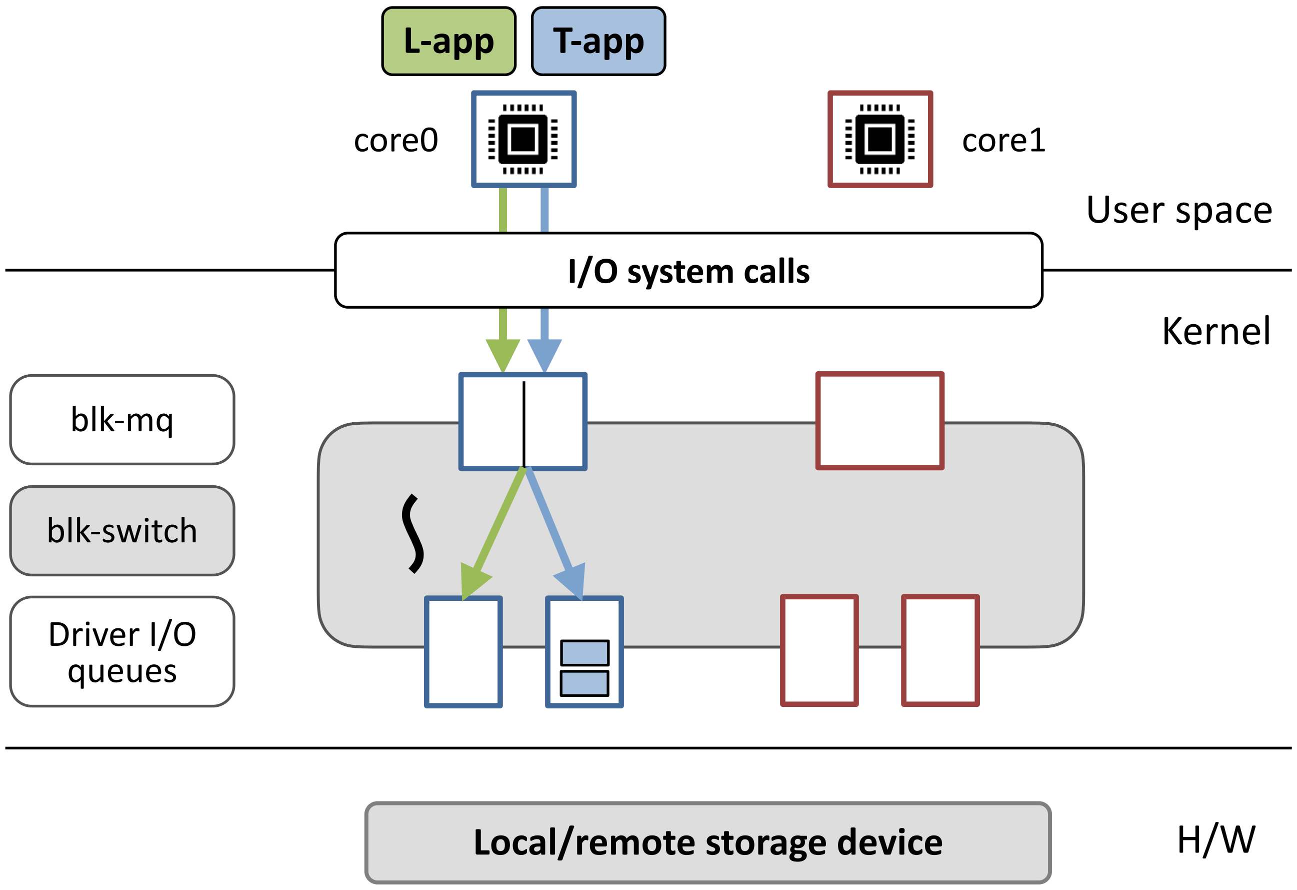

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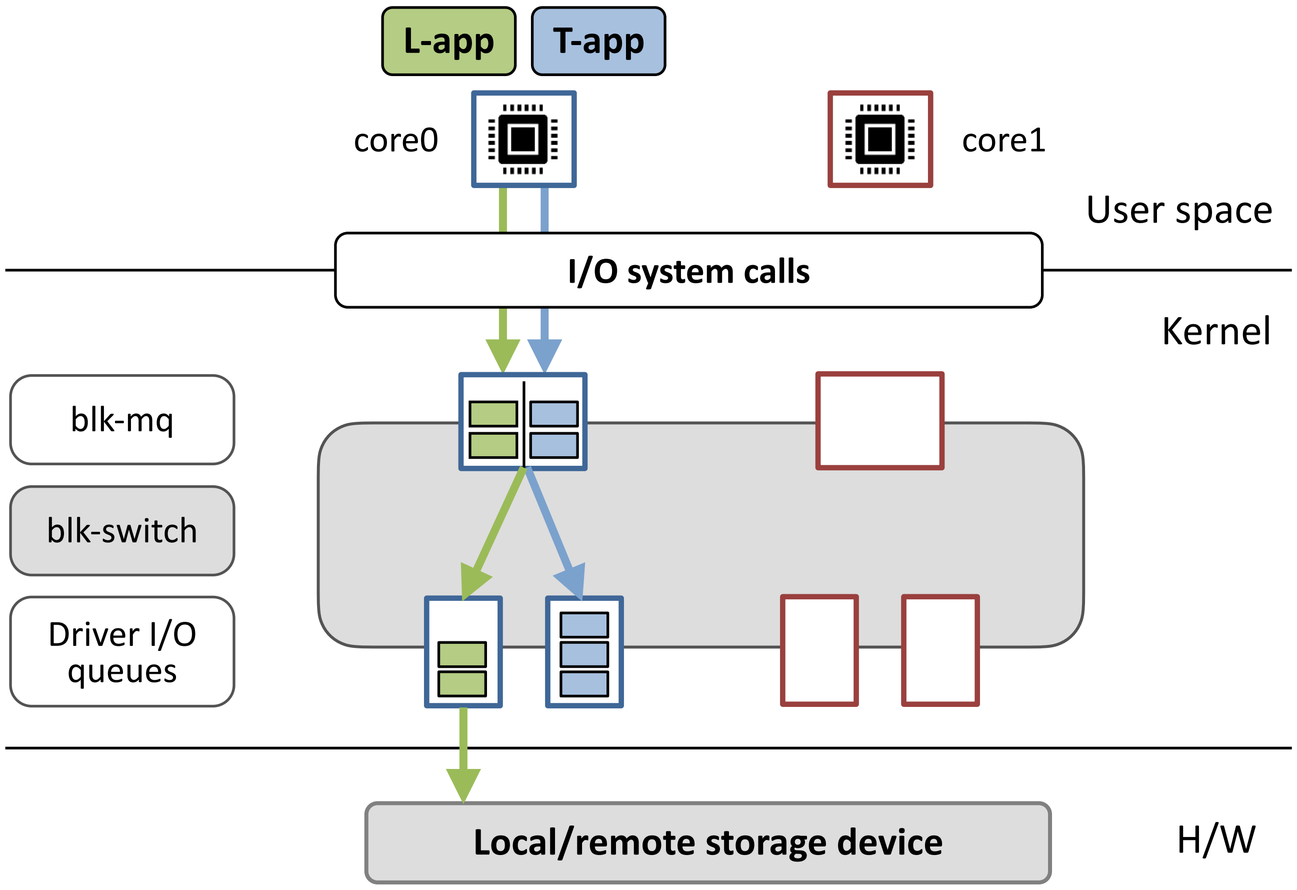
“Multi-egress queues + prioritization”: near optimal latency for L-apps

blk-switch Request Steering for transient loads



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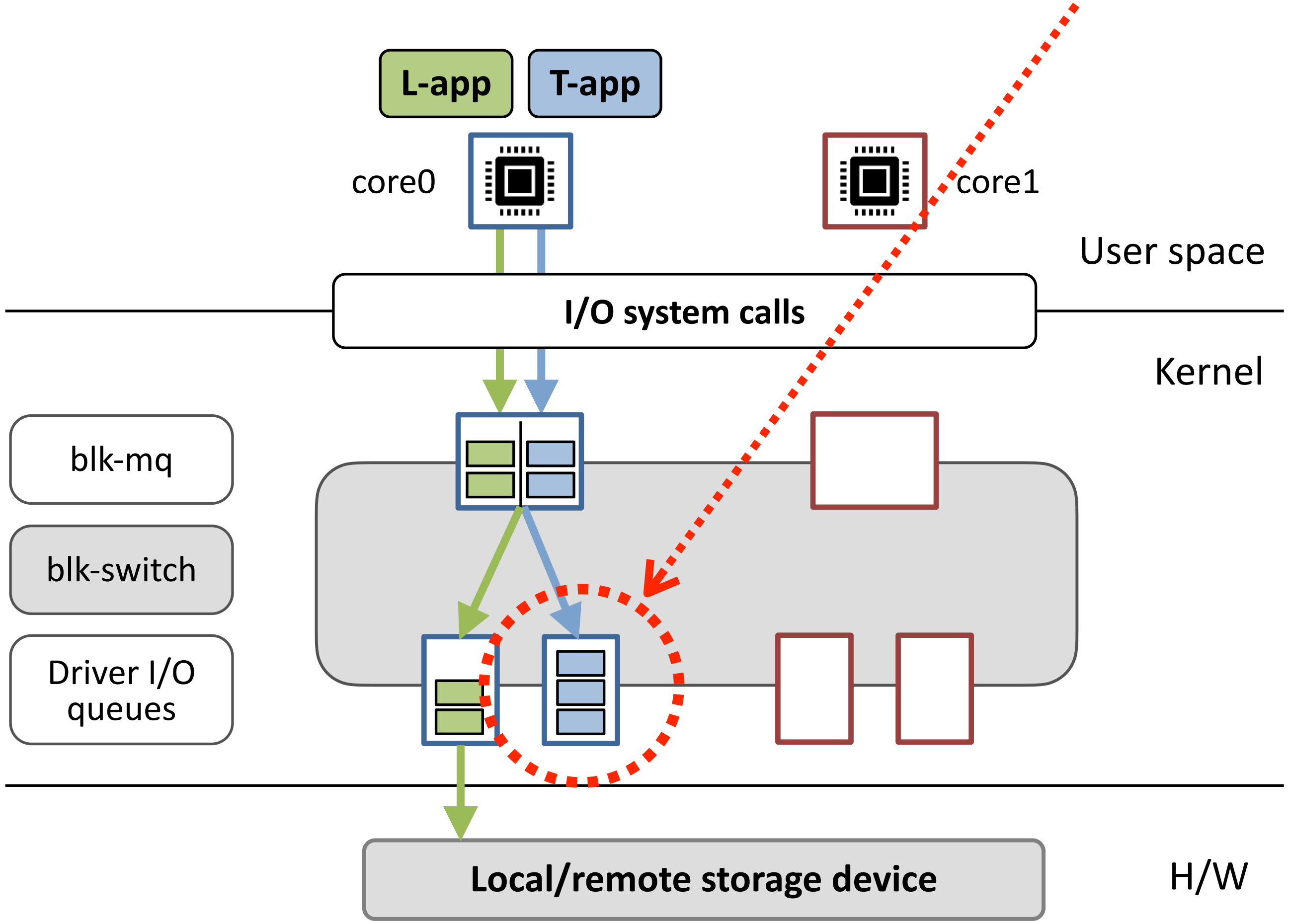

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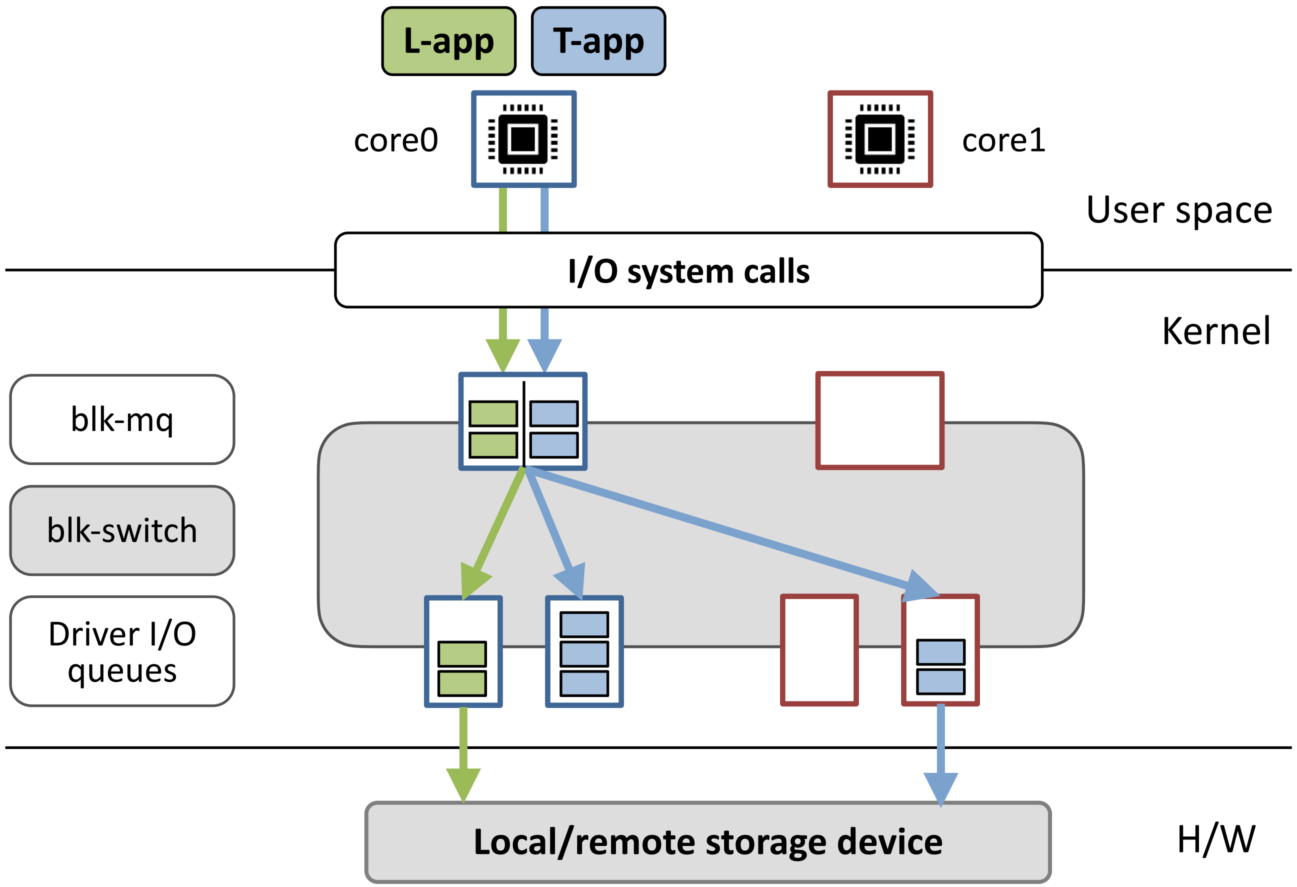

