Here, There and Everywhere: The Past, the Present and the Future of Local Storage in Cloud

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Shanghai Jiao Tong University, †Alibaba Group, *Solidigm

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SHANGHAI JIAO TONG UNIVERSITY

Alibaba

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Outline

- **Background**
- **The Past**
- **The Present**
- **The Future**
- **Conclusion**

Local Storage Model in the Cloud

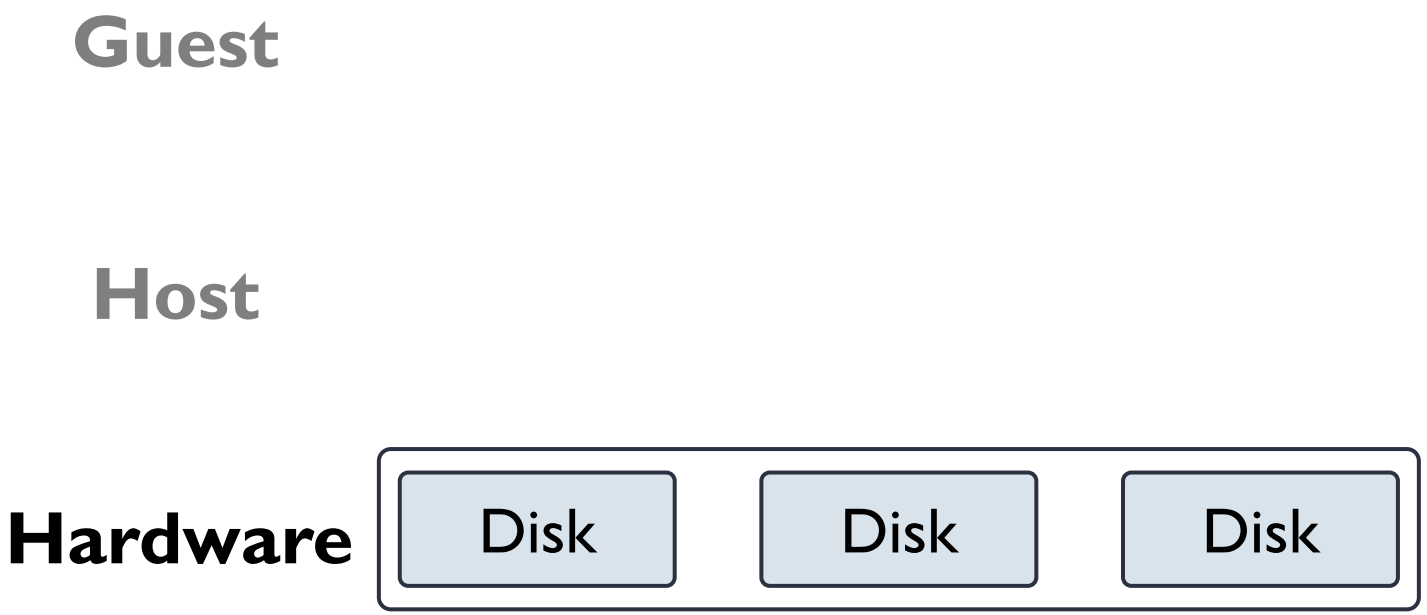
Guest

Host

Hardware

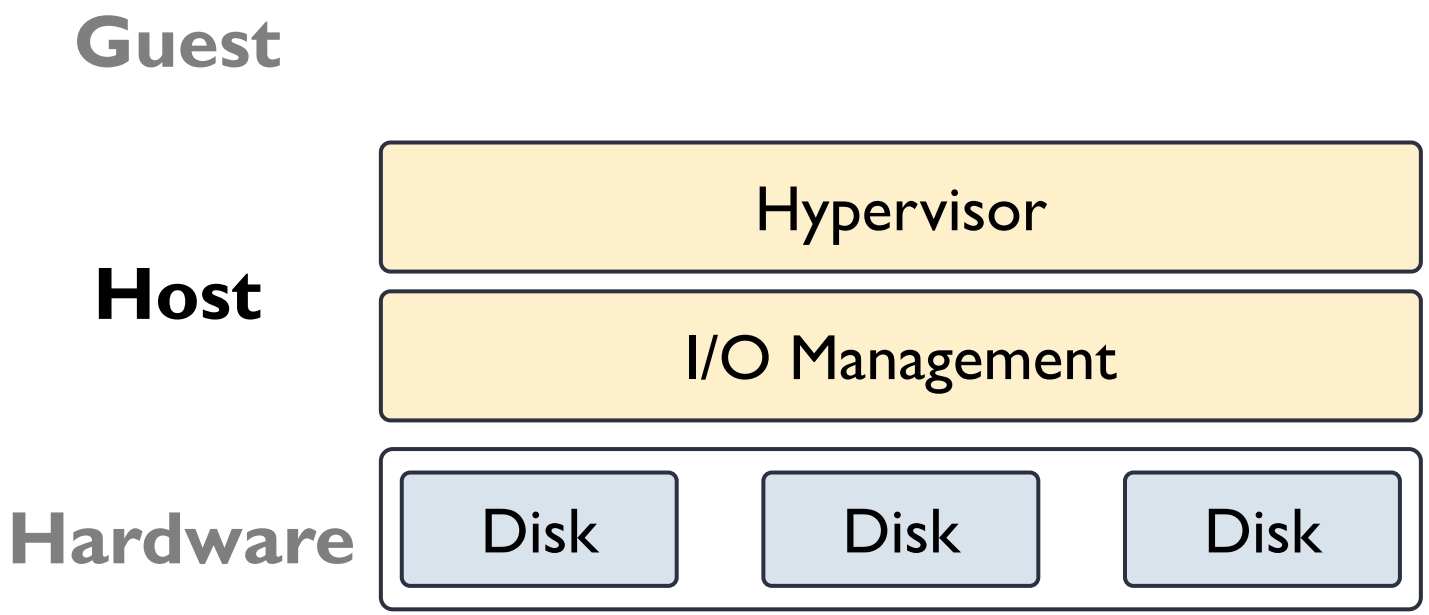
Local Storage Model in the Cloud

- Hardware: directly attached



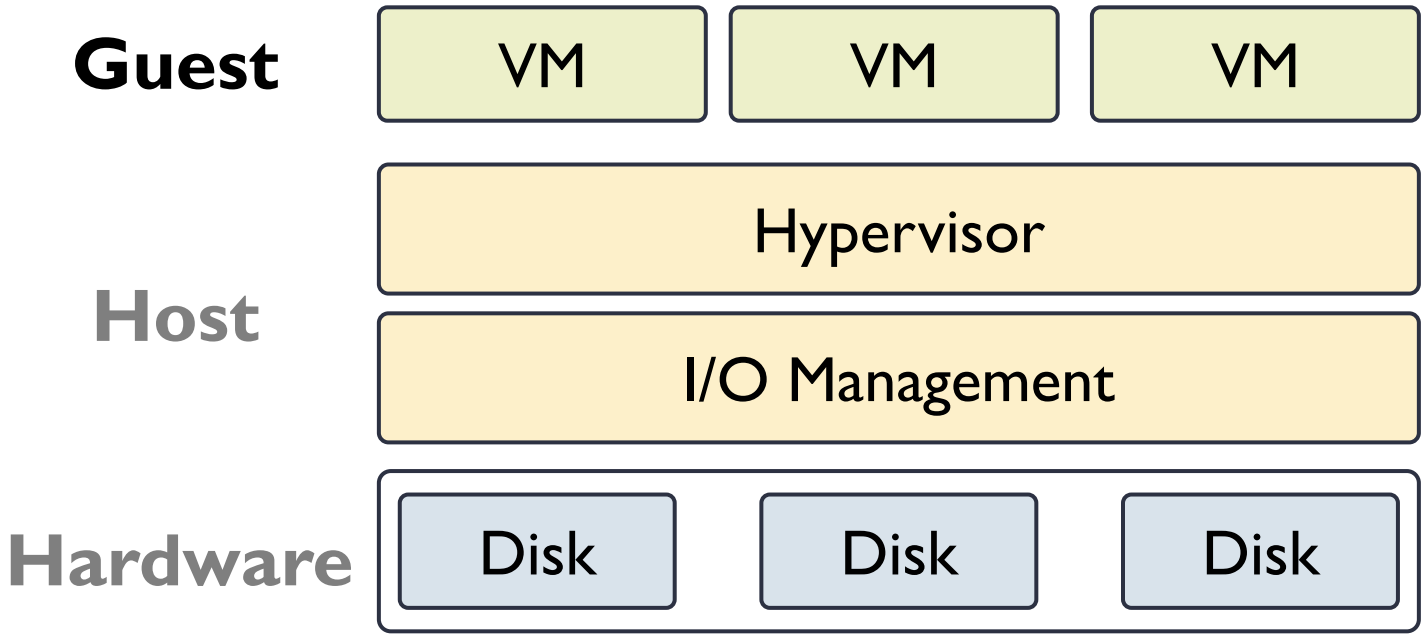
Local Storage Model in the Cloud

- Hardware: directly attached
- Host: manage and virtualize physical disks



Local Storage Model in the Cloud

- Hardware: directly attached
- Host: manage and virtualize physical disks
- Guest: subscribe one/multiple virtual disks



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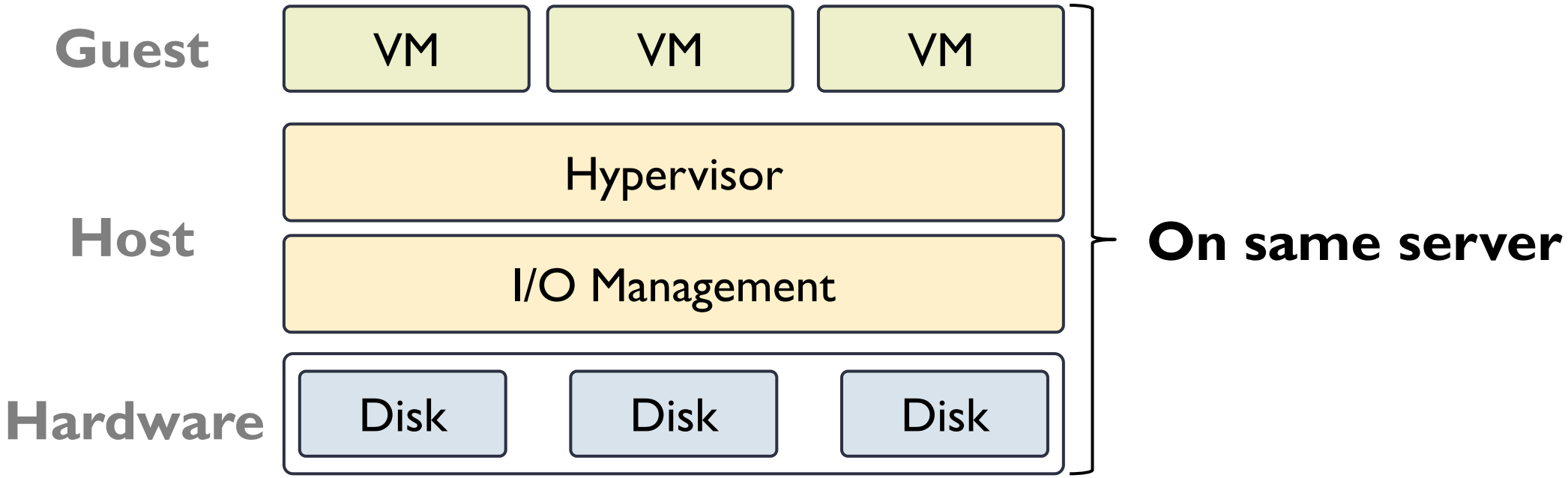

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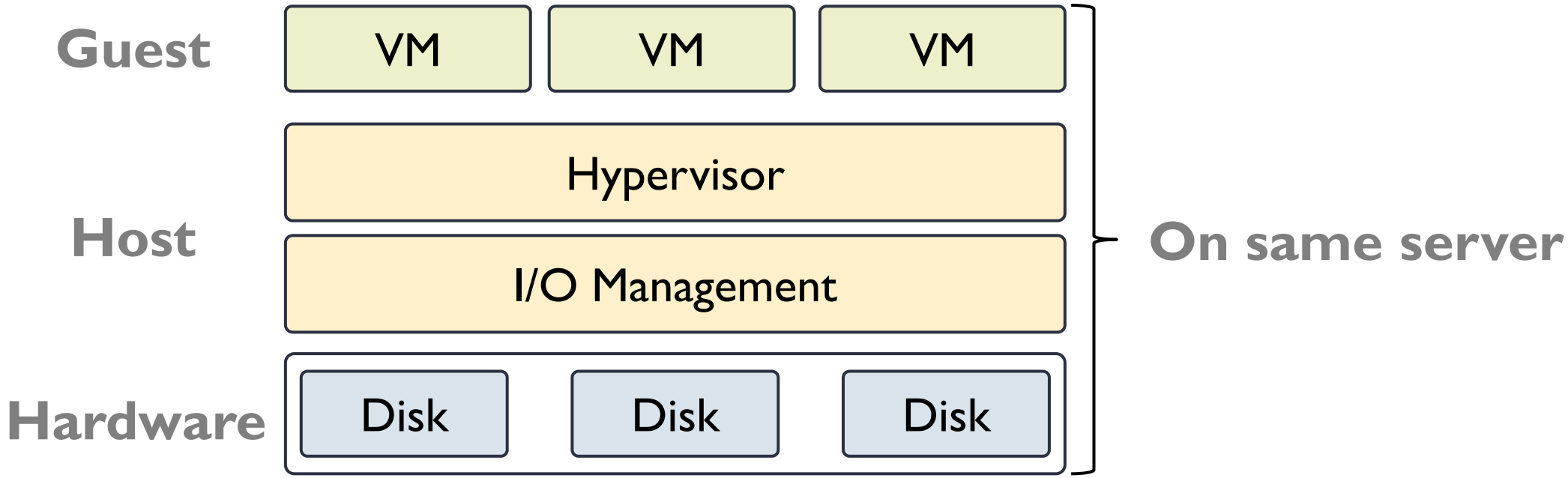

*We focus on the design and deployment of **NVMe SSD-based** local storage*

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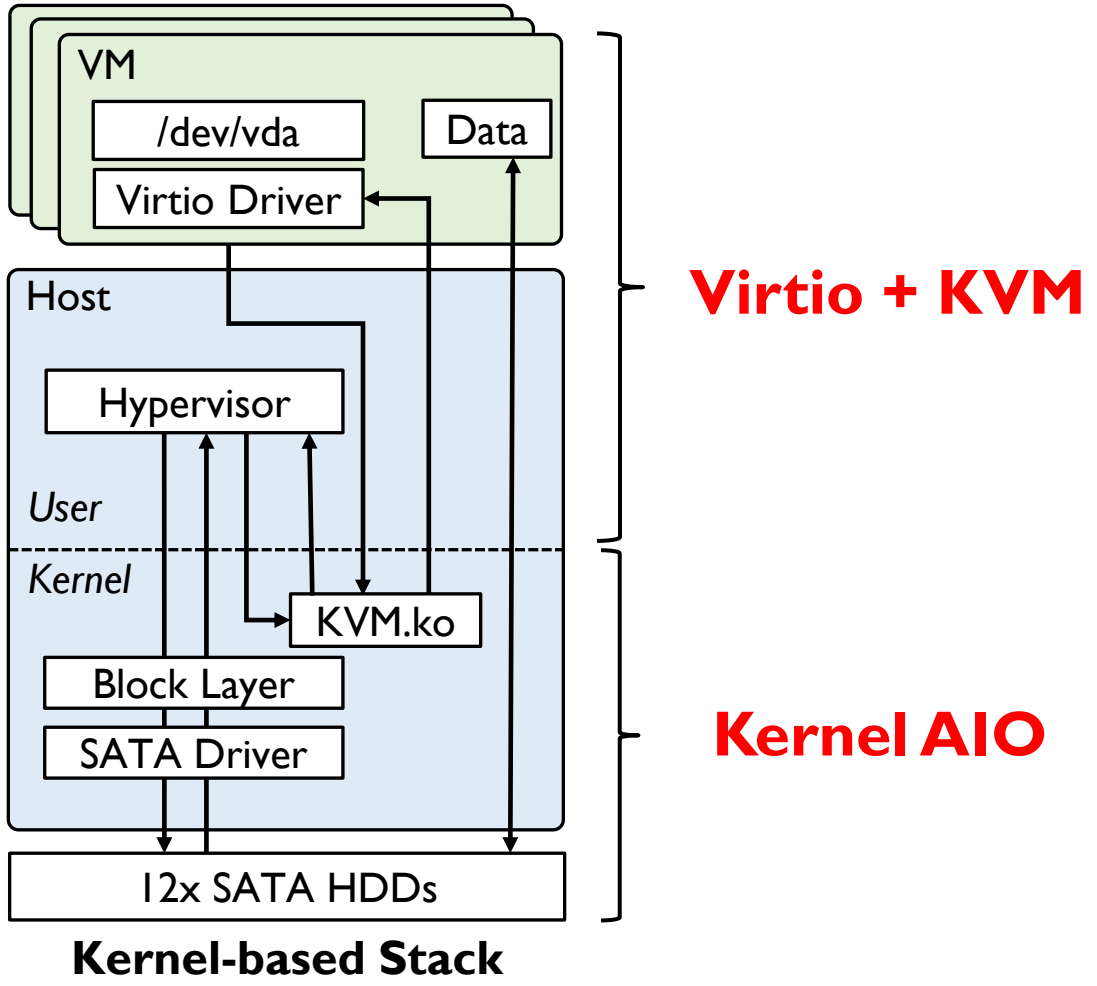
Espresso: From Kernel to SPDK

Kernel-based stack is outdated



Kernel-based Stack

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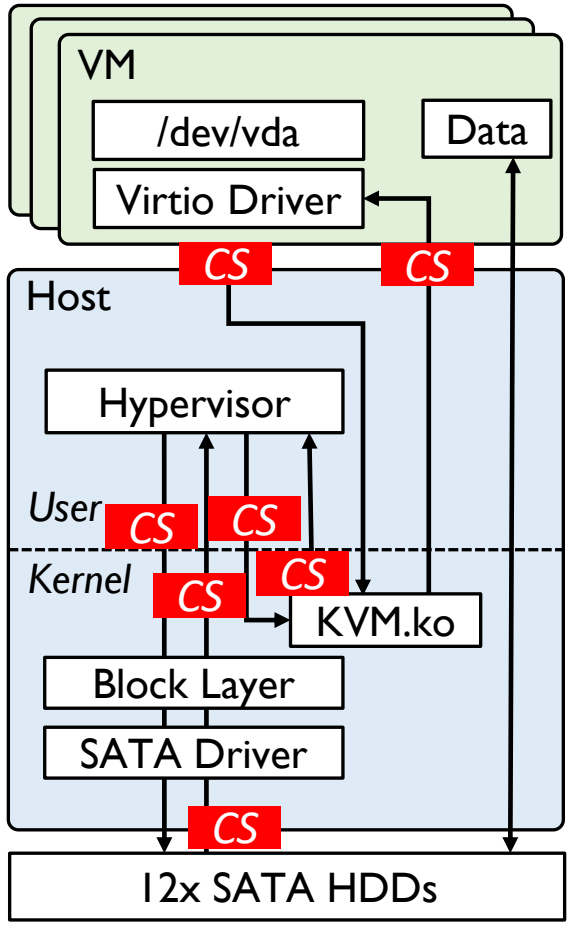
- Context switches (CS)



Kernel-based Stack

Espresso: From Kernel to SPDK

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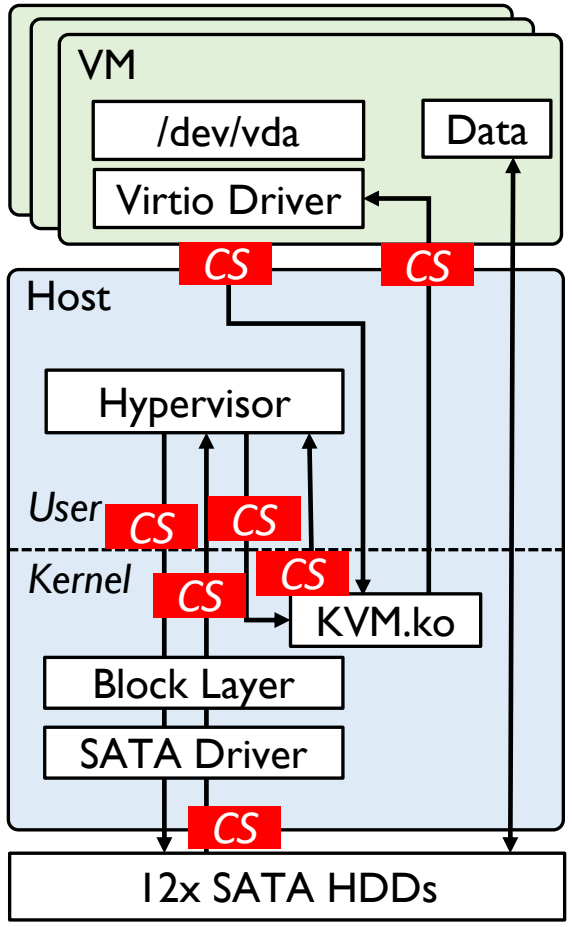