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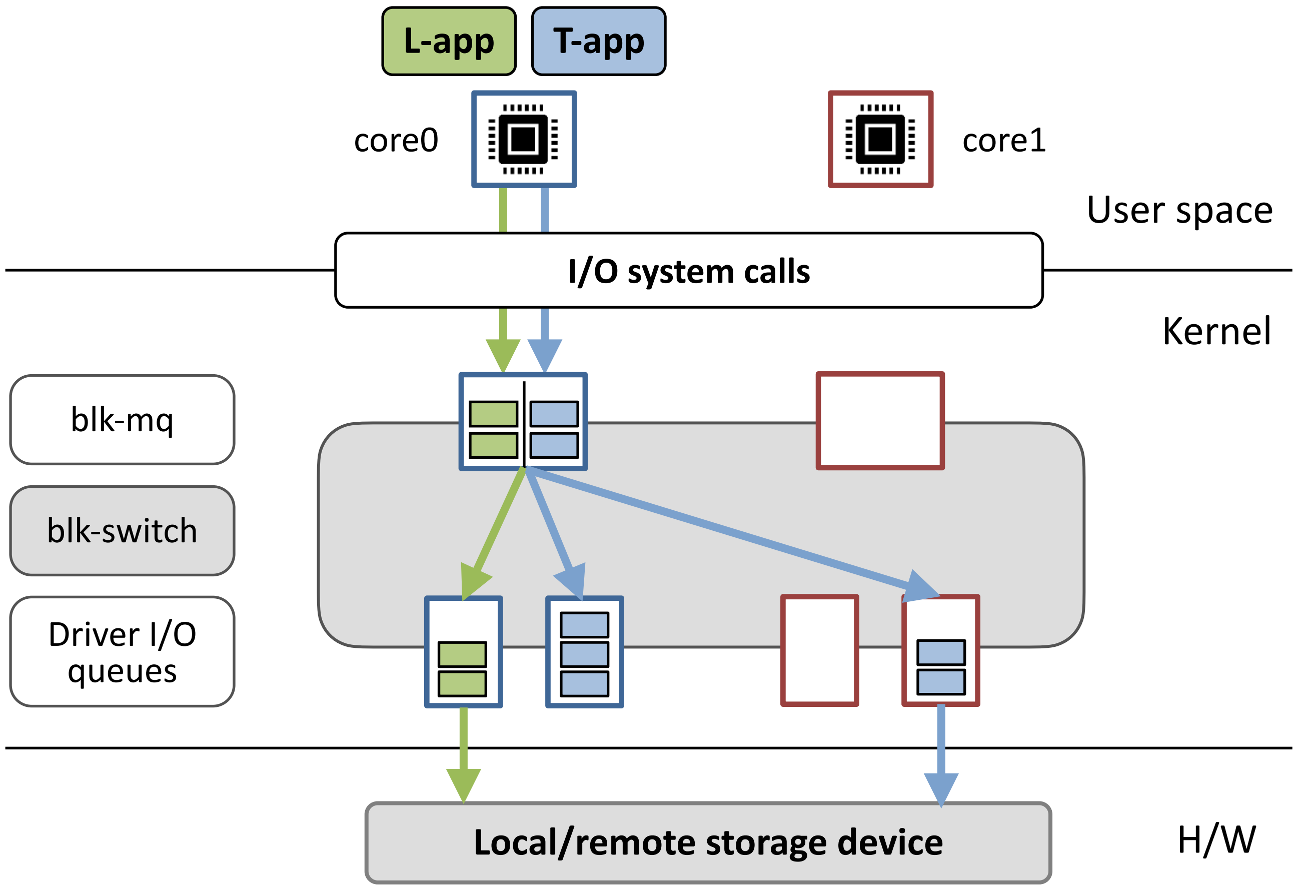

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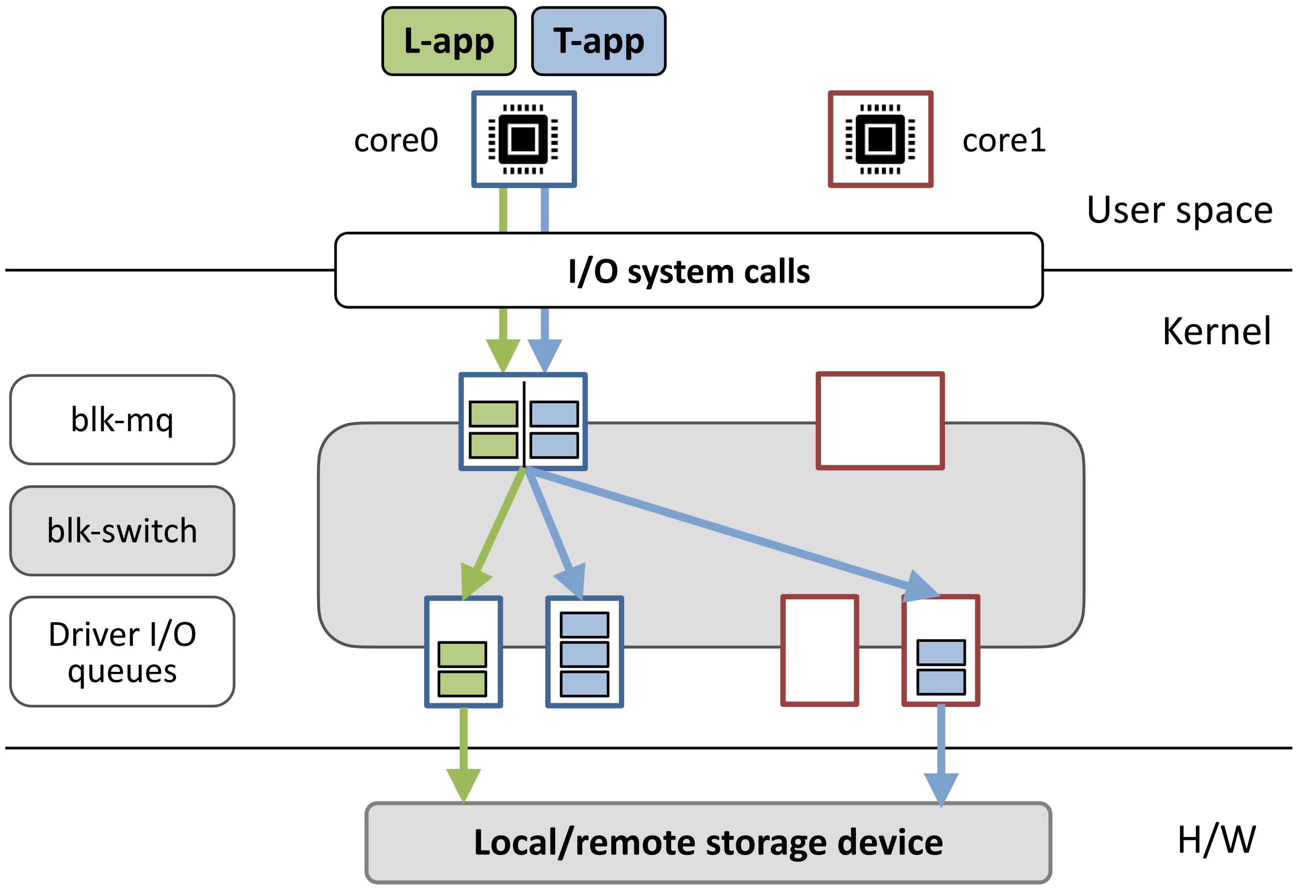

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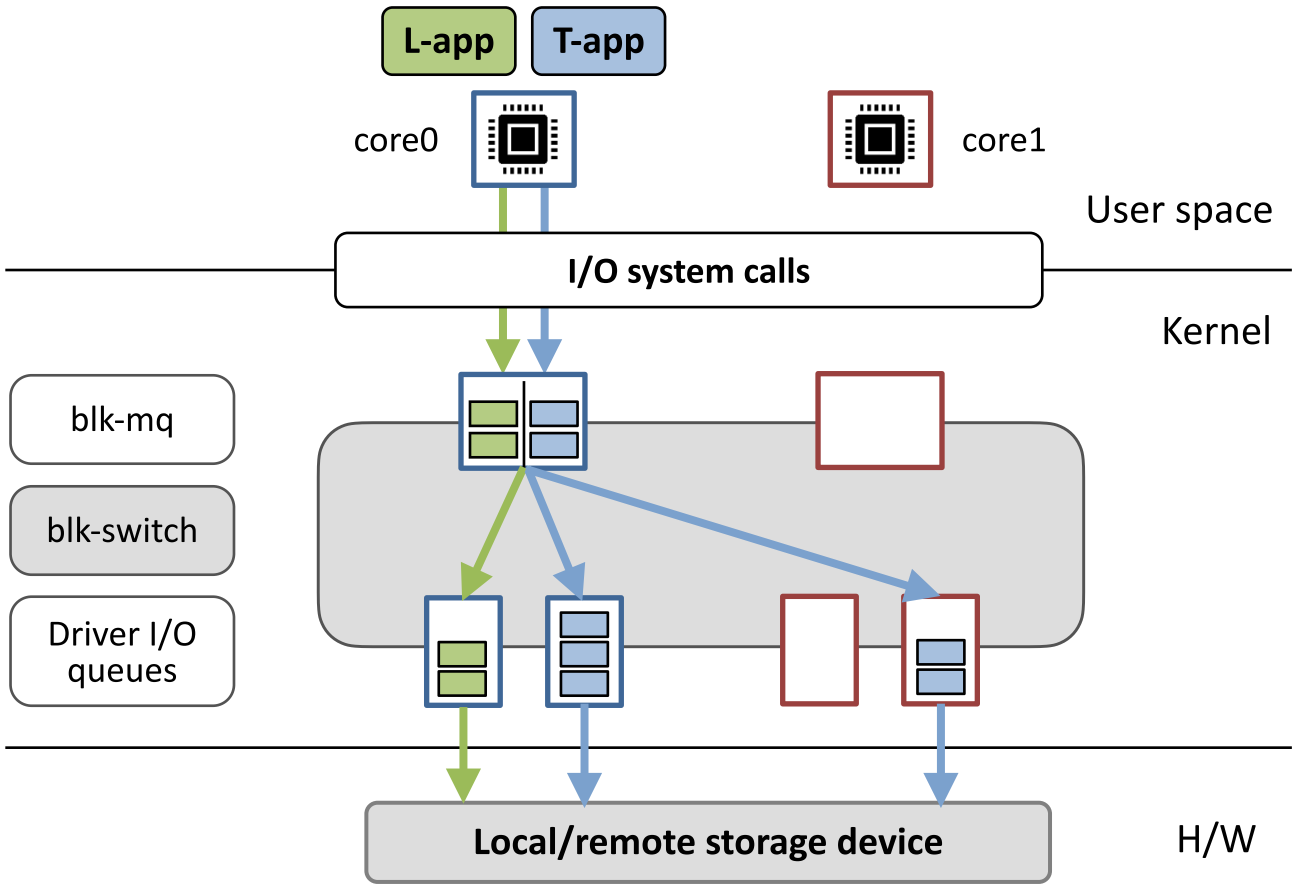
Request steering allows blk-switch to maintain high throughput, even under transient loads

blk-switch Application Steering for persistent loads



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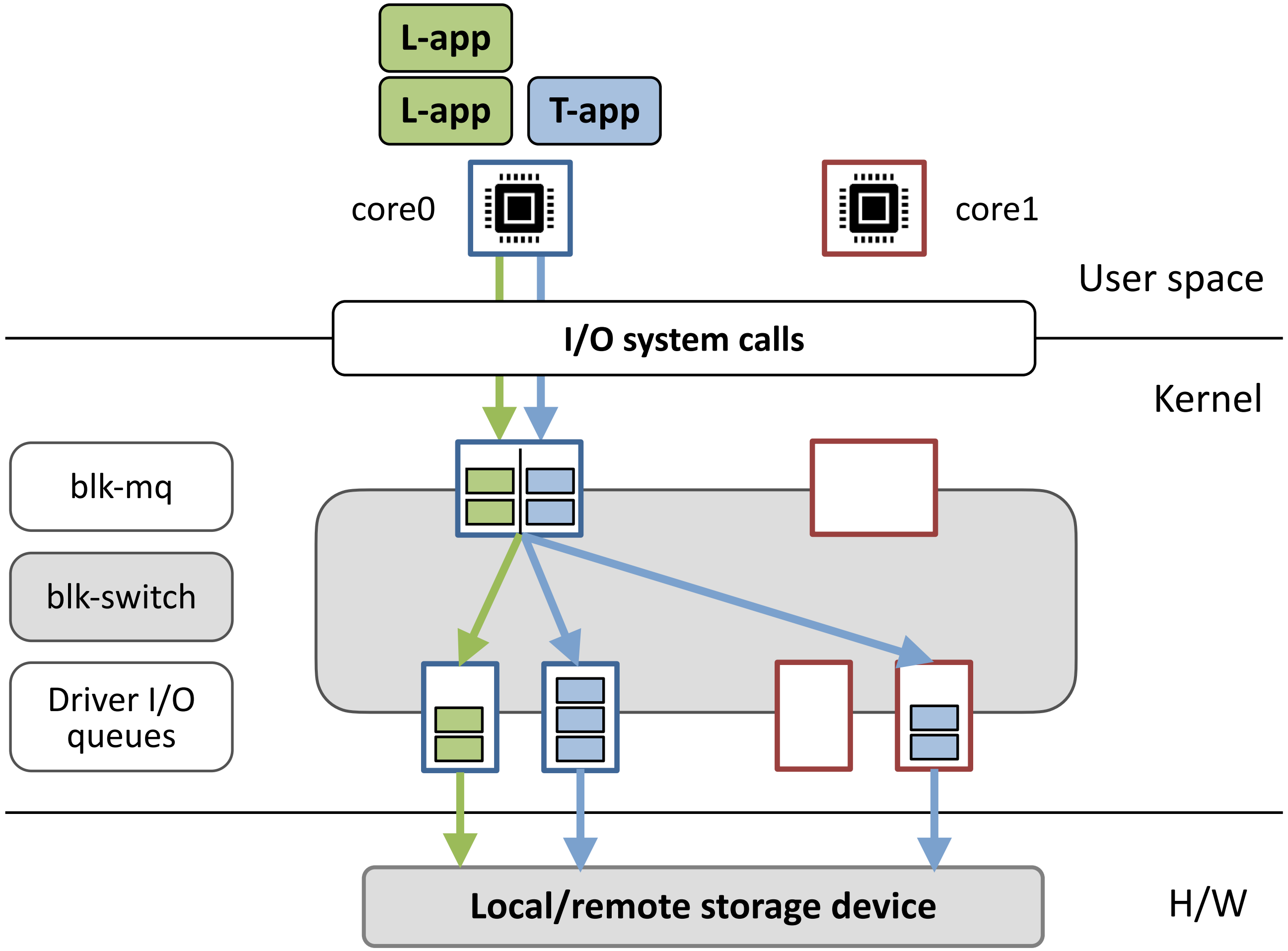

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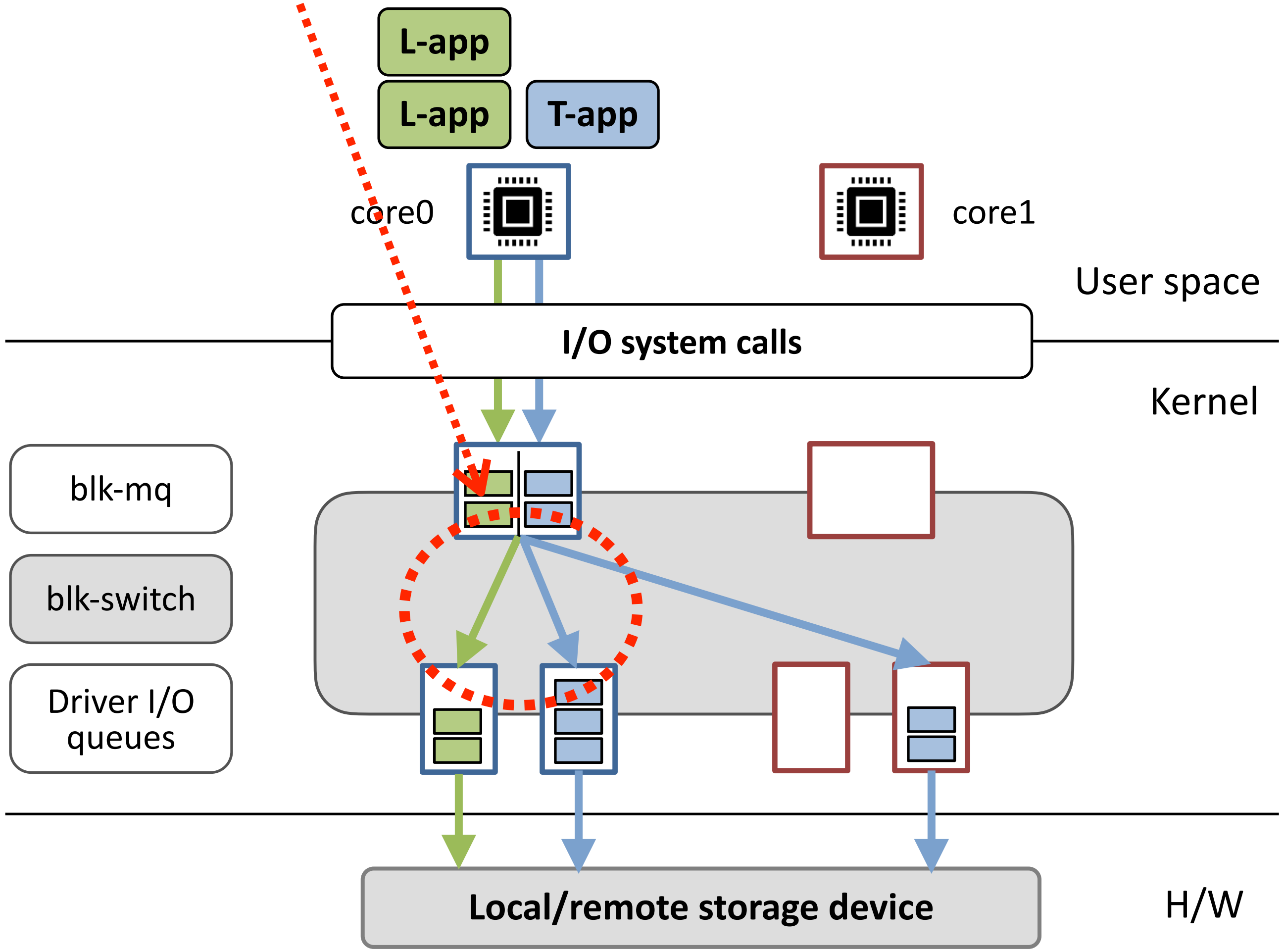