Kernel-based Stack

Espresso: From Kernel to SPDK

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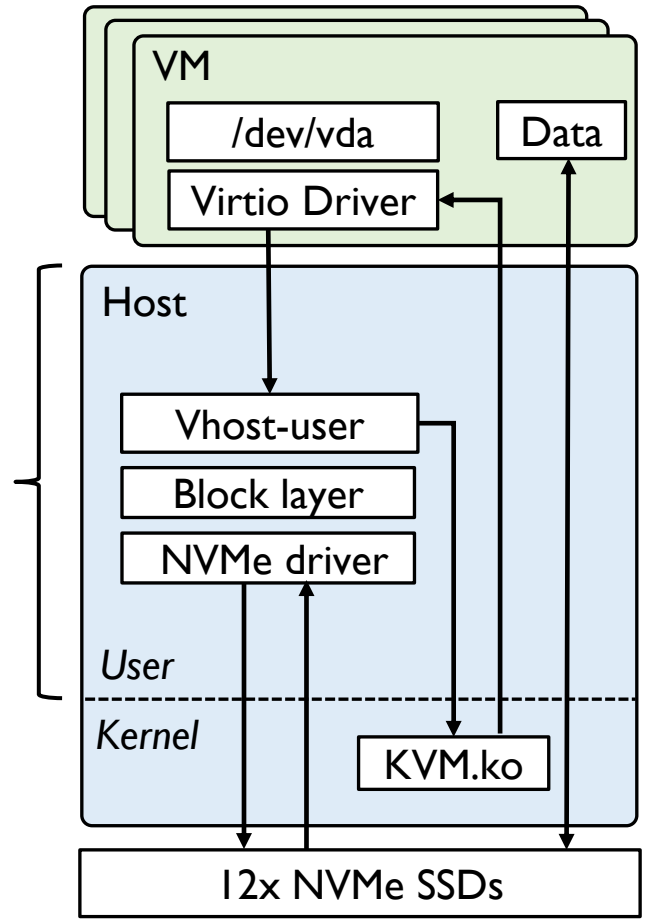
SPDK-based stack best fits

SPDK

Vhost-user

+ NVMe



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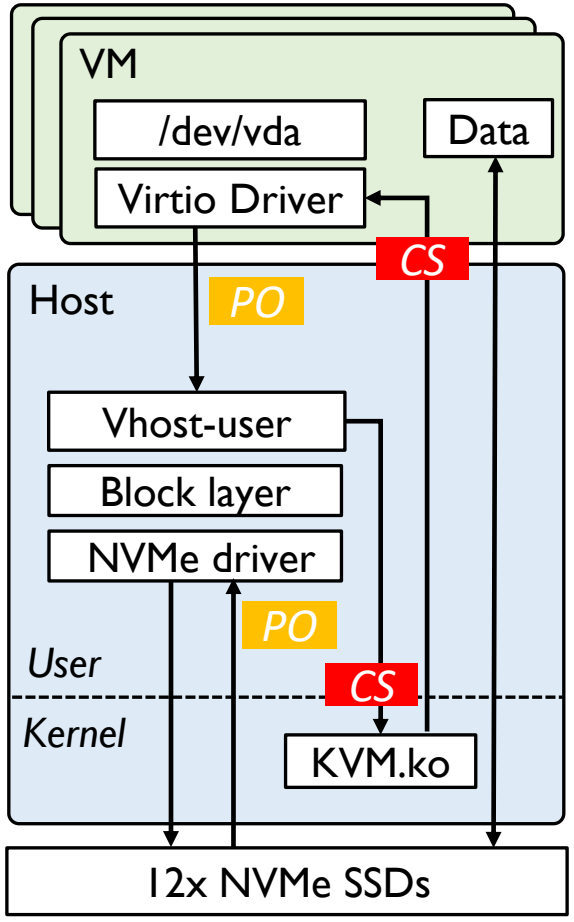

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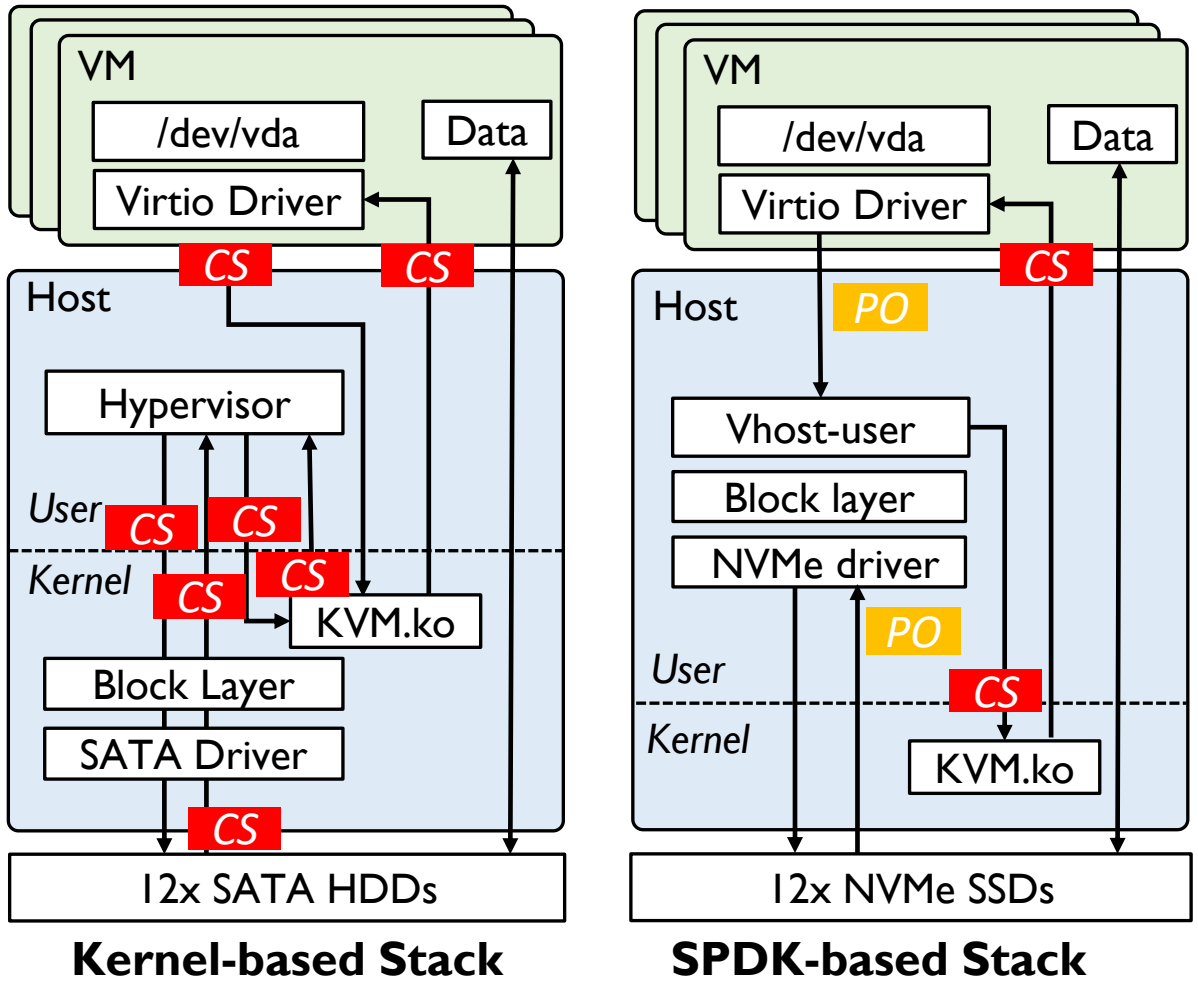
- Userspace polling (PO)
- Low latency & High CPU-efficiency



Lessons from Espresso Deployment

SPDK shows limitations especially for future evolution

No bare-metal support

- Dedicating CPU cores for I/O

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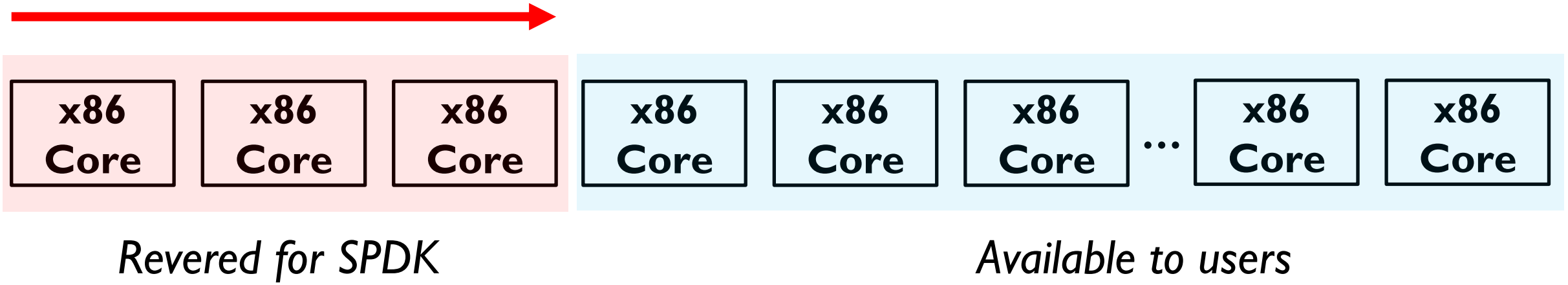


Lessons from Espresso Deployment

SPDK shows limitations especially for future evolution

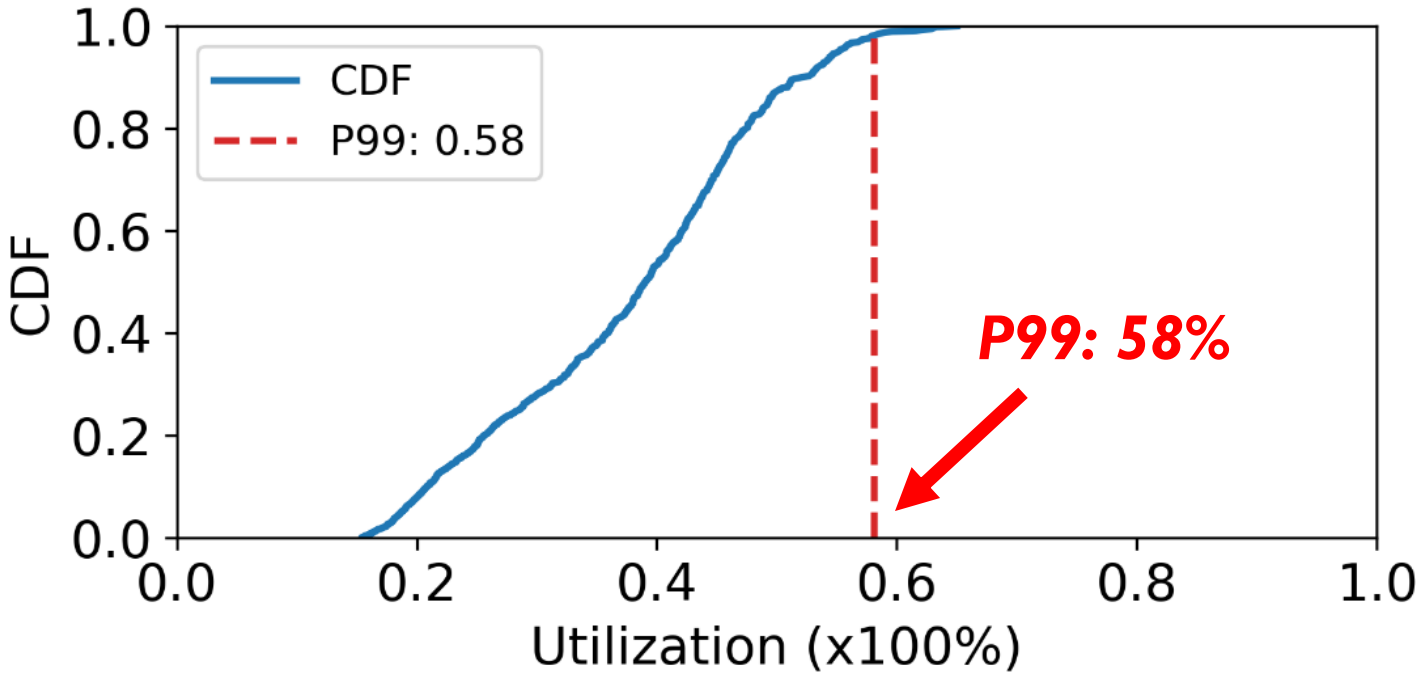
No bare-metal support

- Dedicating CPU cores for I/O

Not efficiently using CPU

- Busy polling

40%+ CPU cycles are wasted!



Effective CPU utilization

Lessons from Espresso Deployment

SPDK shows limitations especially for future evolution

No bare-metal support

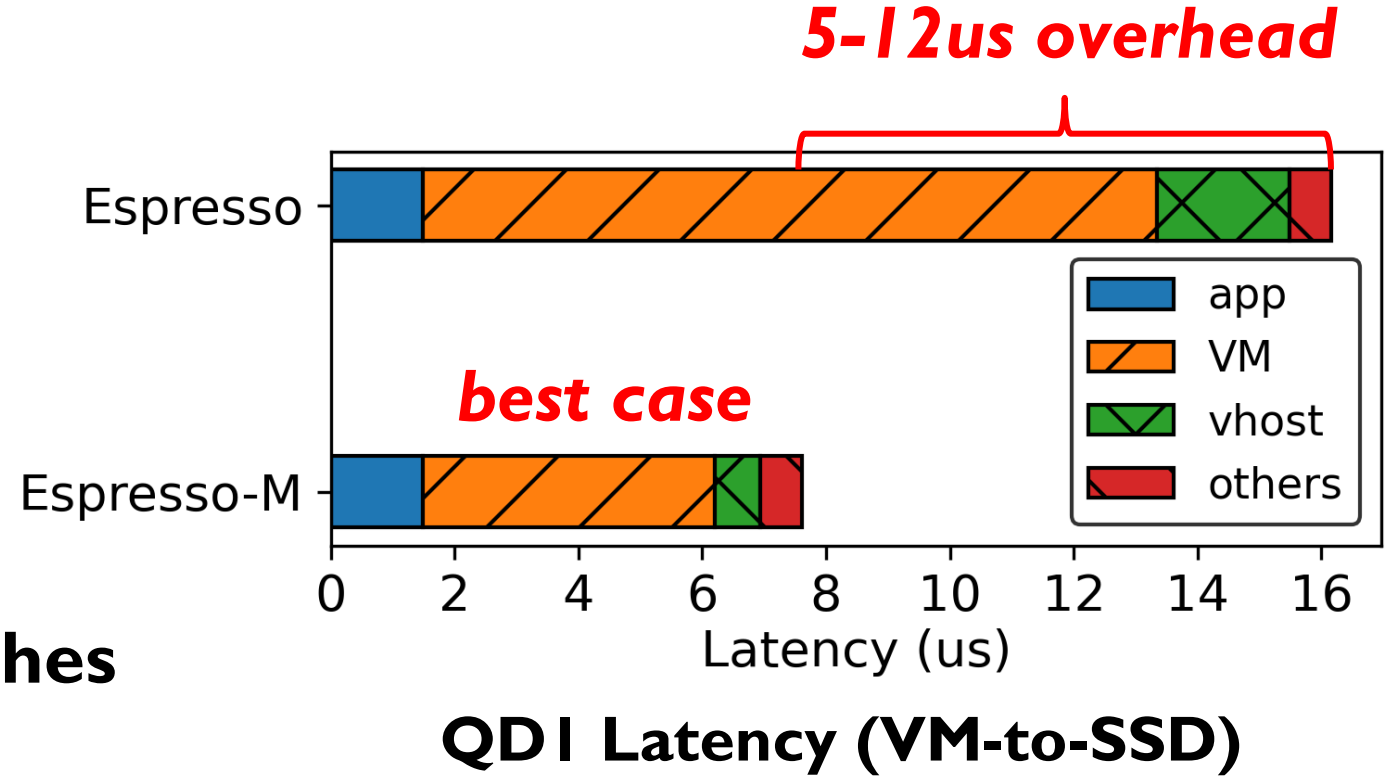
- Dedicating CPU cores for I/O

Not efficiently using CPU

- Busy polling

Not free from context switches

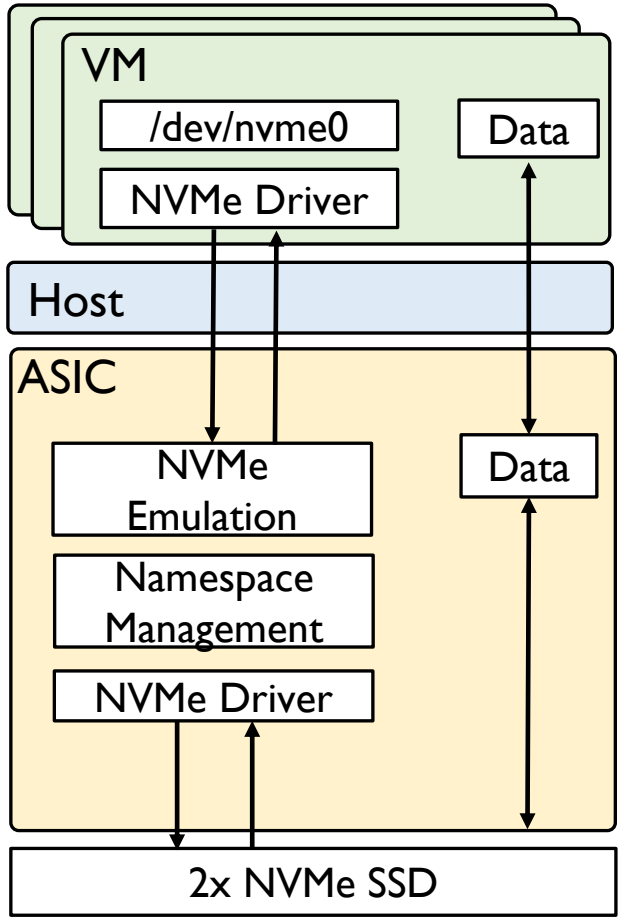
- Final step I/O to VMs



QD1 Latency (VM-to-SSD)

Doppio: From CPU to ASIC

ASIC-based hardware offloading



ASIC-based DPU

Doppio: From CPU to ASIC

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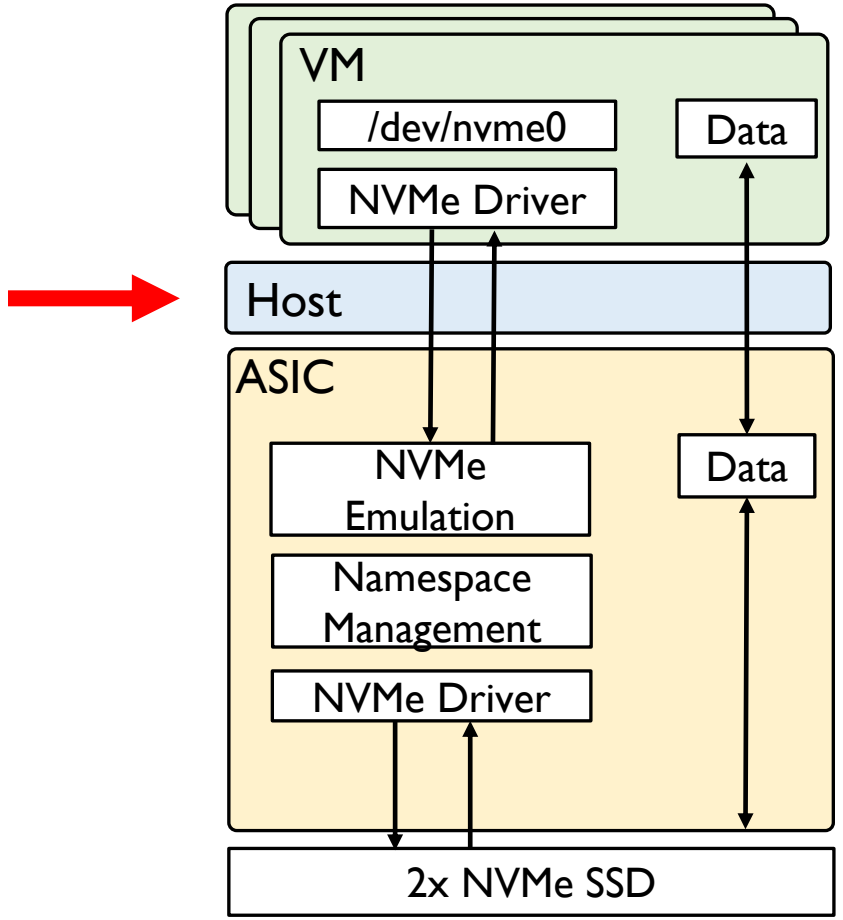
- Bare-metal support