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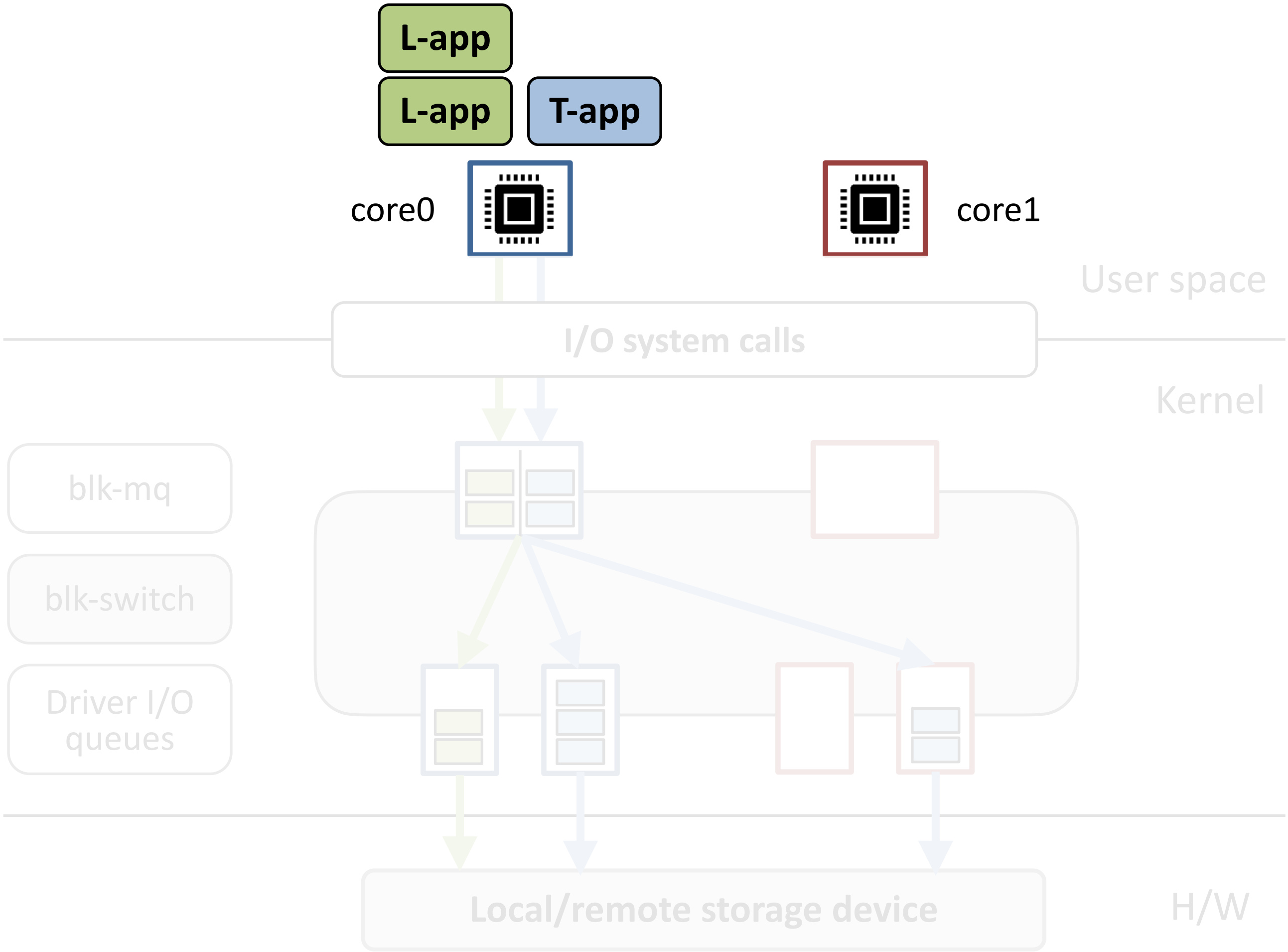

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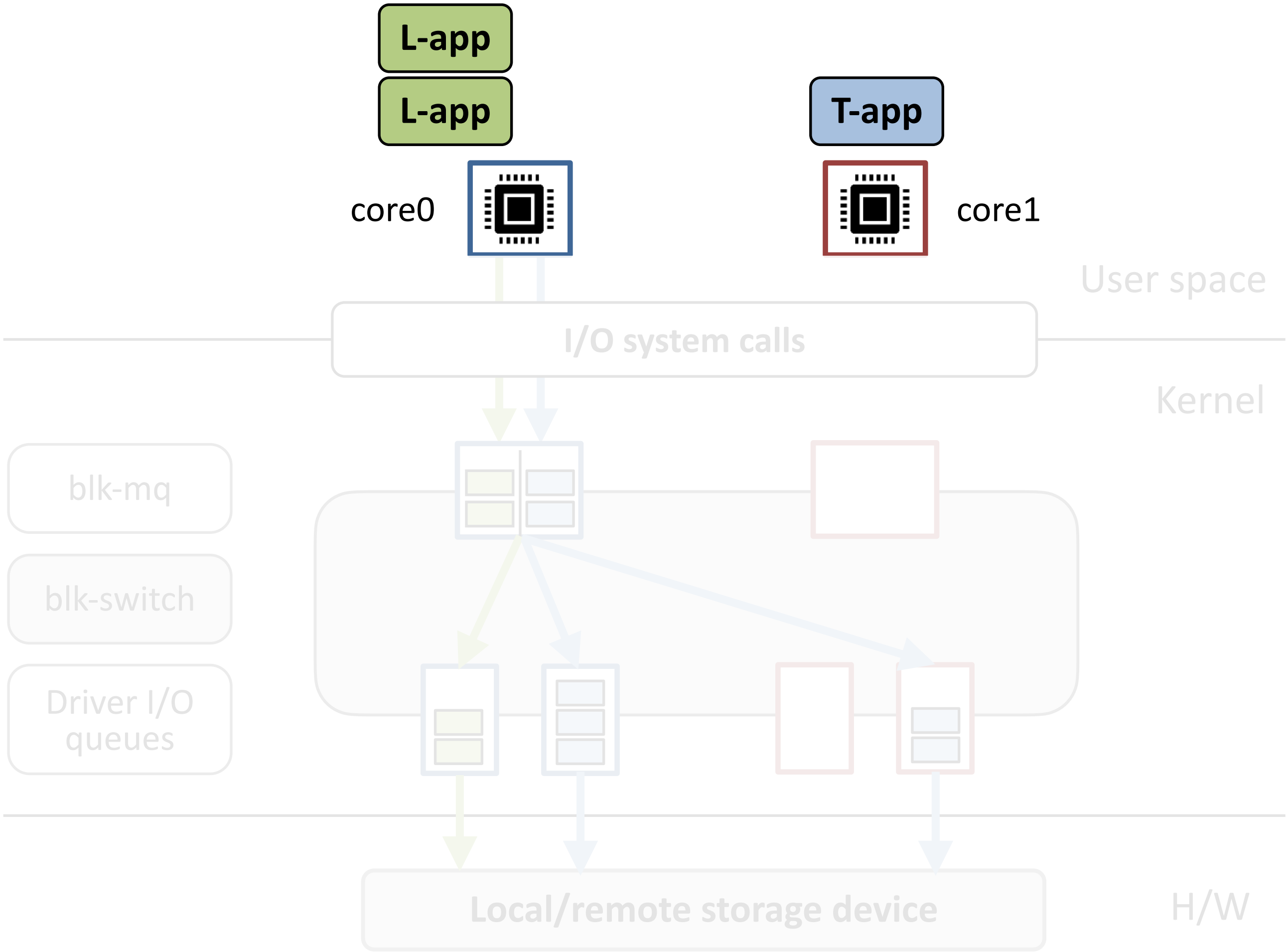

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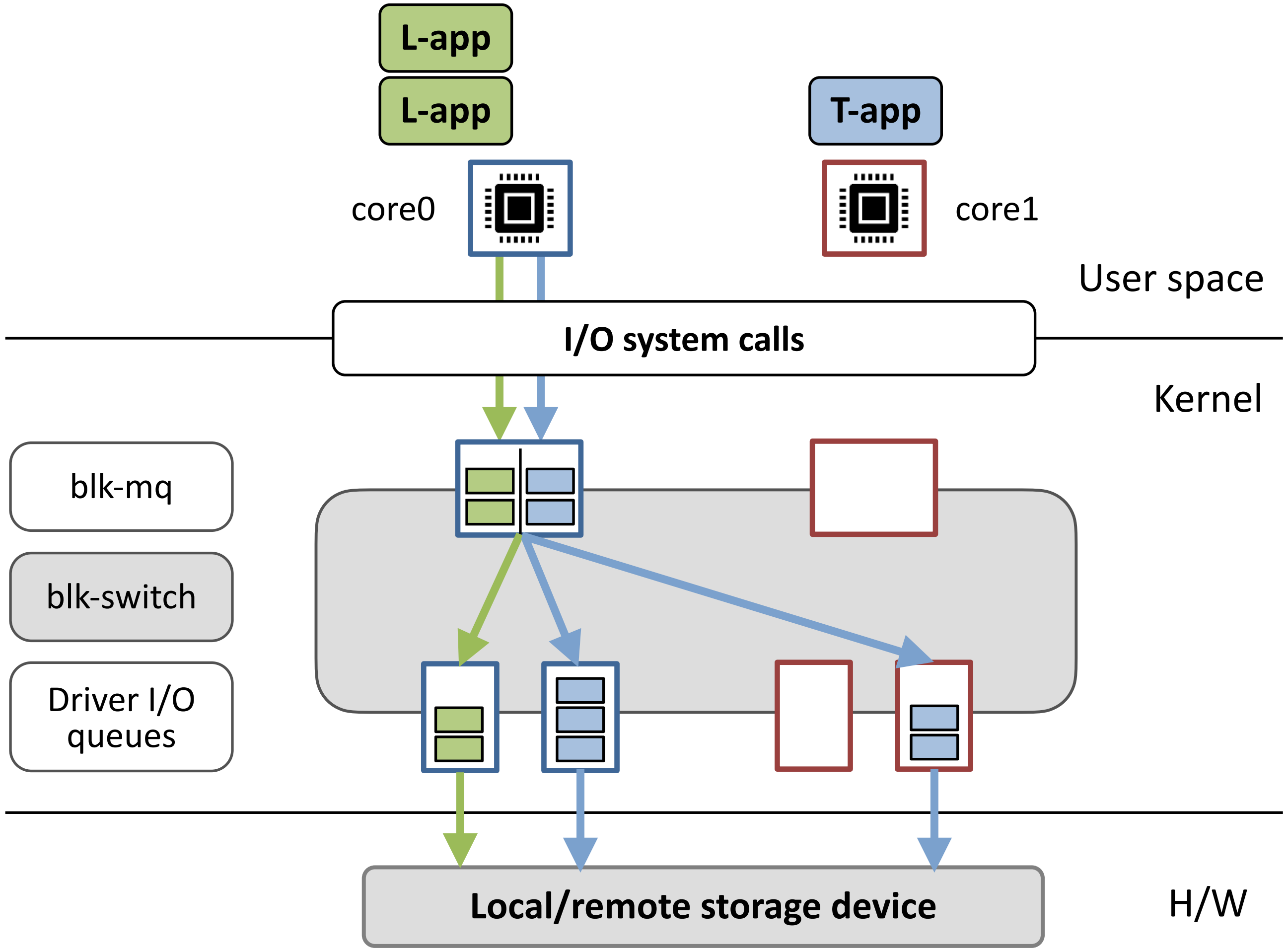

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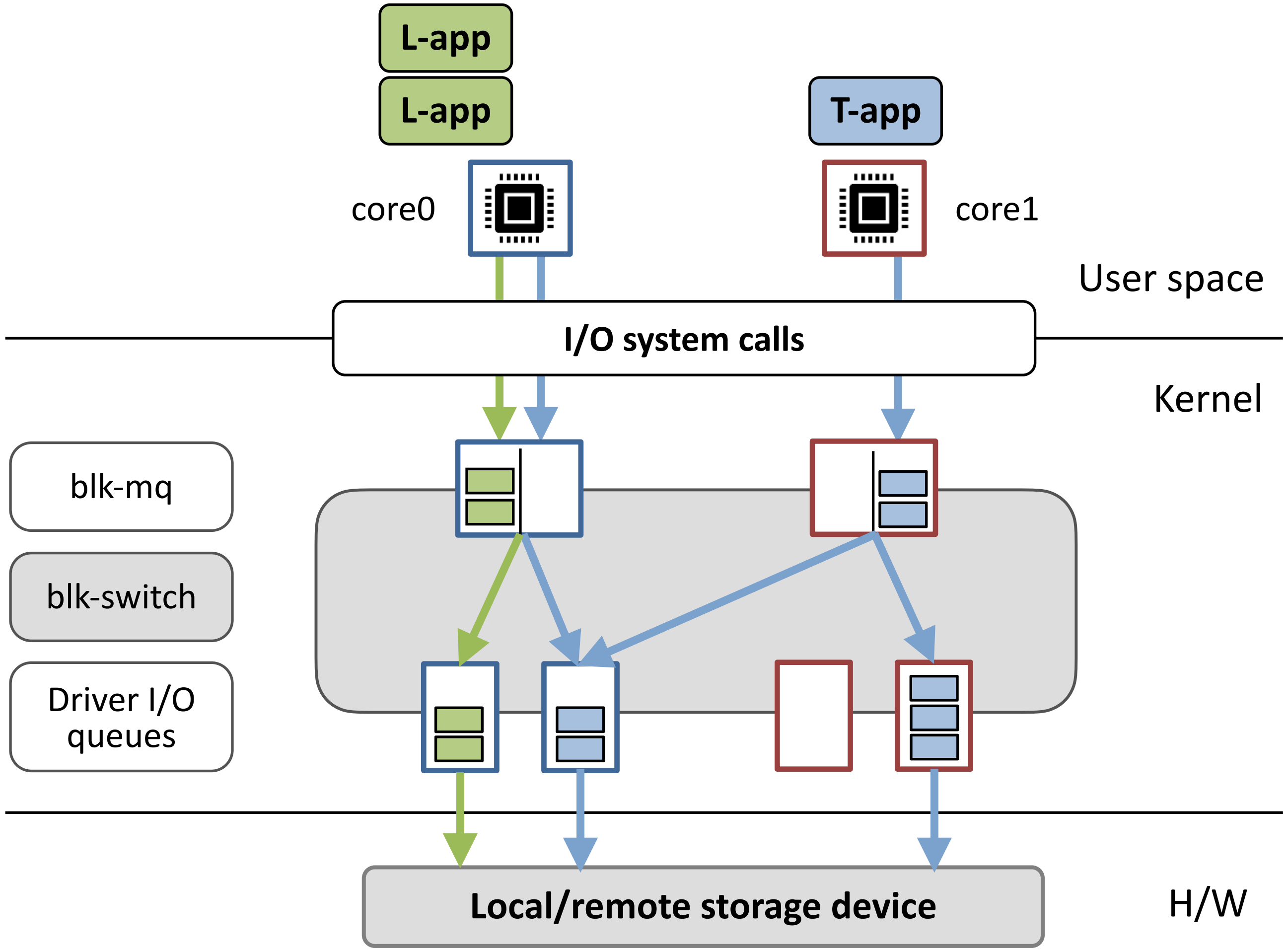