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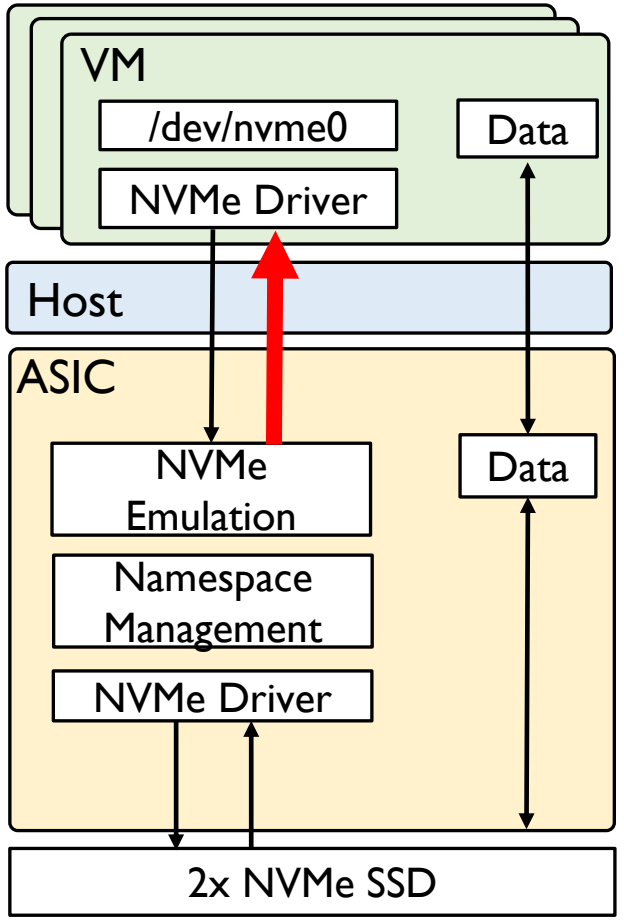
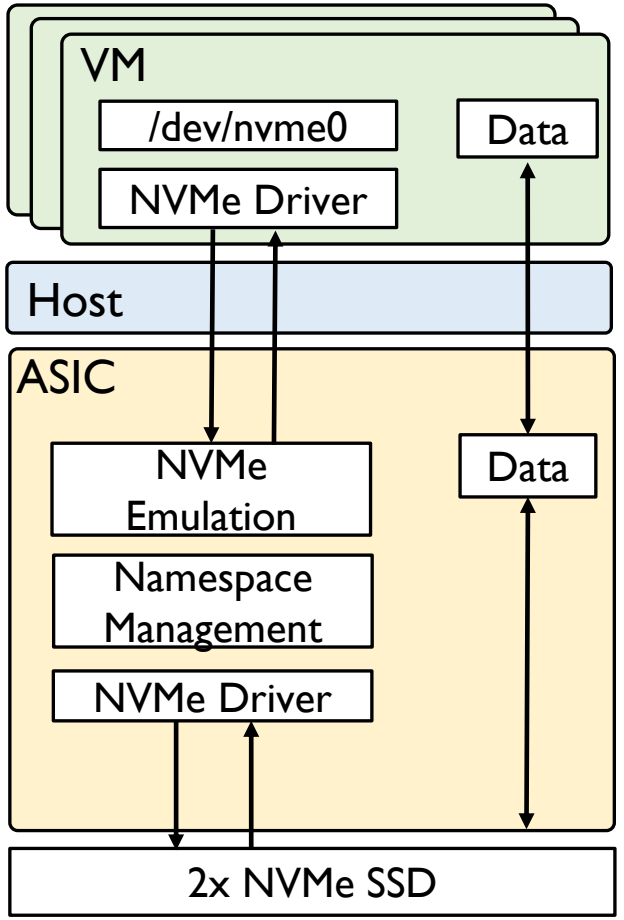


ASIC-based DPU

Doppio: From CPU to ASIC

ASIC-based hardware offloading

- Bare-metal support
- Free from host-side context switches
- Low cost and power consumption



ASIC-based DPU

Lessons from Doppio Deployment

ASIC-based offloading is not the cure-all

Hard to keep up with rapid SSD evolution

- ASIC takes longer time to manufacture

	2017		2020		2023	
	Read	Write	Read	Write	Read	Write
Vendor-1	490K	38K	920K	135K	1.1M	390K
Vendor-2	430K	40K	1M	180K	1.5M	250K

SSD performance (IOPS) evolution

Lessons from Doppio Deployment

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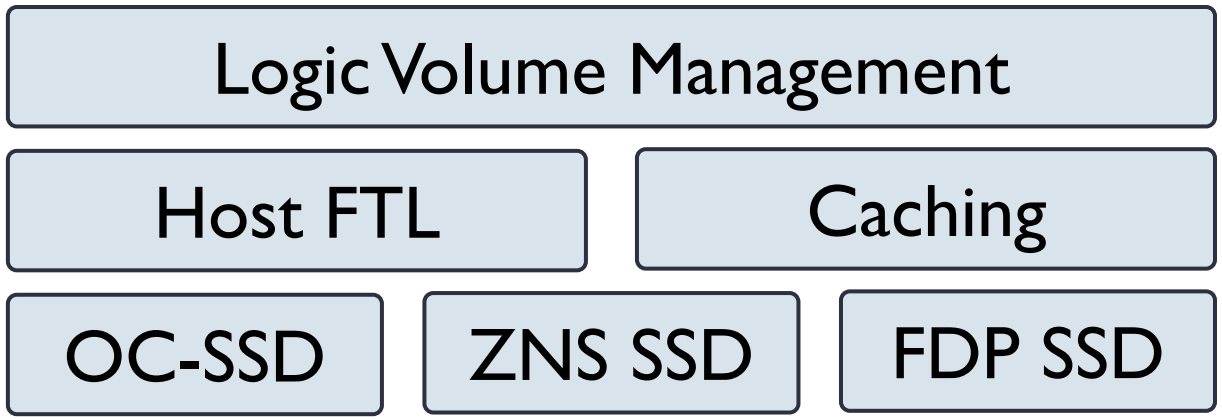
Inadequate for cloud features

- Hard for complex logics
- Logics are hard-wired



Cloud features

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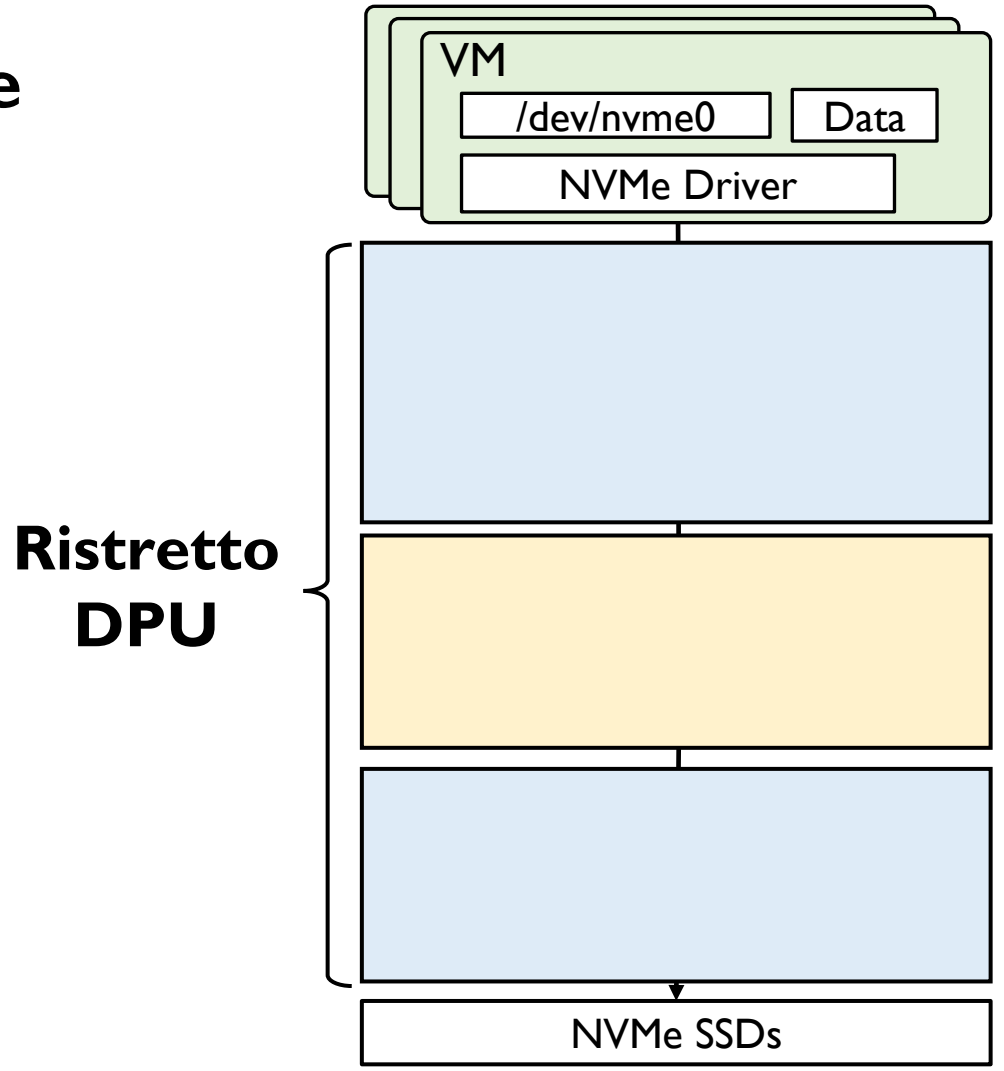
Ristretto: From ASIC to ASIC/SoC Co-design

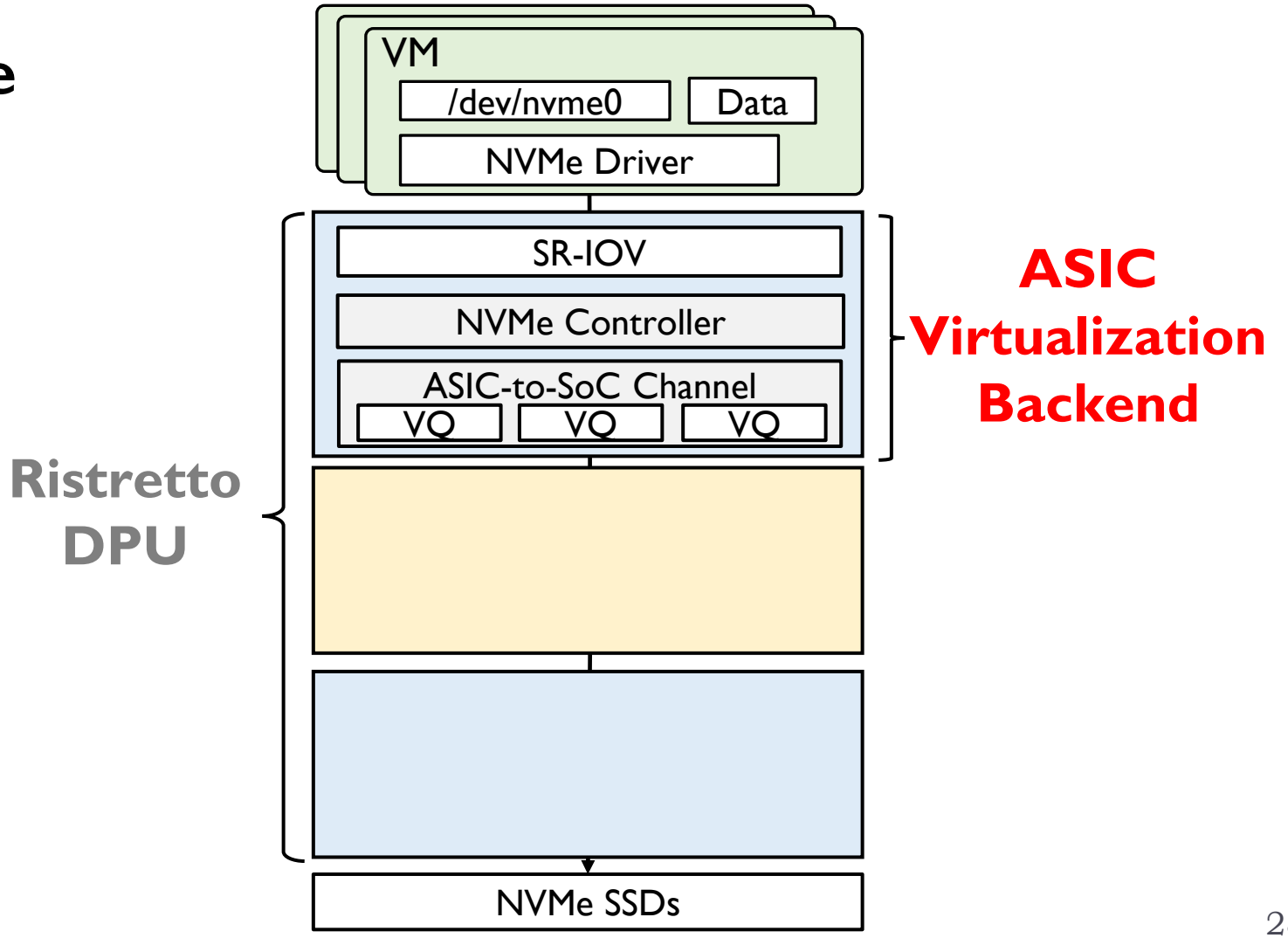
A three-layer architecture



Ristretto: From ASIC to ASIC/SoC Co-design

A three-layer architecture

- ASIC virtualization backend



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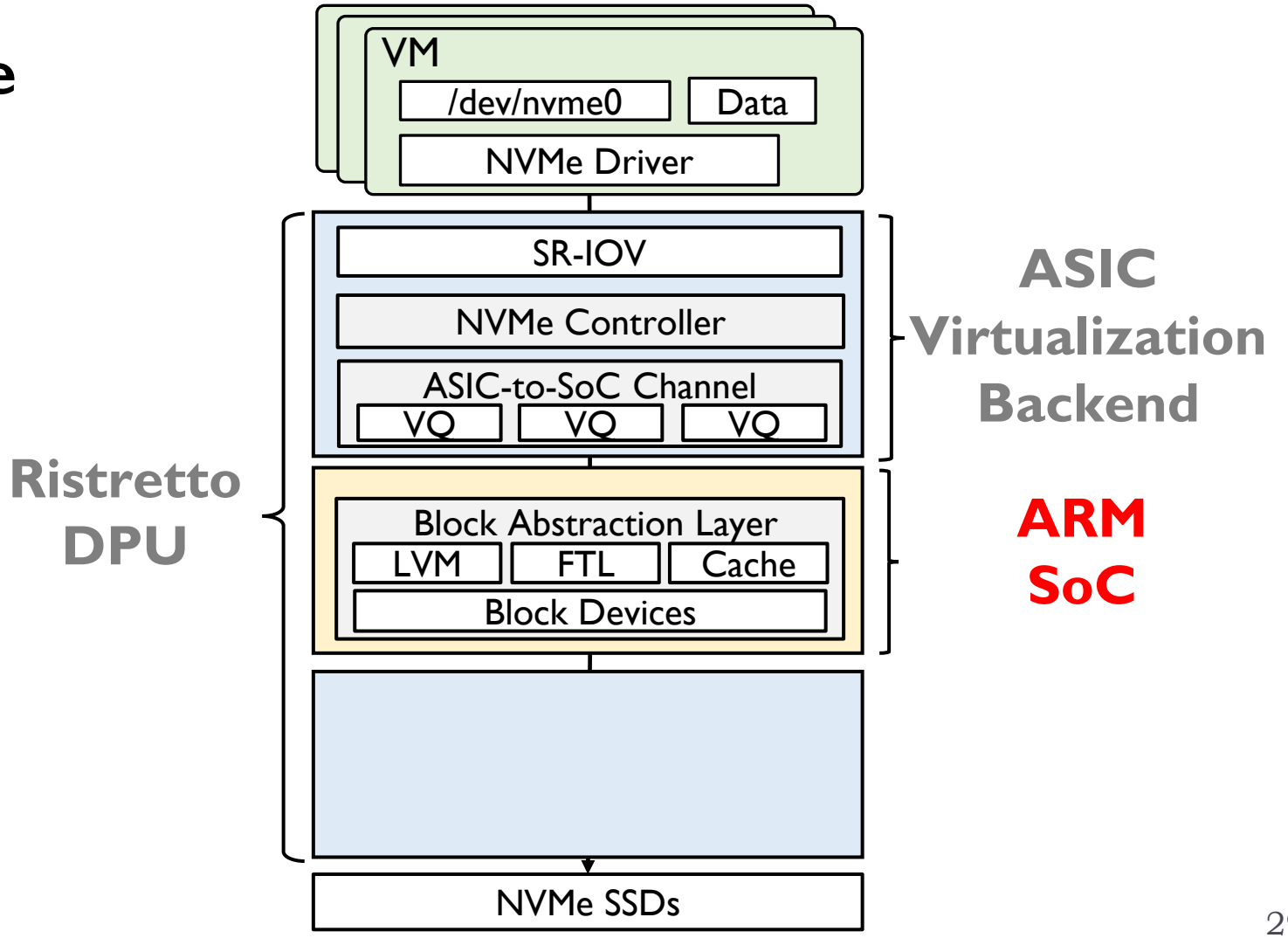
- ASIC virtualization backend
- ARM SoC



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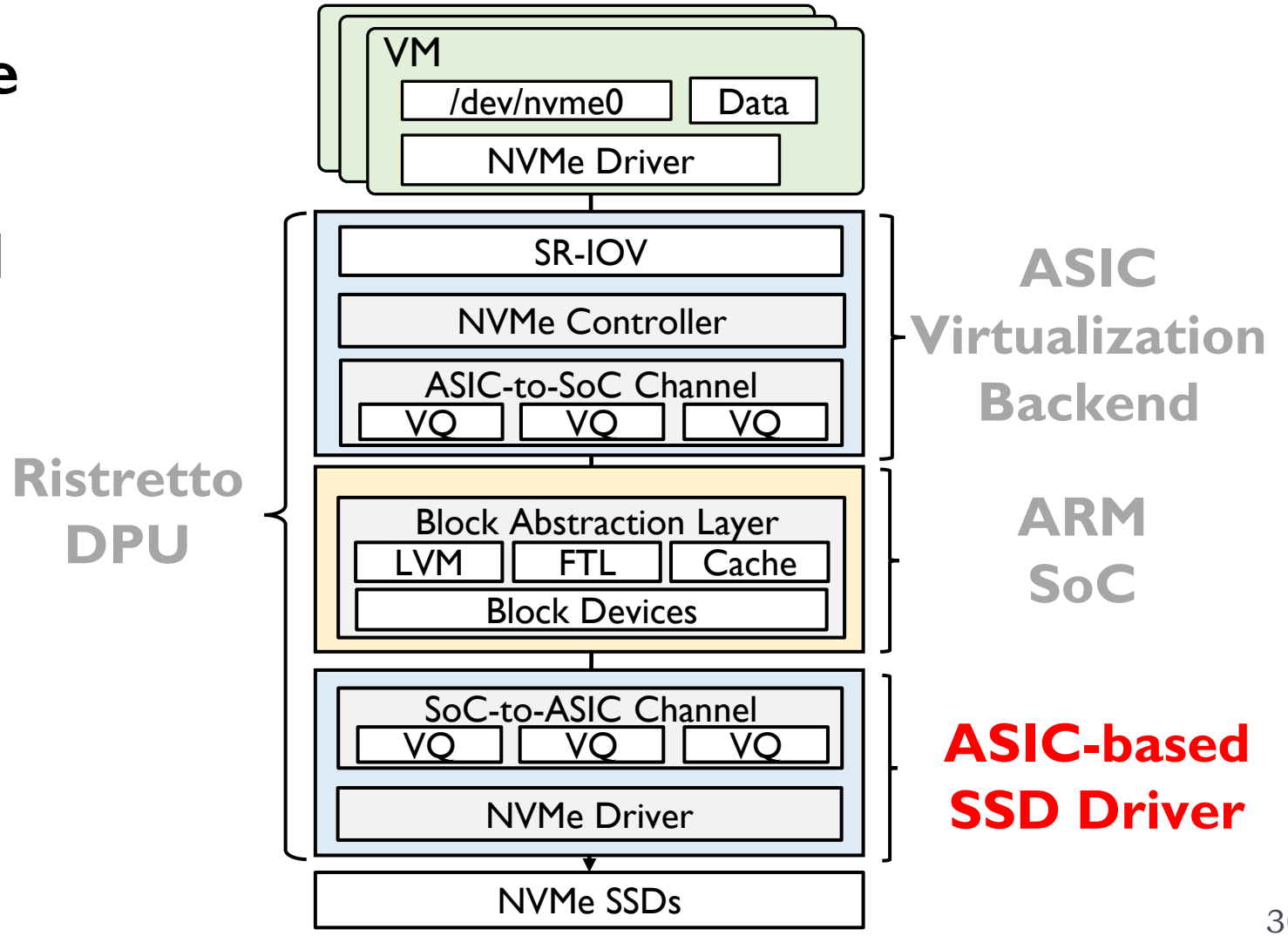
- ASIC virtualization backend
- ARM SoC
- ASIC-based SSD driver