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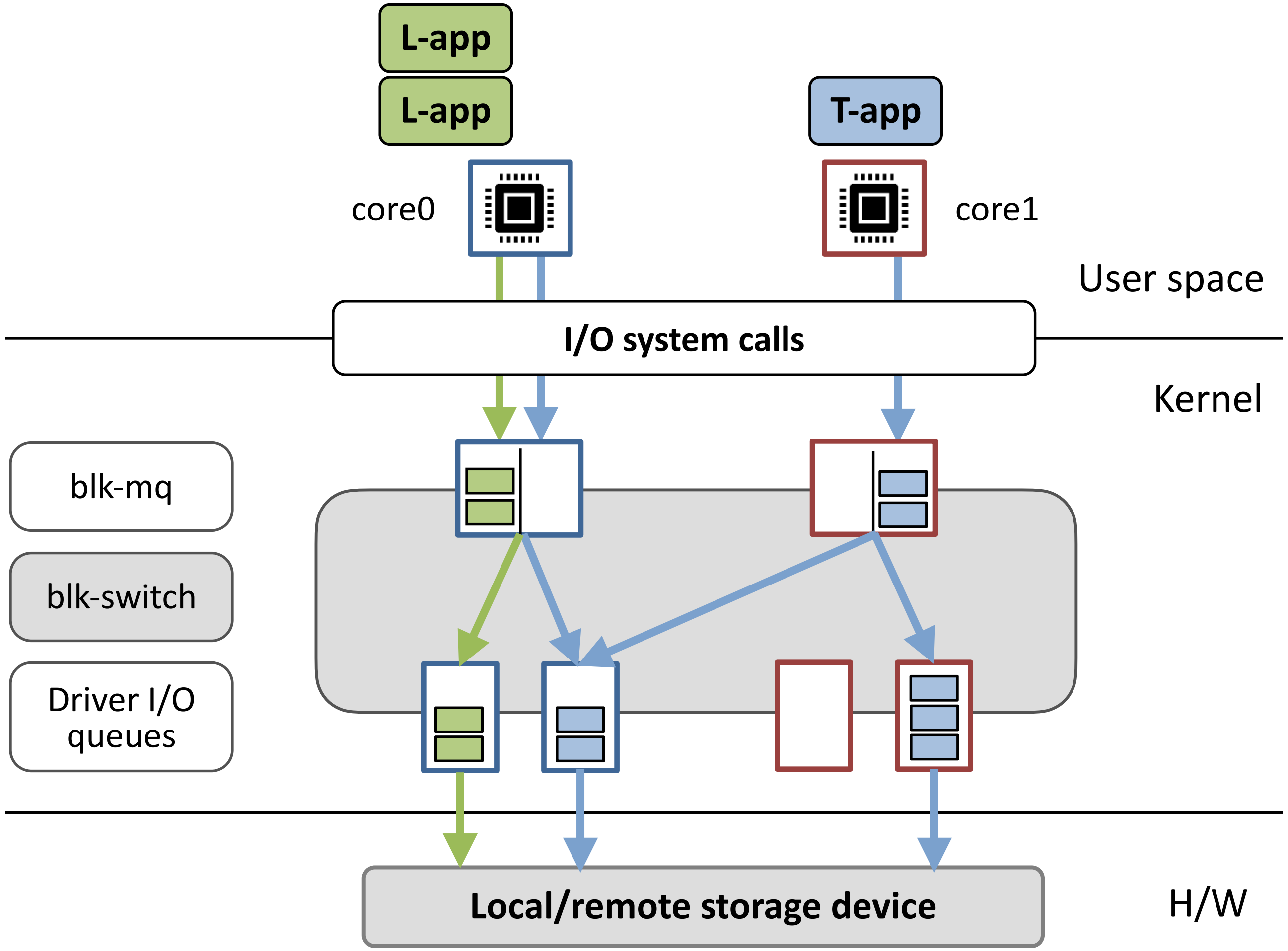

Steer **apps to cores with low average utilization**

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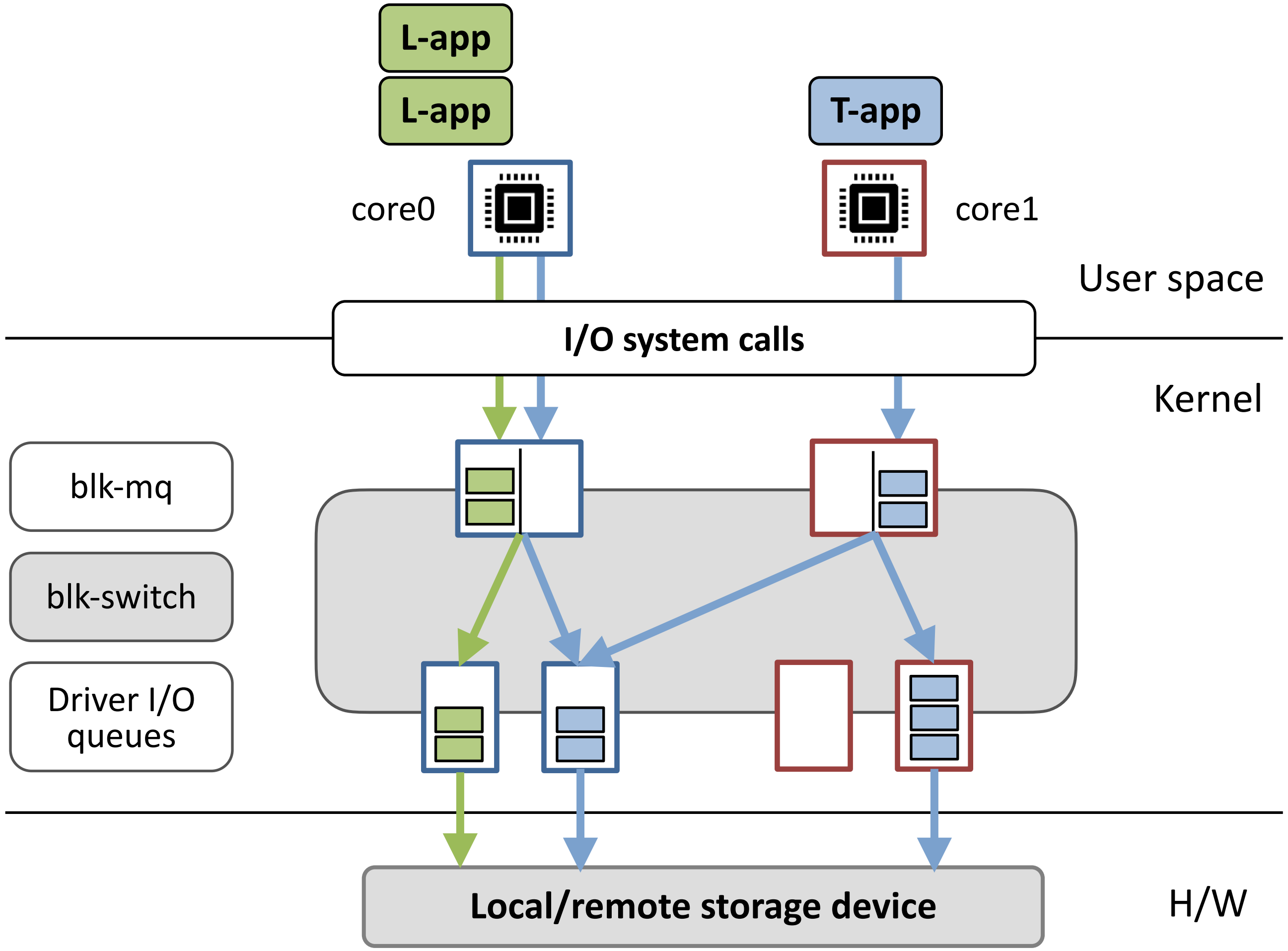

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- **High throughput for T-apps even under persistent loads**
- **Even lower latency for L-apps due to fewer context-switches**

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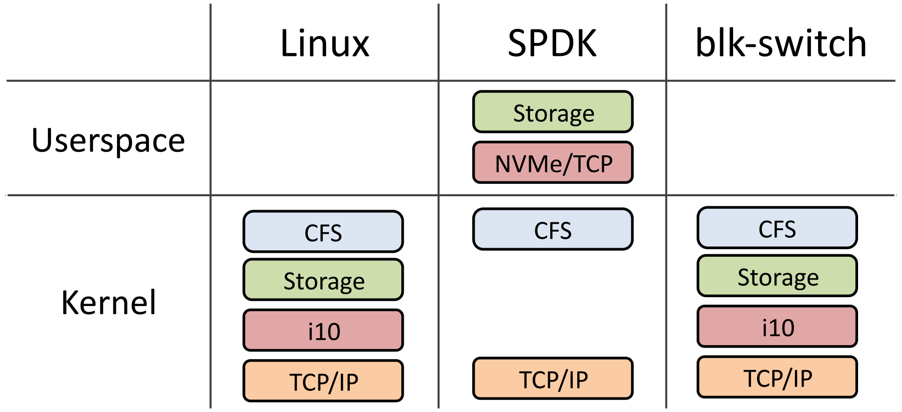
- **To access data on remote servers**
  - Linux/blk-switch use i10 (state-of-the-art remote I/O stack, NSDI’20)
  - SPDK uses userspace NVMe-over-TCP



High Contention Scenario (In-memory)

Configurations:
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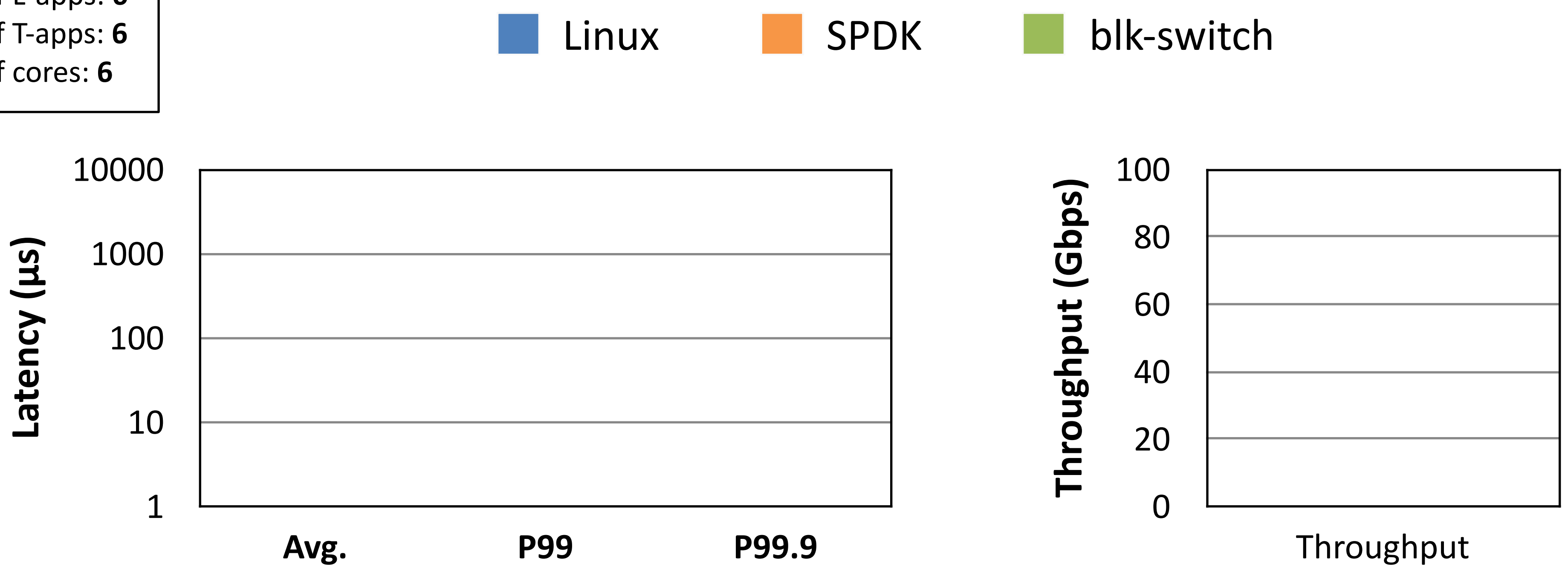

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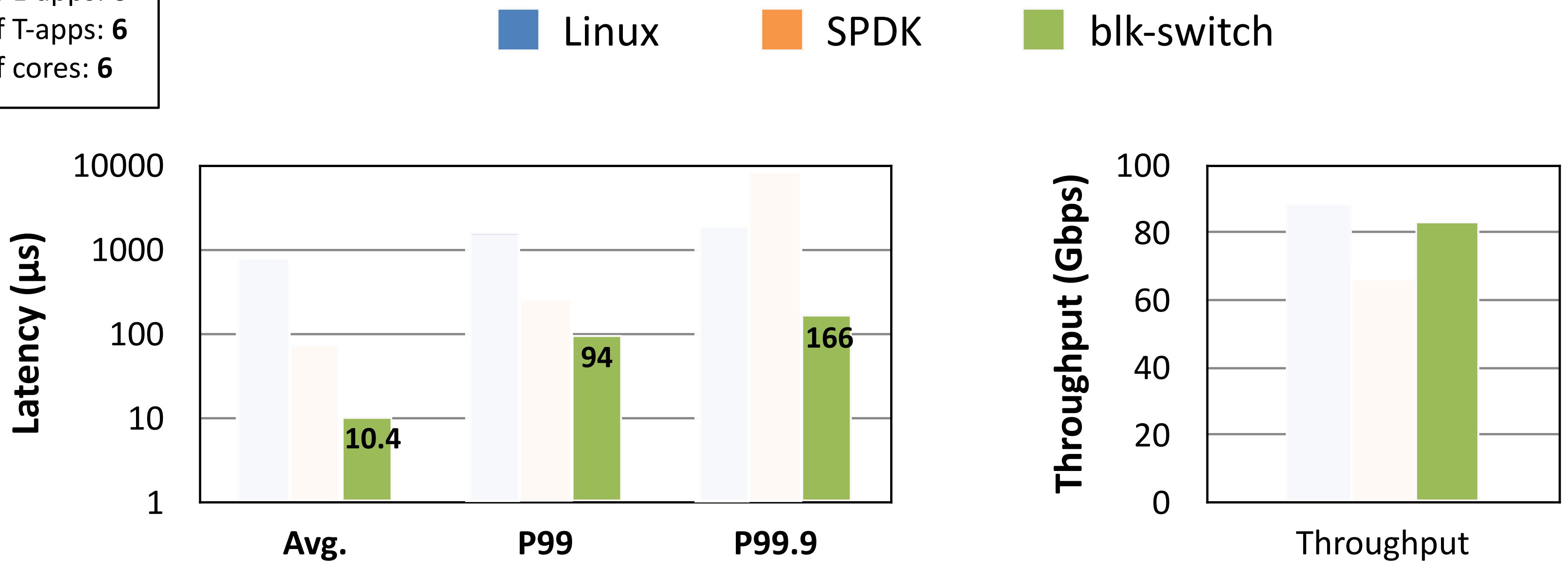

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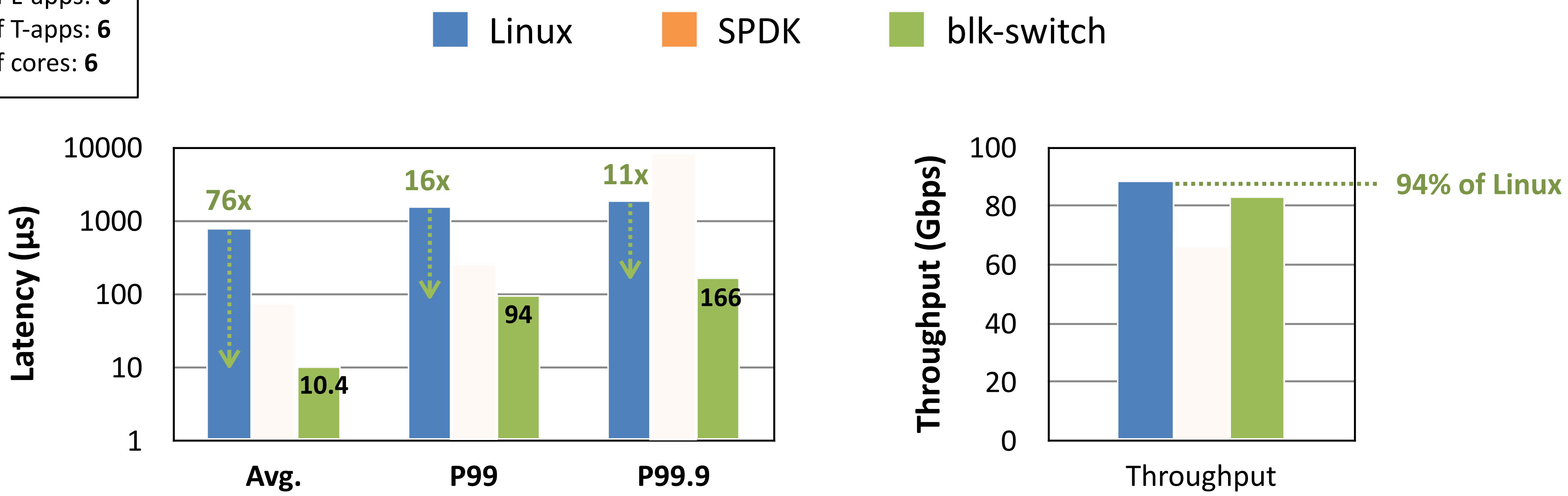

vs. Linux: low latency by avoiding HoL and high throughput by efficiently using multiple cores

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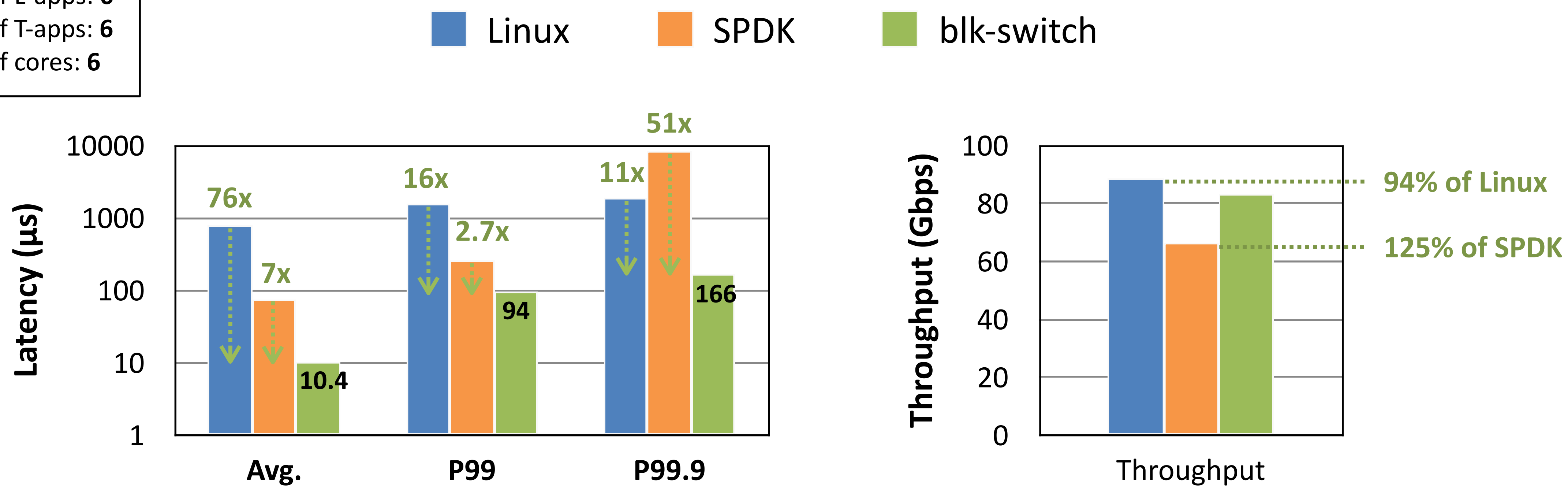

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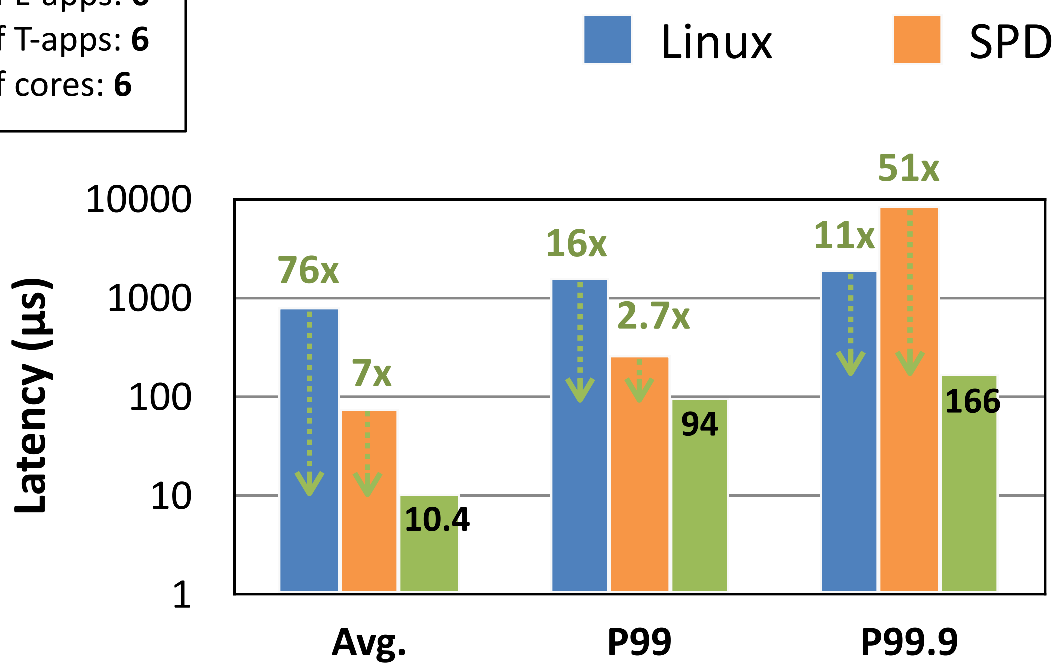

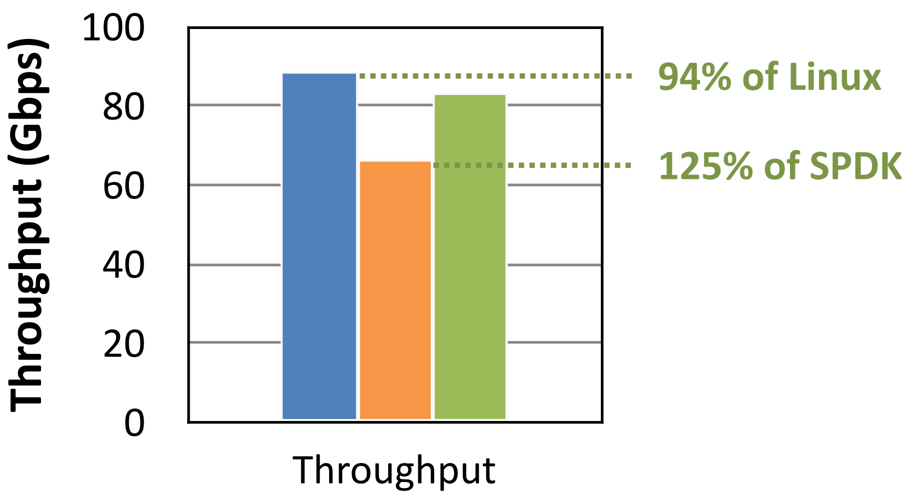

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Even with tens of applications contending for host resources, blk-switch achieves both *µs*-scale latency and high throughput!

blk-switch Performance Breakdown

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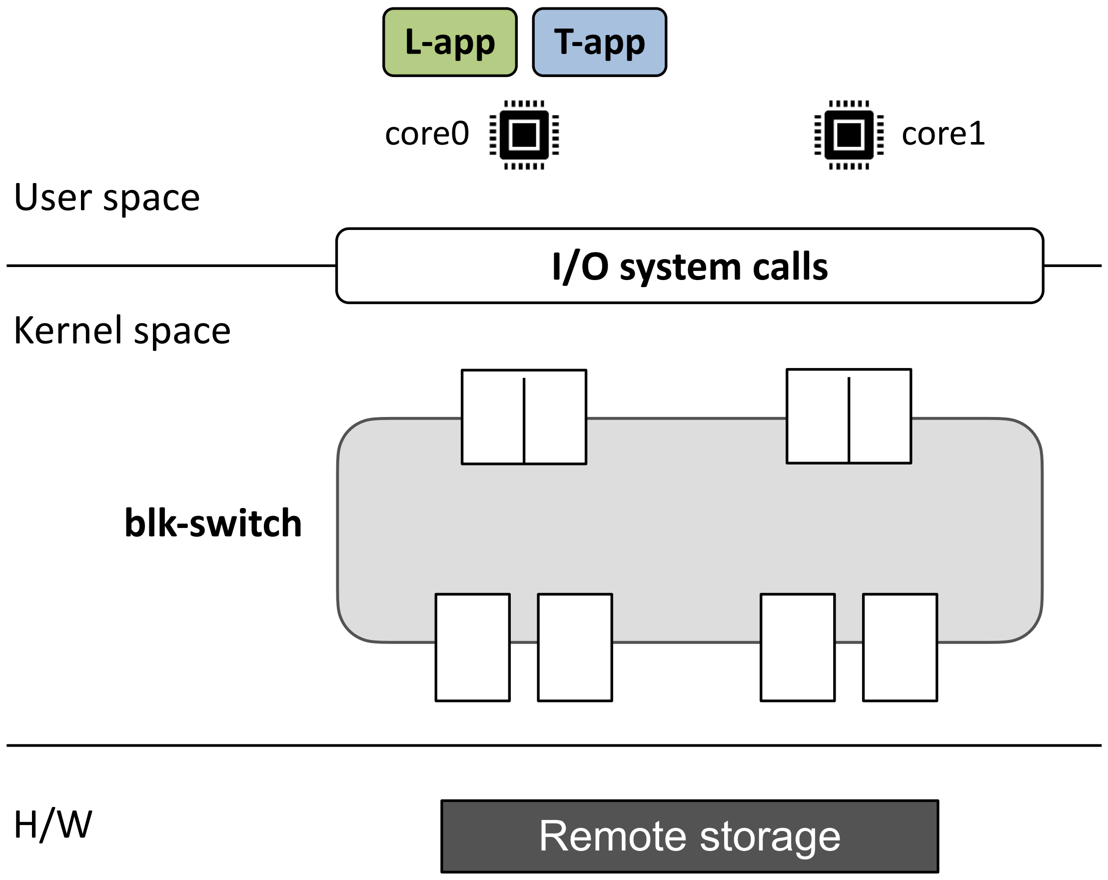

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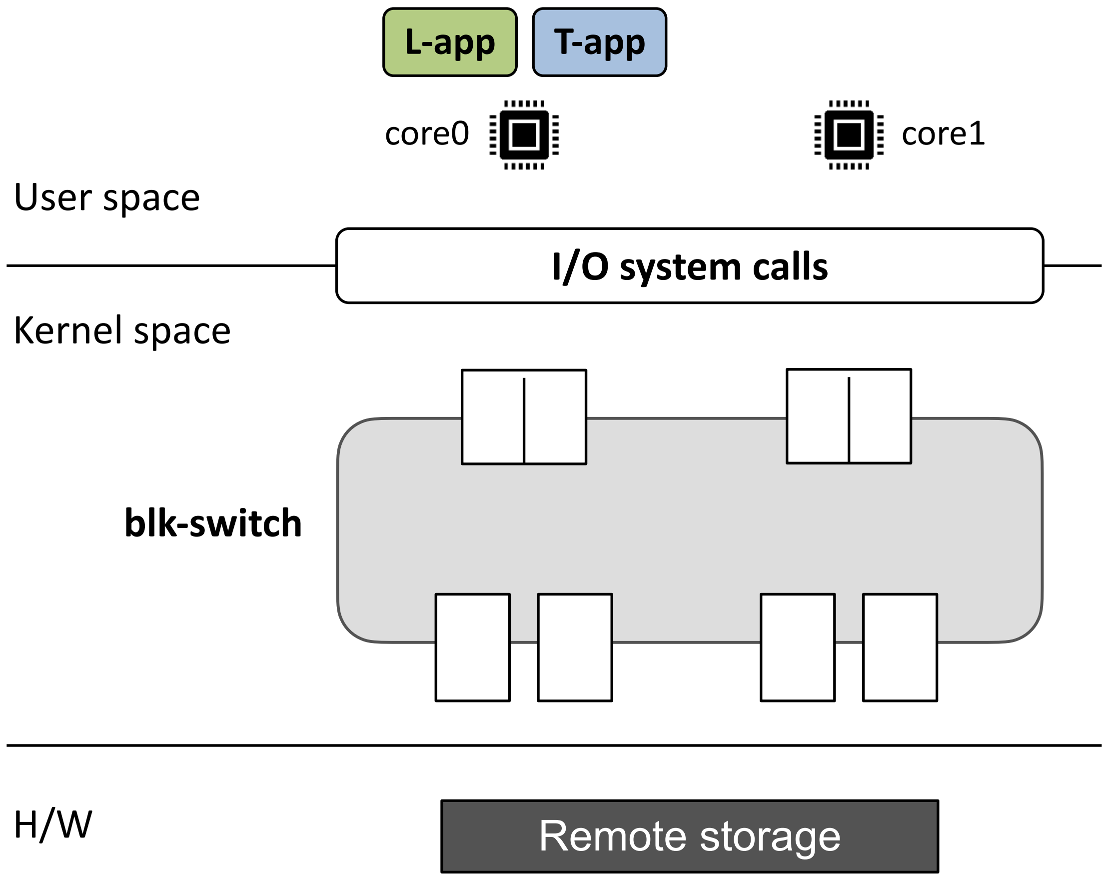