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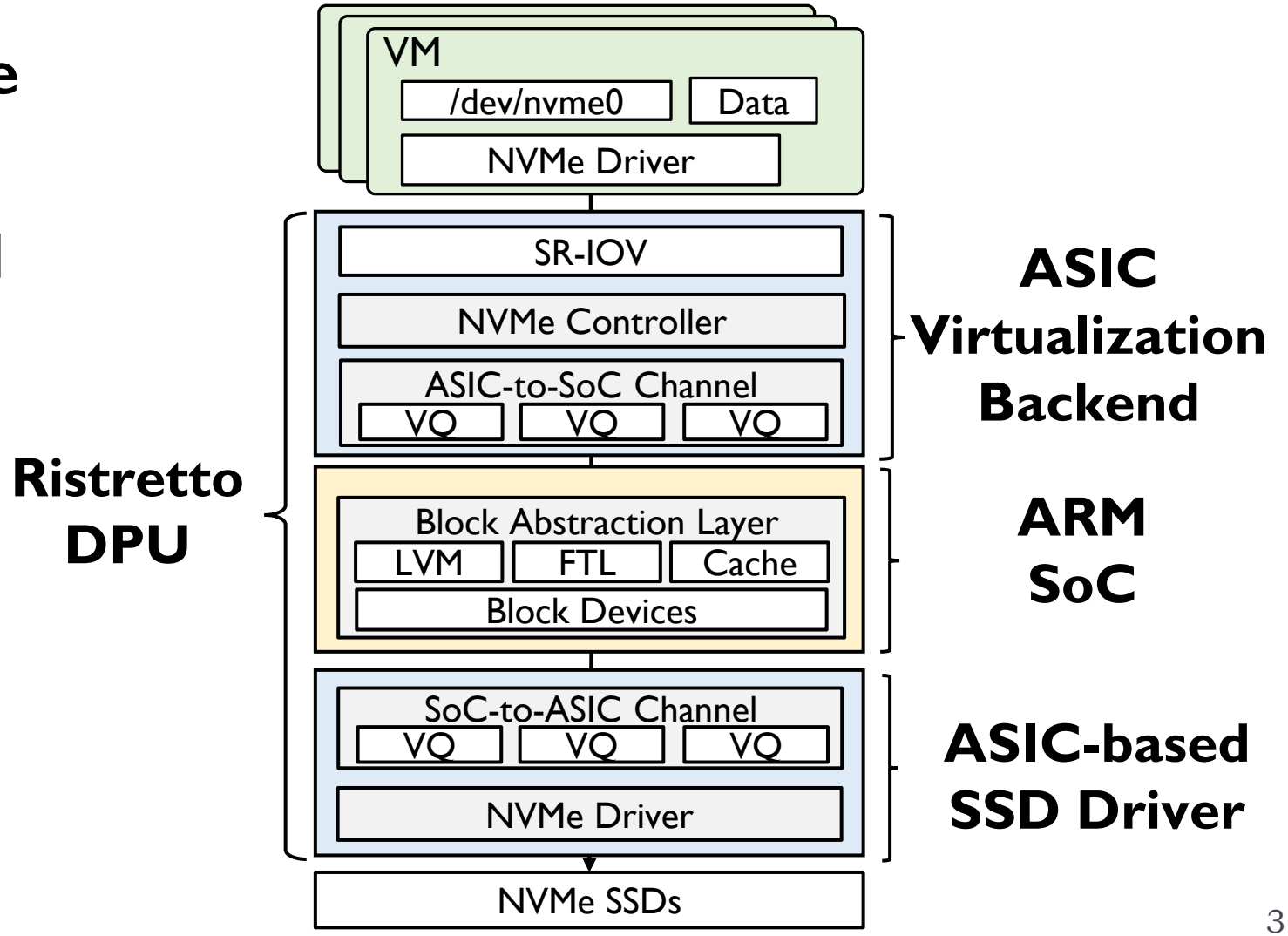

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Elastic Block Storage (EBS)

Compute-Storage Co-located

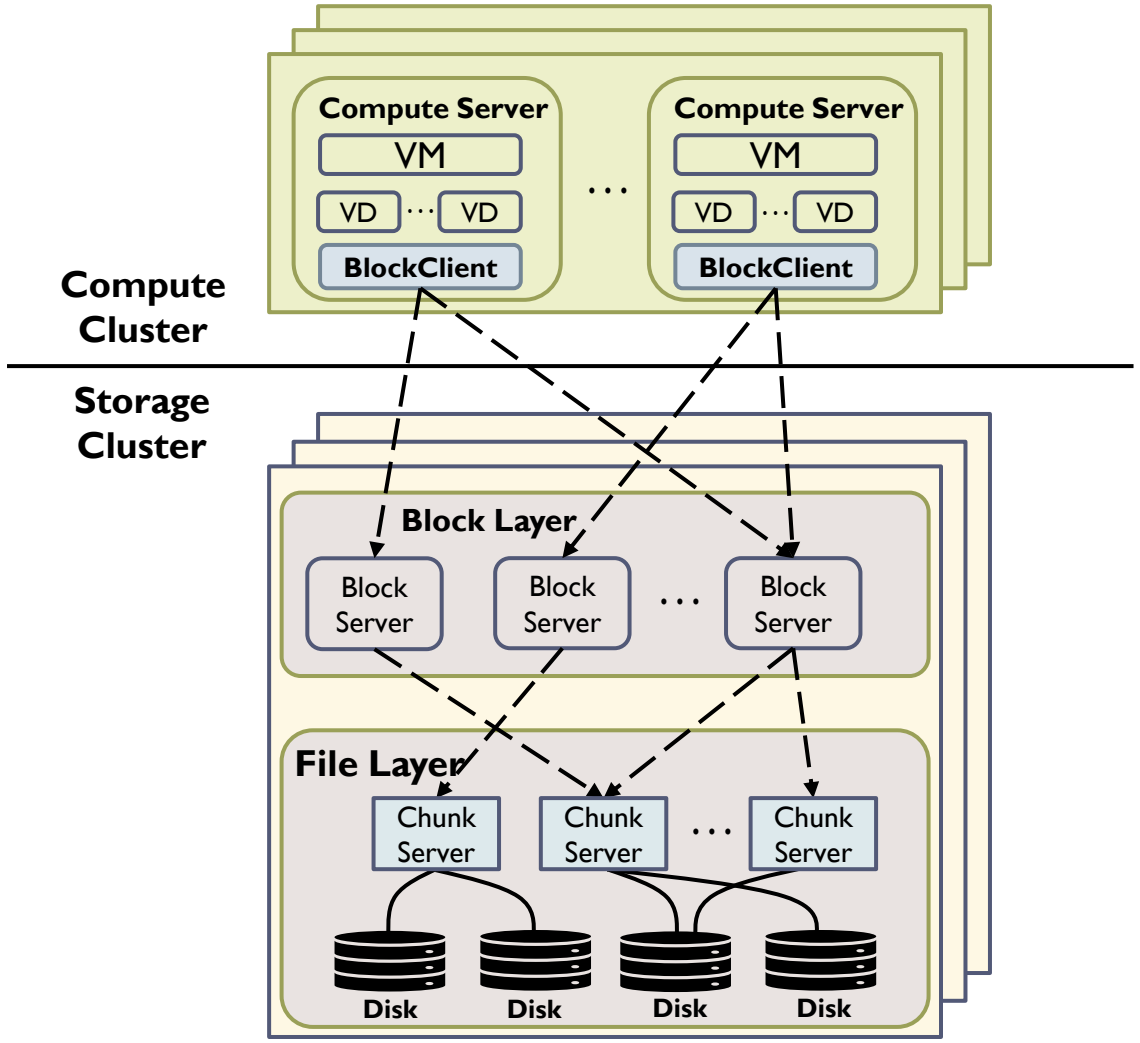
- Local Storage Limitations
  - Limited elasticity (unable to scale)
  - Limited to regions (certain AZs)
  - Limited availability (data loss)

V.S.

Compute-Storage Disaggregation

- EBS Advantages
  - Capacity scaling
  - Easy to access
  - Data redundancy

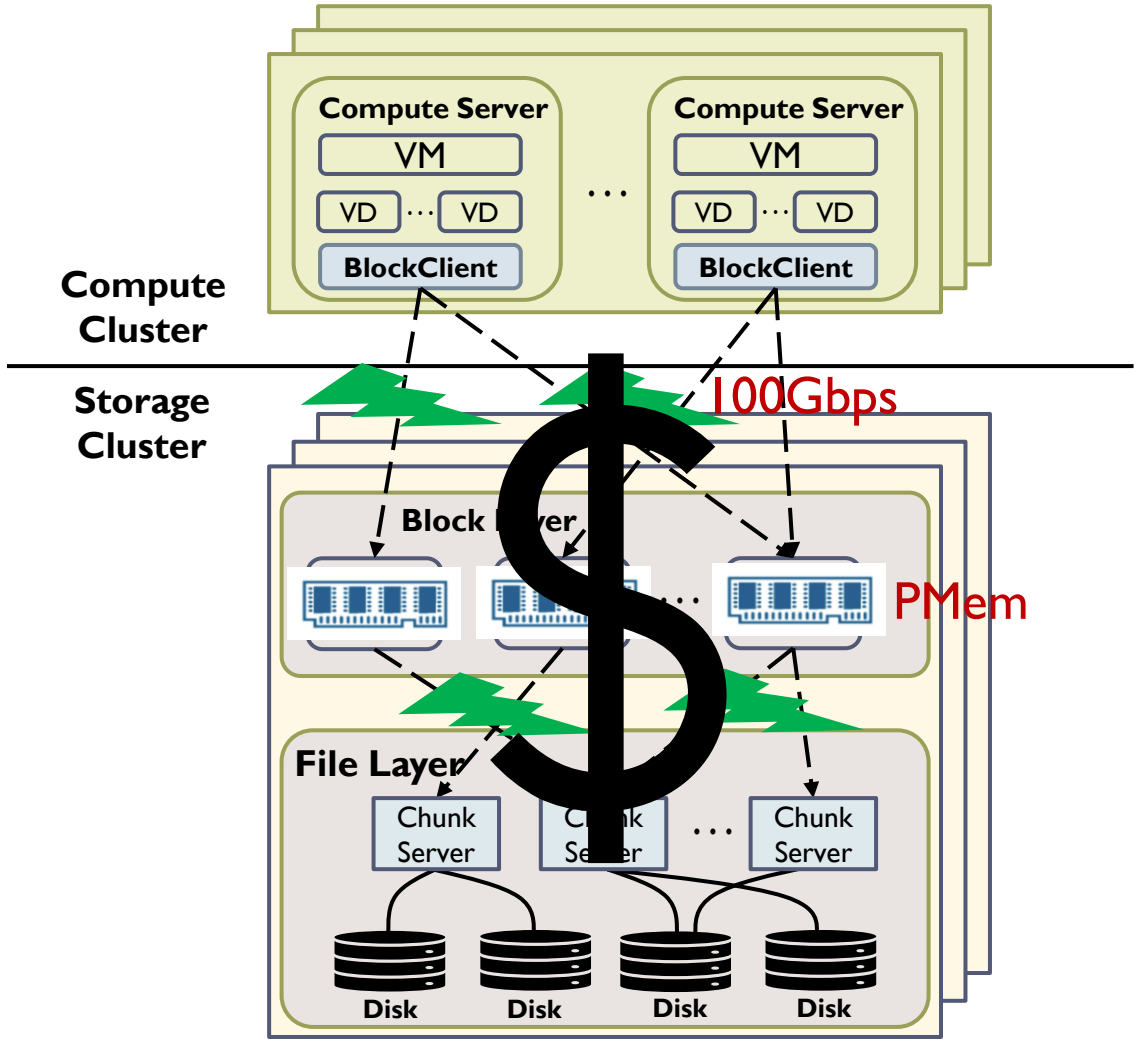
Elastic Block Storage (EBS)



Compute-Storage Disaggregation

- EBS Advantages
  - Capacity scaling (from 1GiB to 64TiB)
  - Easy to access (available in every AZ)
  - Data redundancy (three-replicas/EC)