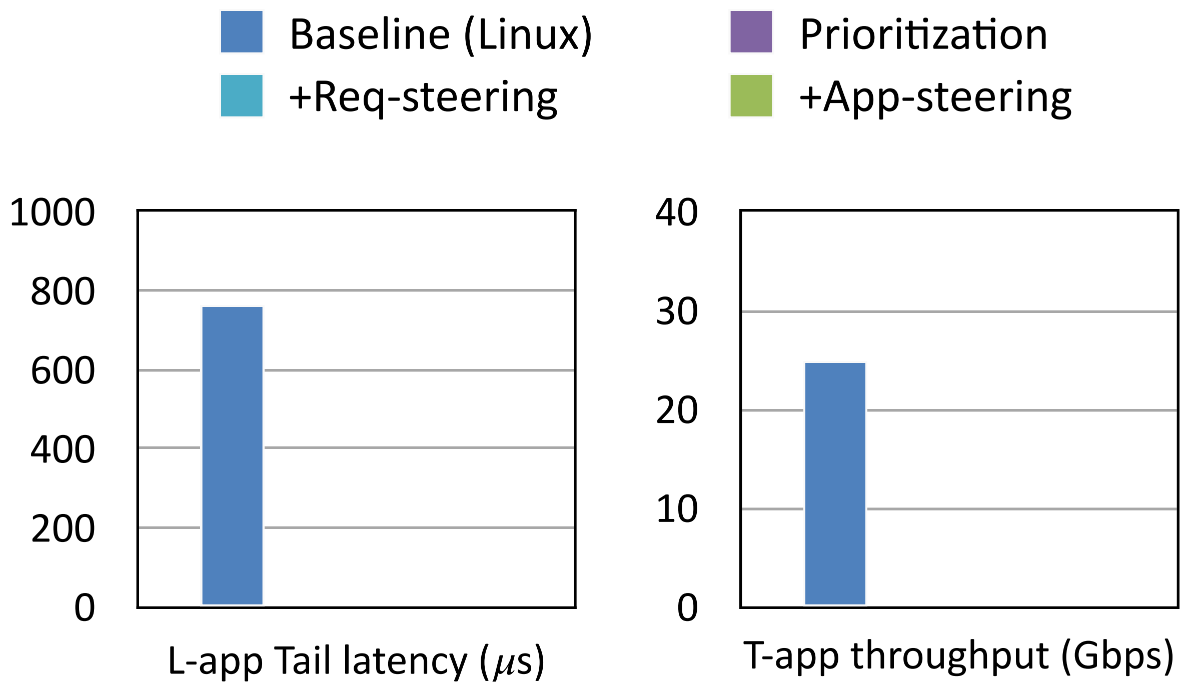

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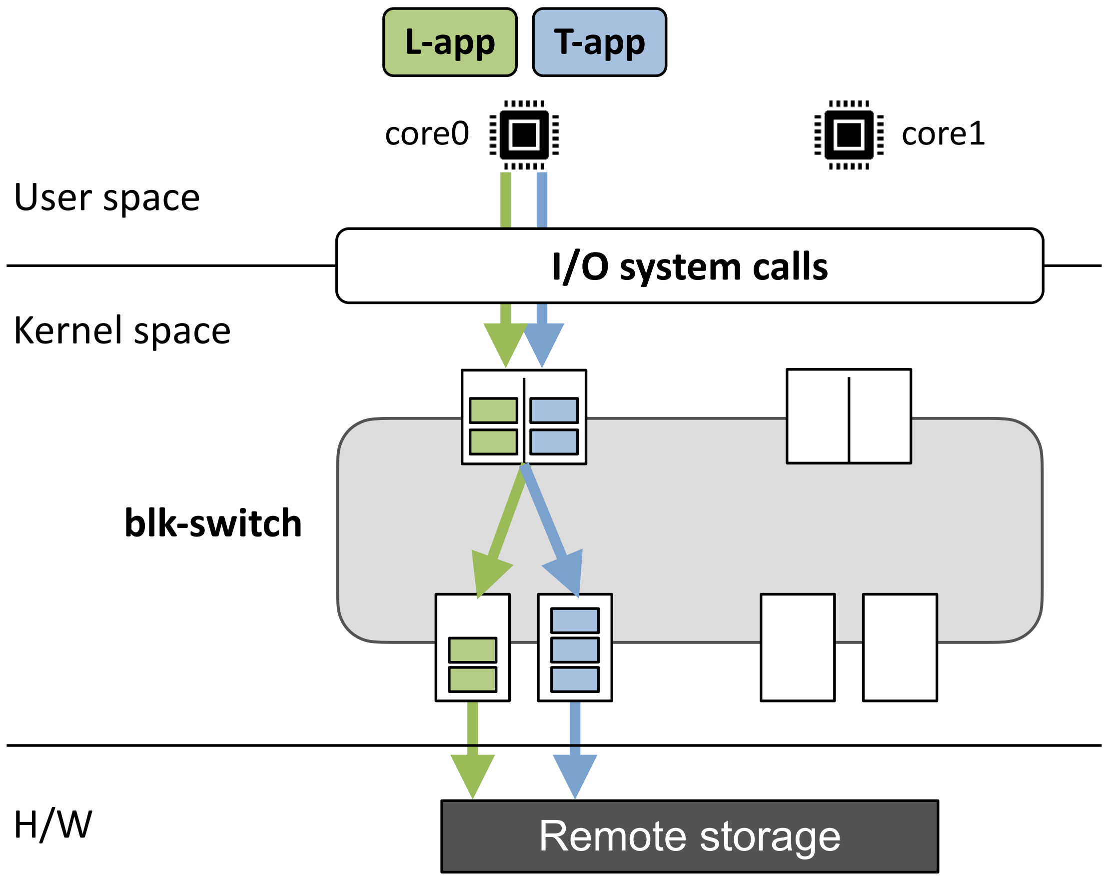

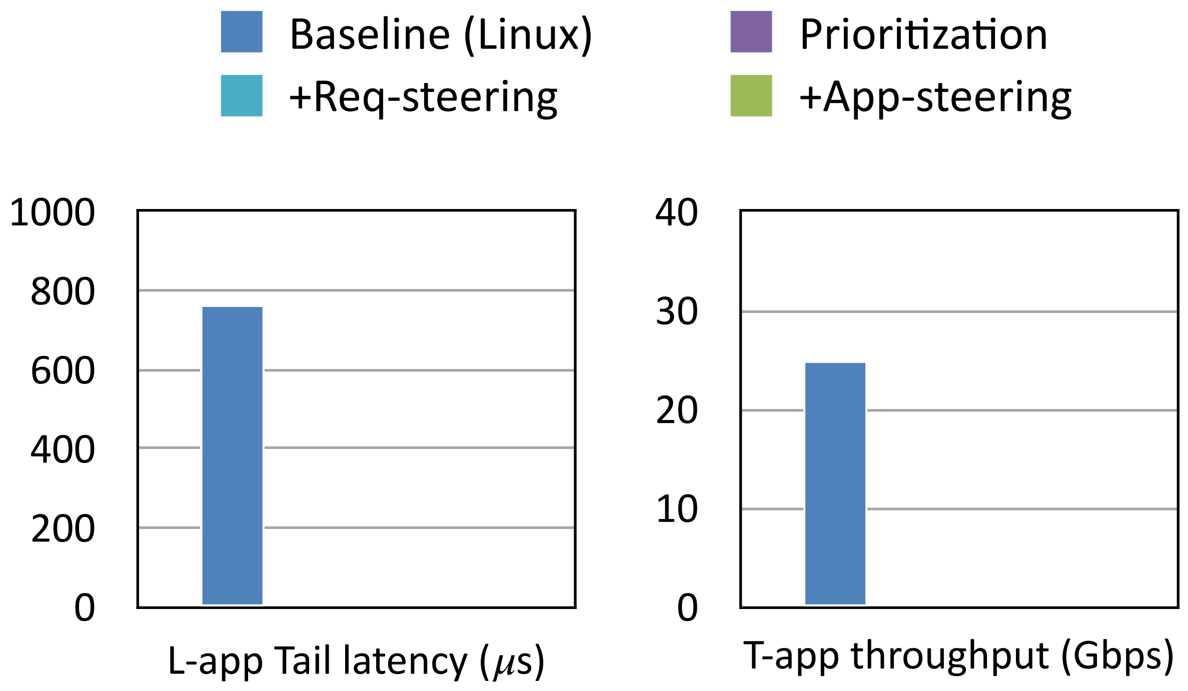

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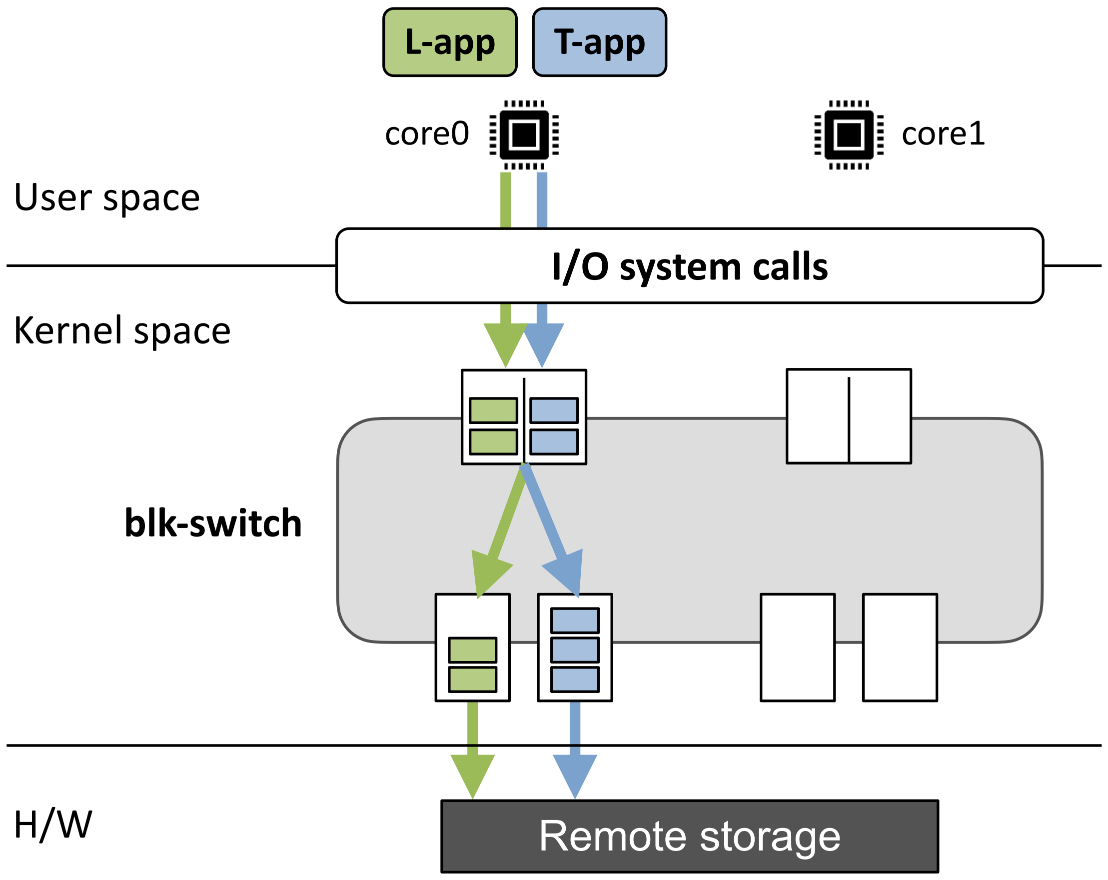

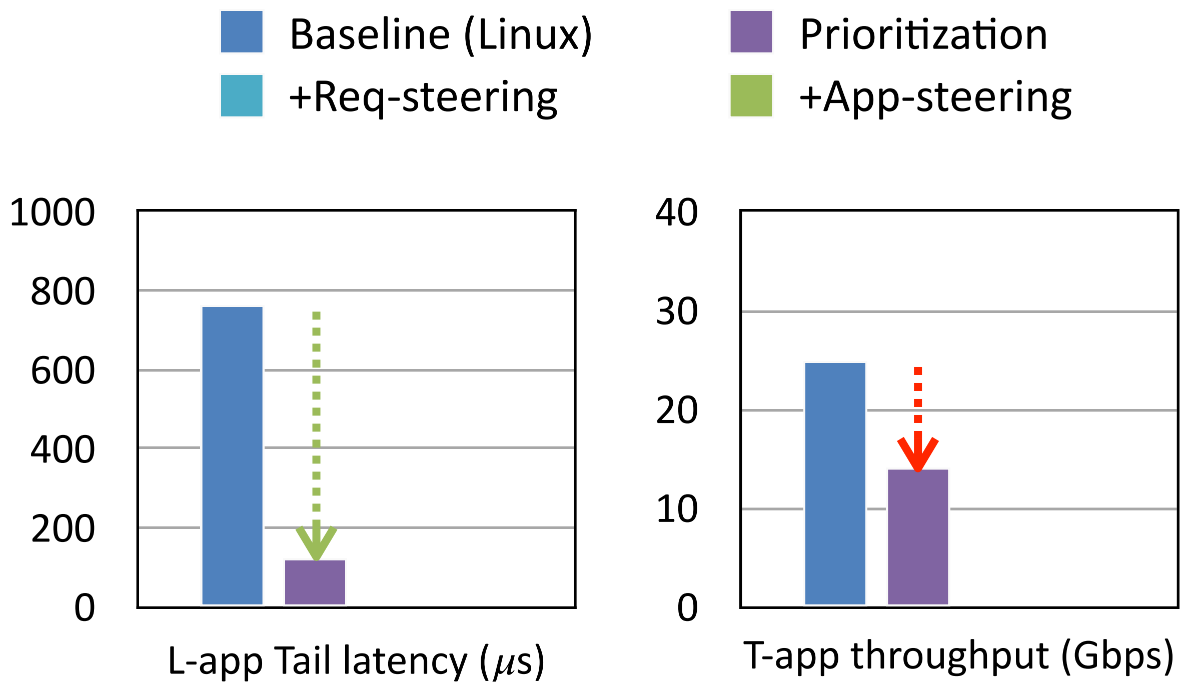

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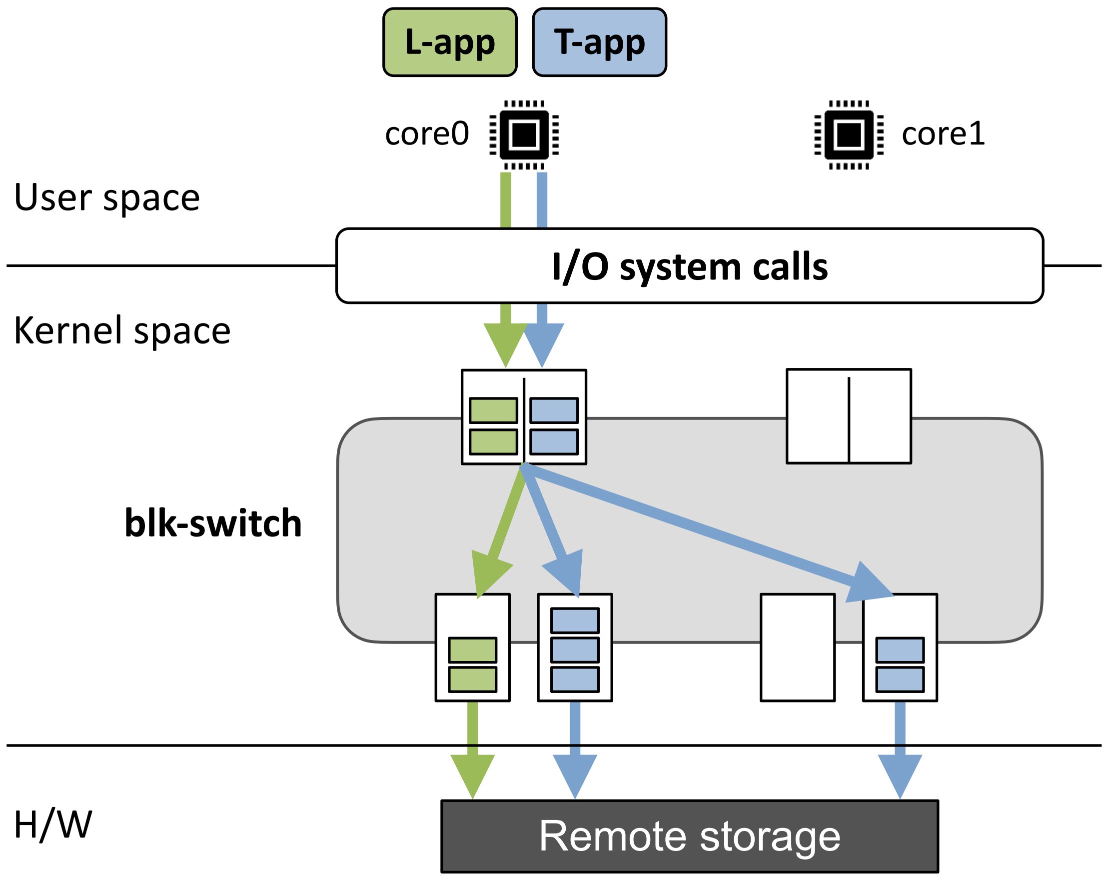

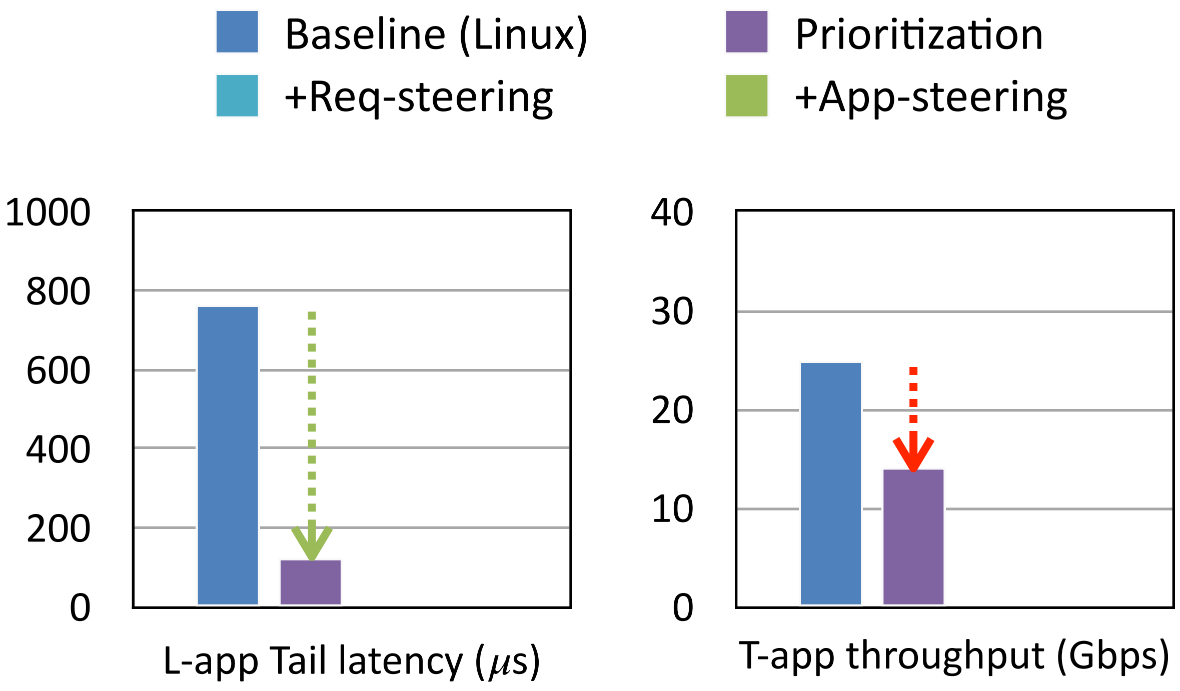

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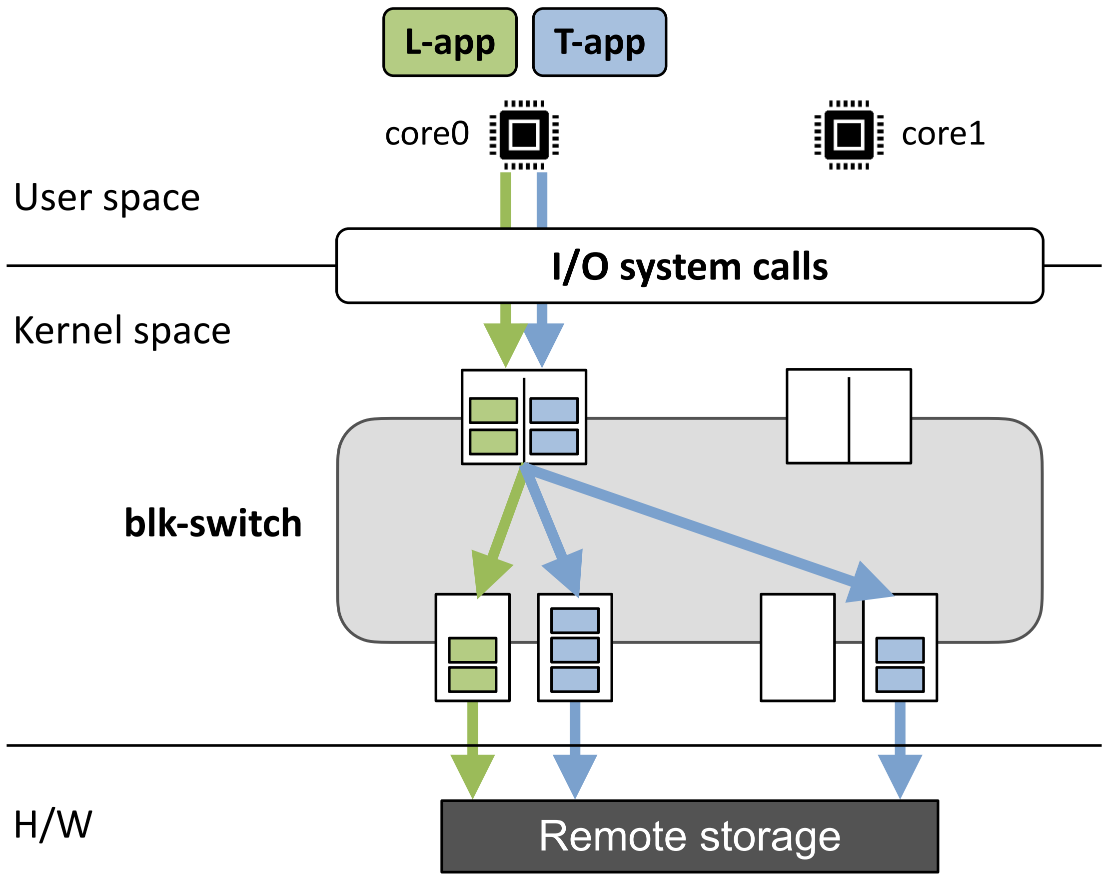

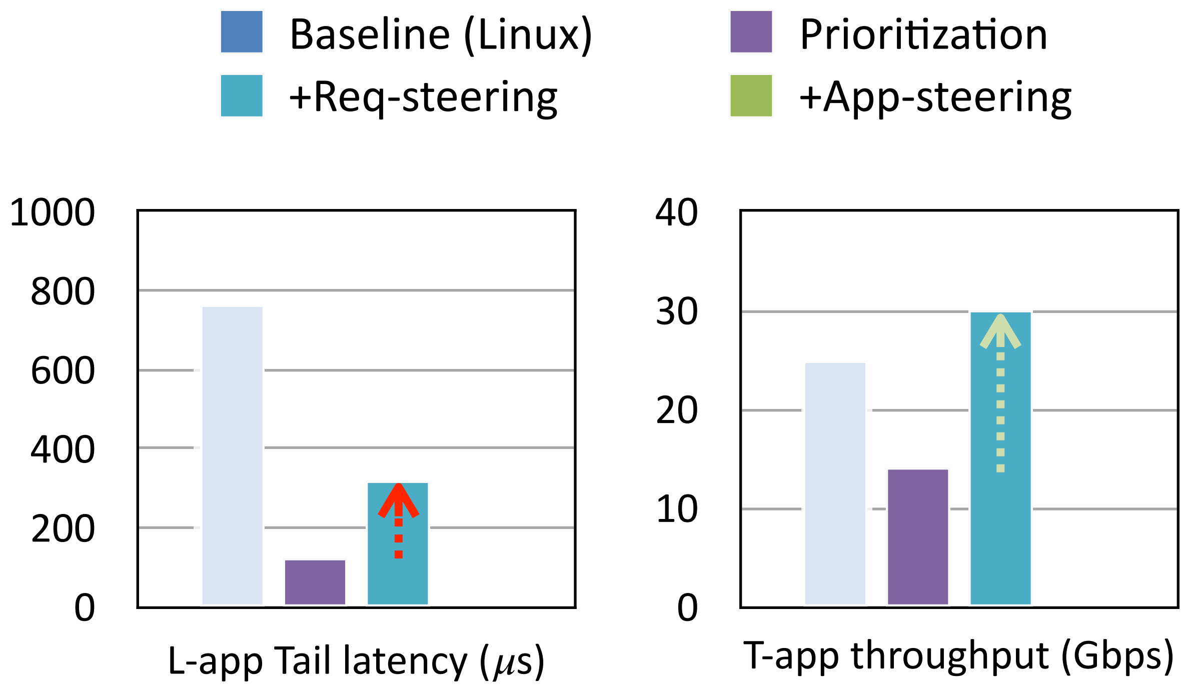

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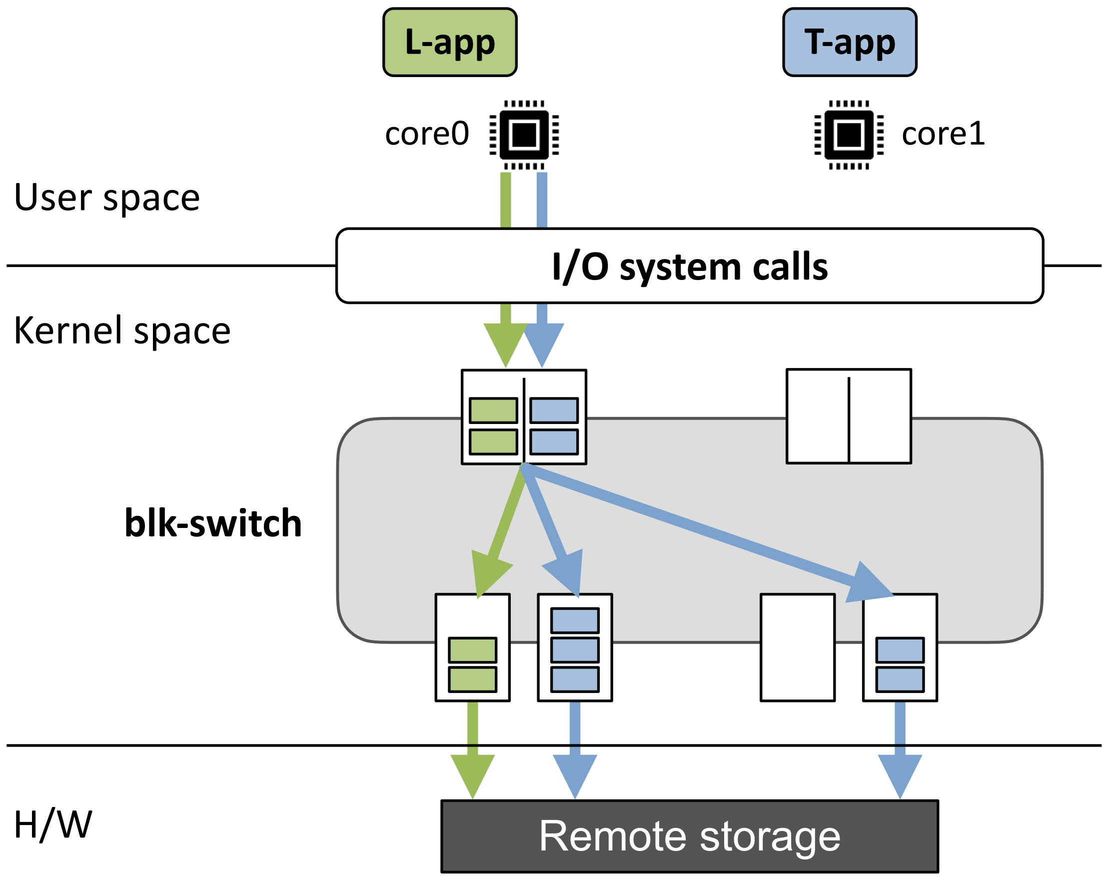

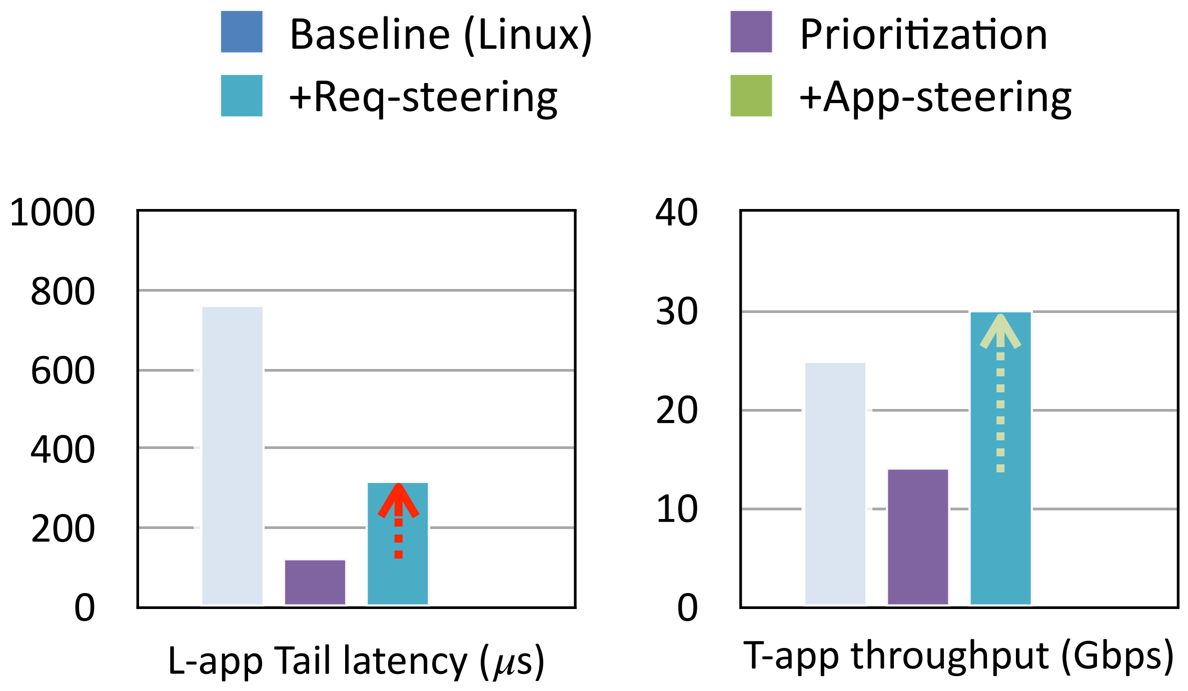

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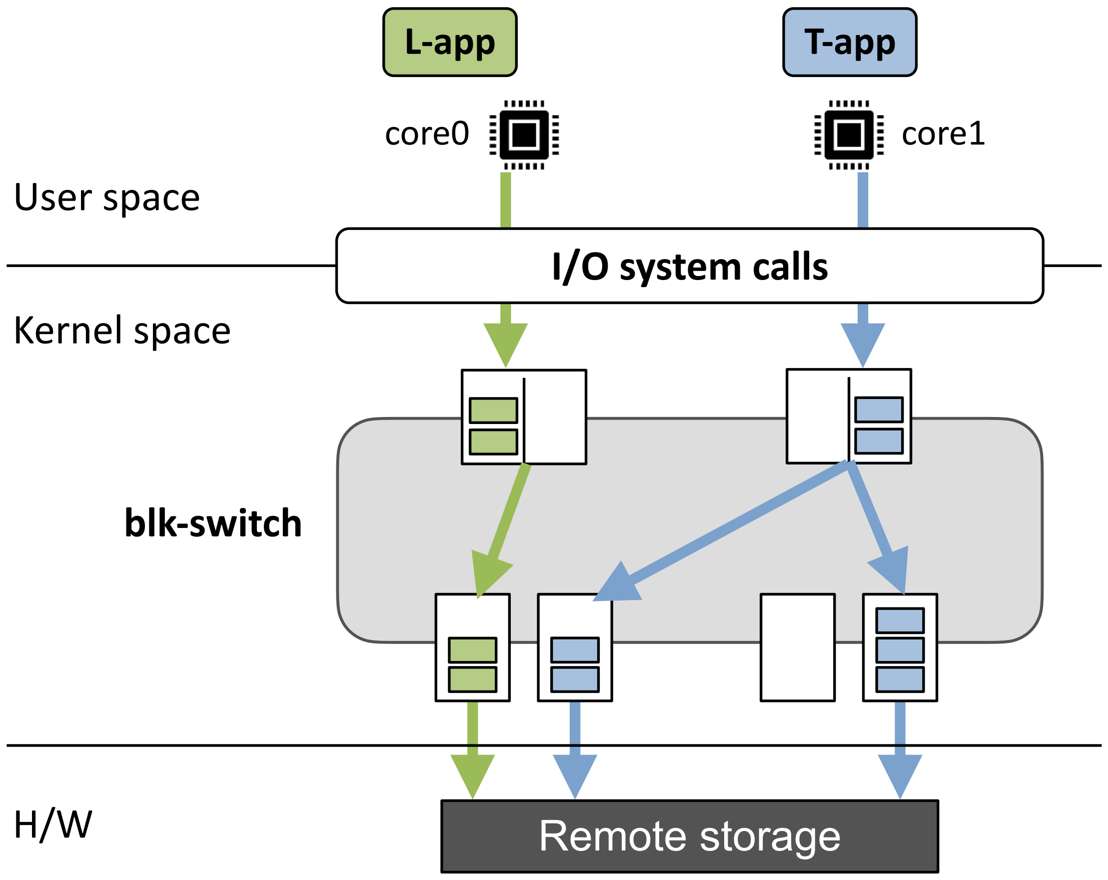

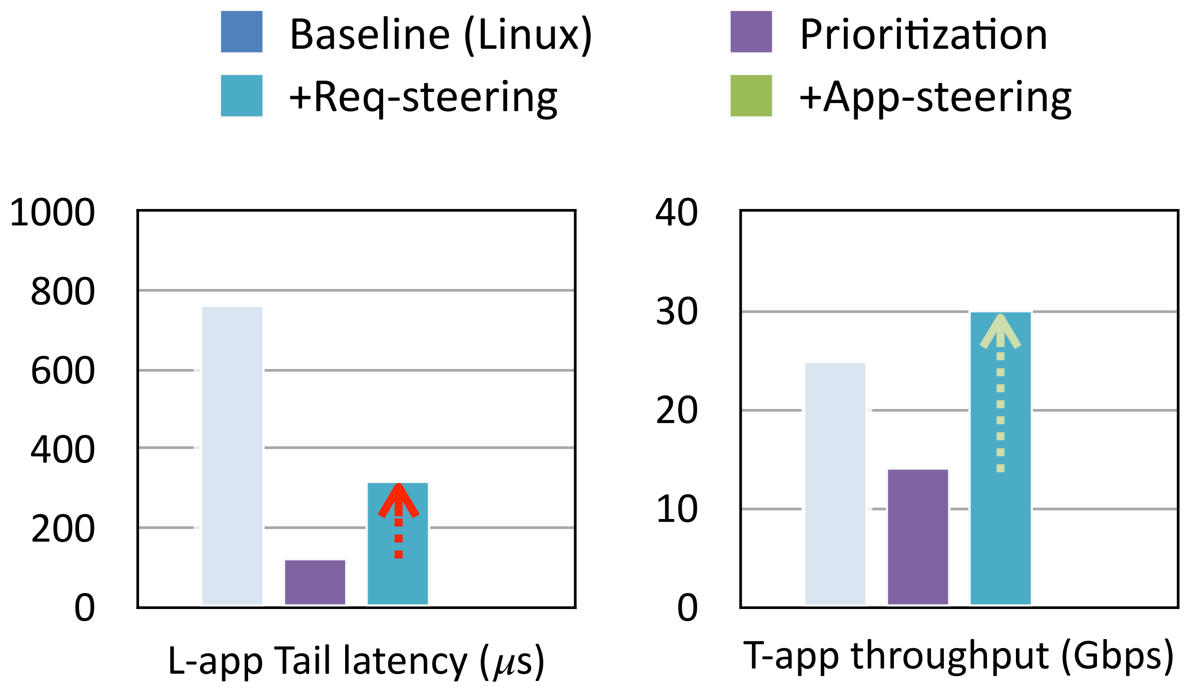

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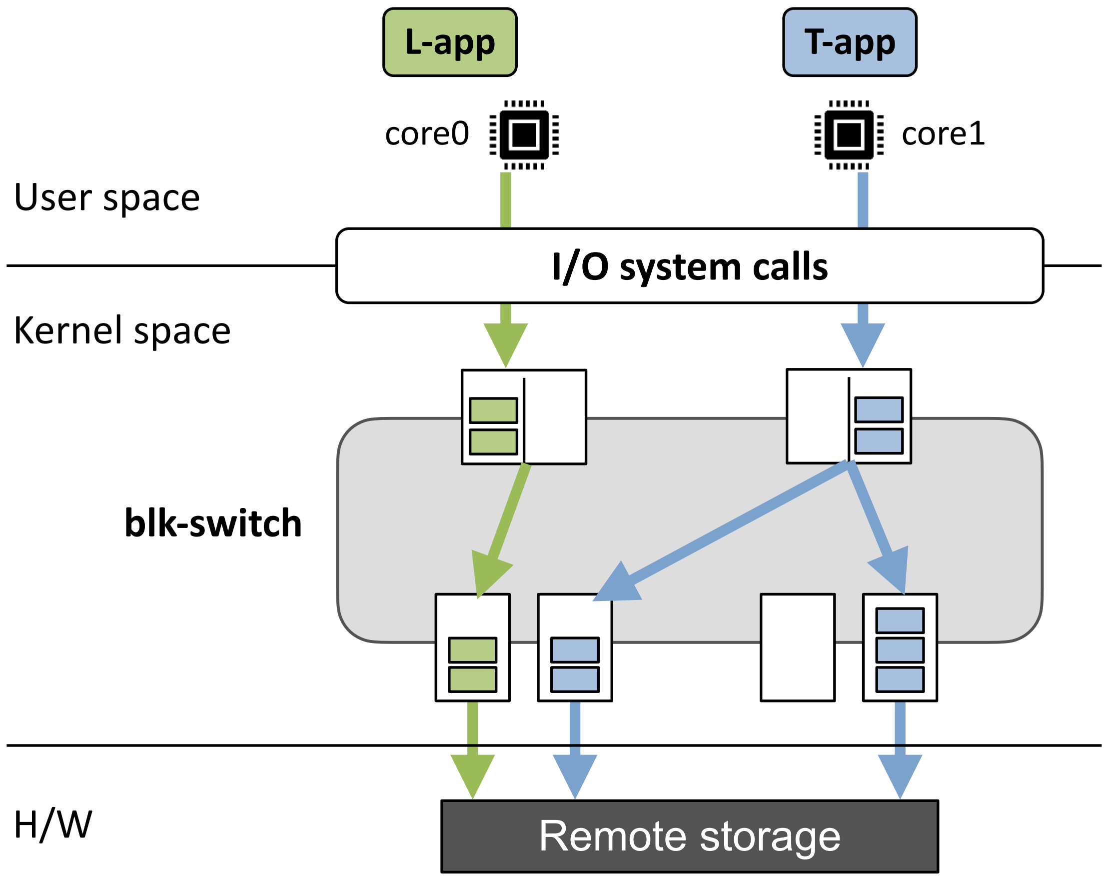

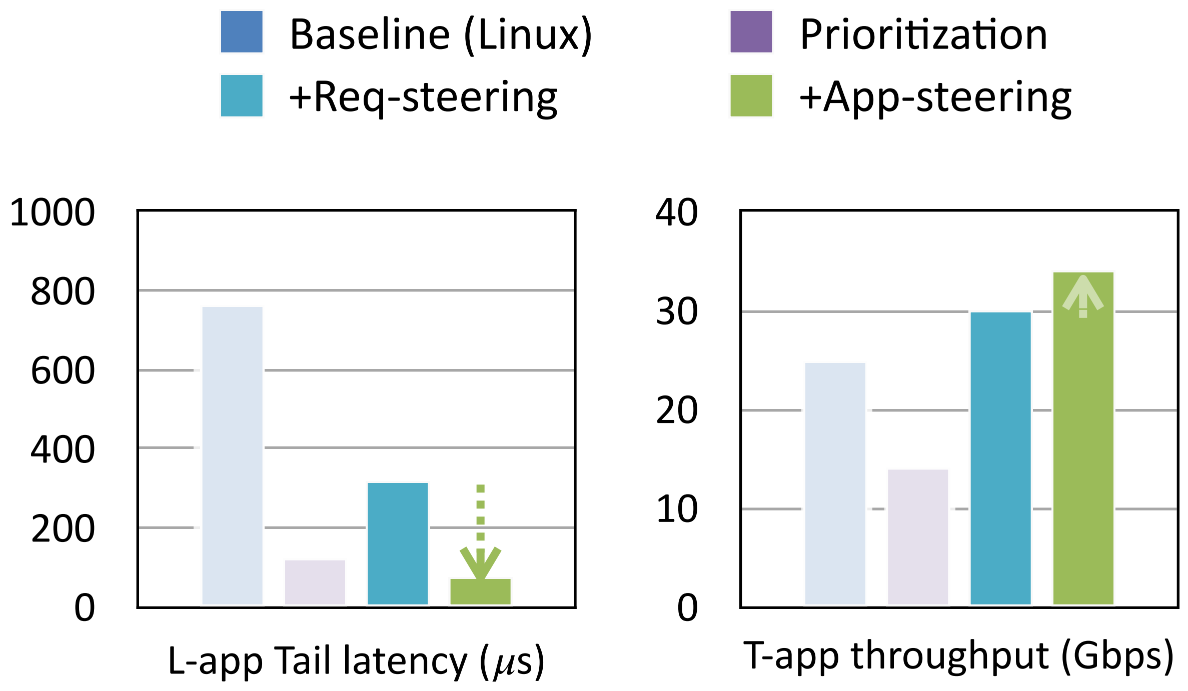

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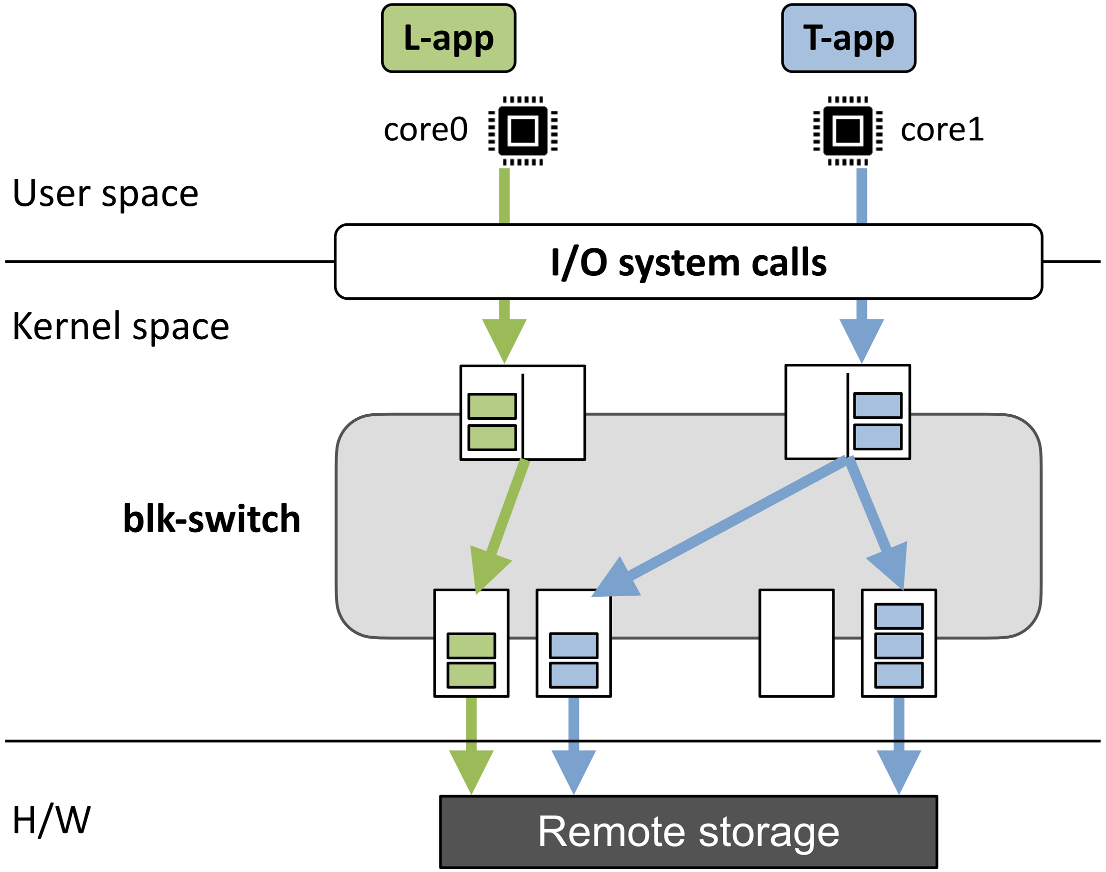

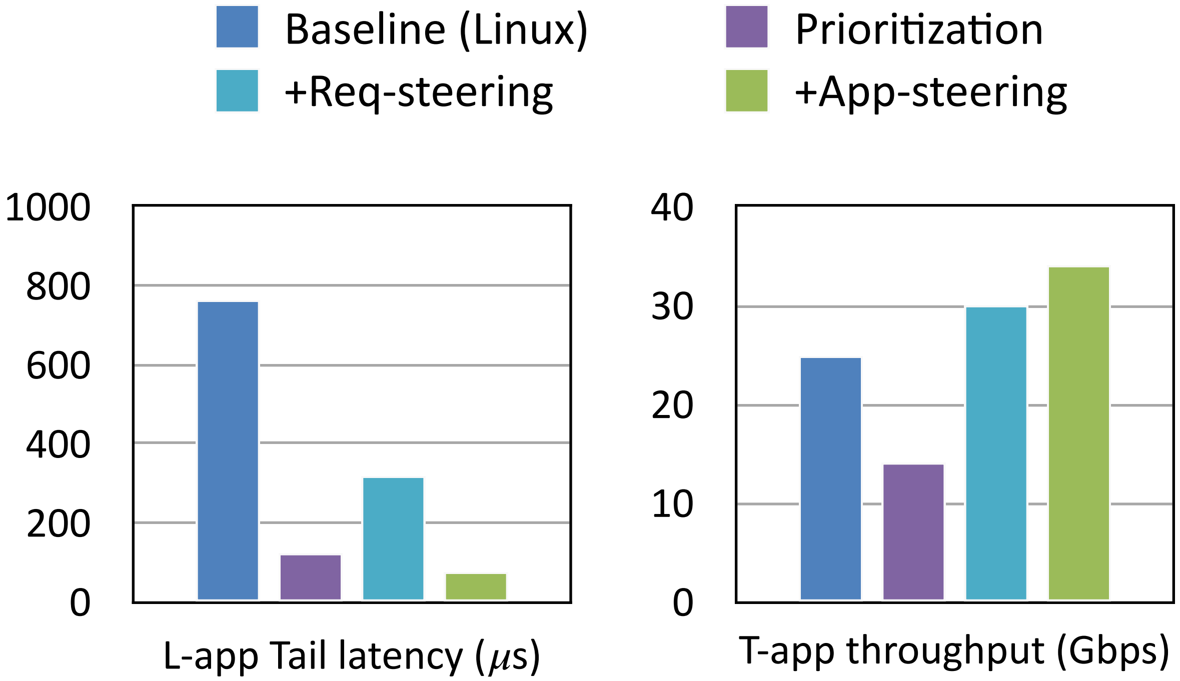

All design components contribute to achieving μs-scale latency and high throughput

Many more evaluation results in the paper

- **Performance** under different workloads, hardware, and applications
  - Number of L-apps
  - I/O depth of T-apps
  - Single-threaded vs. multi-threaded
  - Storage device access latency
  - Real applications
  - Request size of T-apps
  - Read/write ratios
  - …
- **Performance scalability with number of cores**
- **Performance scalability beyond 100Gbps**

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ARTIFACT EVALUATED usenix ASSOCIATION AVAILABLE

ARTIFACT EVALUATED usenix ASSOCIATION FUNCTIONAL

ARTIFACT EVALUATED usenix ASSOCIATION REPRODUCED

https://github.com/resource-disaggregation/blk-switch

Thank you!

Jaehyun Hwang
Cornell University
(jaehyun.hwang@cornell.edu)

Midhul Vuppalapati
Cornell University
(midhul@cs.cornell.edu)

Simon Peter
UT Austin
(simon@cs.utexas.edu)

Rachit Agarwal
Cornell University
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