EBSX ---- High-performance EBS



Compute-Storage Disaggregation

- EBSX as local storage
  - With all EBS advantages
  - Better storage media (PMem)
  - Low latency network (100Gbps)
  - Much higher price (~20x)

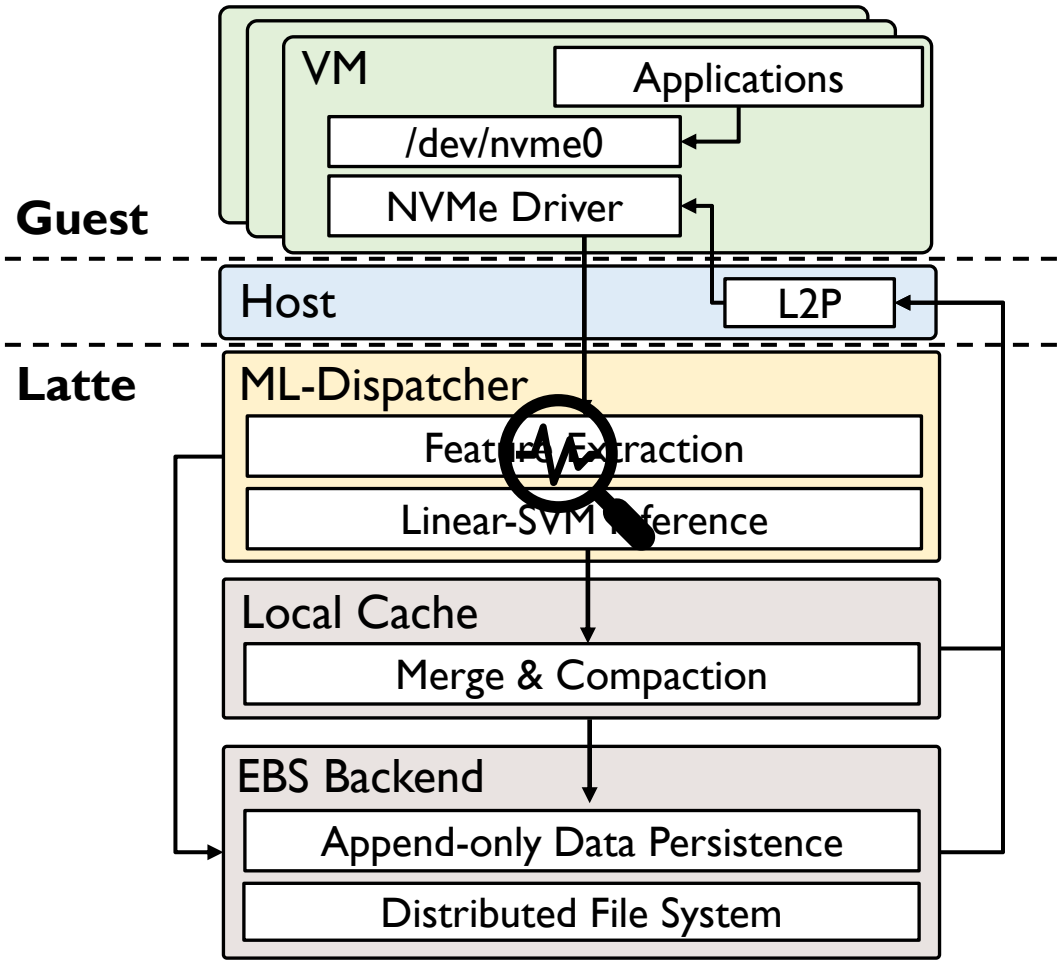
Latte: Local-Cloud Combined Storage

Local as Cache & EBS as Backend

- Append-only write
- Merge I/O in local cache
- Elastic backend capacity
- Strong reliability

ML-based dispatcher for write

- Learn workload pattern
- Write-to/-bypass cache
- Detect I/O tail-latency



(a) Write Path

Latte: Local-Cloud Combined Storage

Local as Cache & EBS as Backend

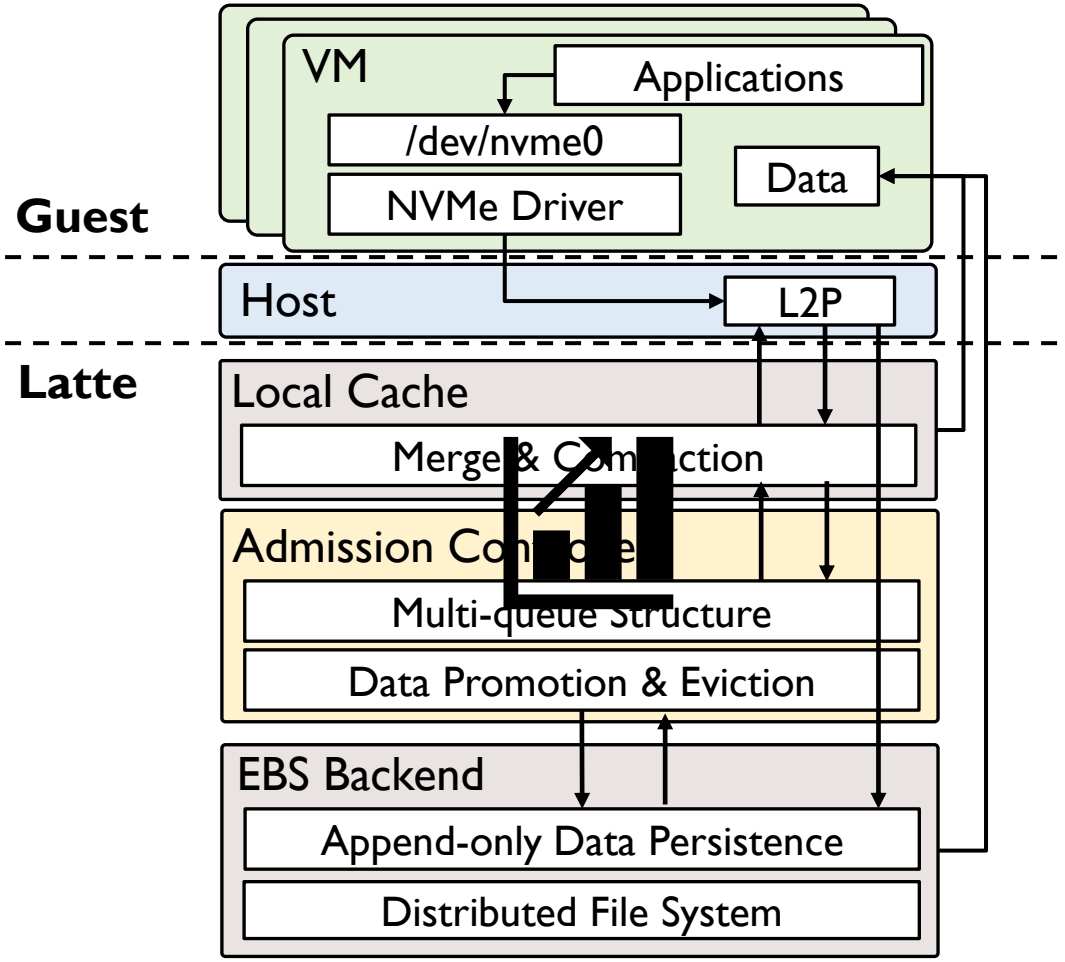
- Low local latency and elasticity of EBS

ML-based dispatcher for write

- Decide I/O path for lower tail-latency

Admission control for read

- Track data access frequency
- Promote hot data & Evict cold data
- Improve cache hit rate and space utilization



(b) Read Path

Experimental Setup

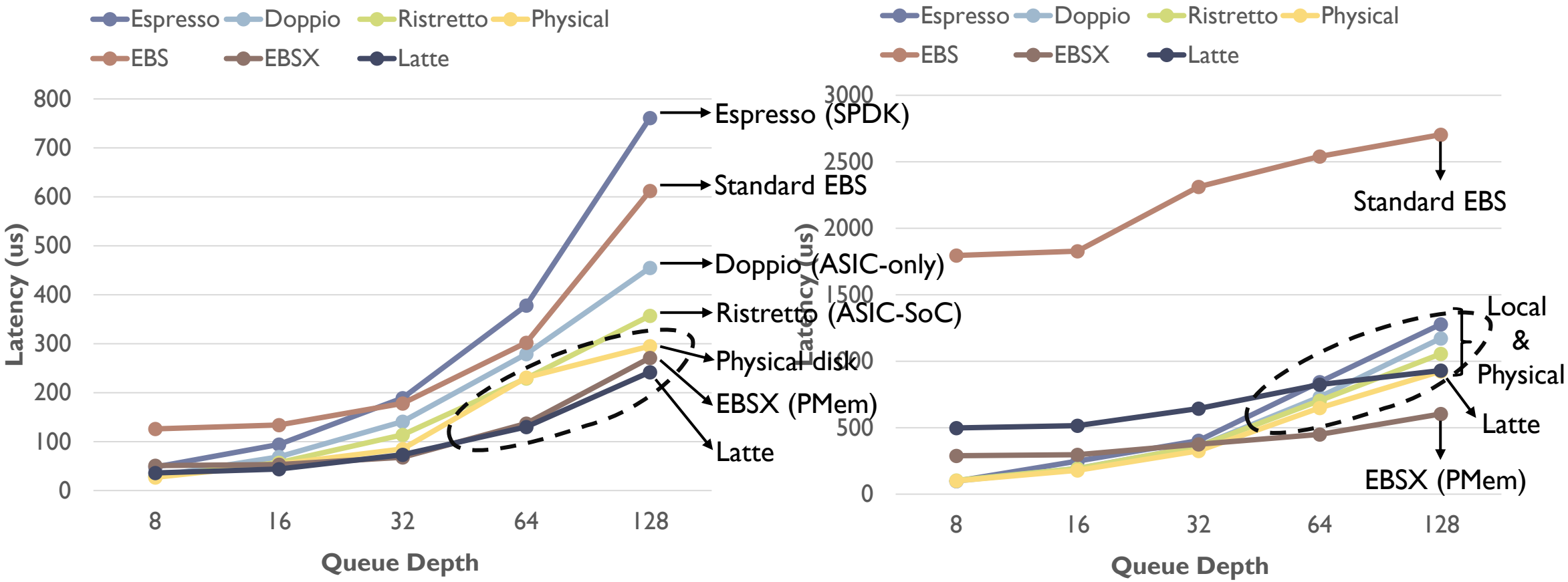
Hardware

- Local storage disks:
  - Espresso, Doppio and Ristretto
- Physical disks:
  - Enterprise Gen4 NVMe SSD
- Cloud disks:
  - Standard EBS, EBSX
- Latte:
  - Ristretto cache + Standard EBS backend

Software

- VMs:
  - 8 VDs backed by 8 PCIe Gen4 local disks
  - 128 vCPU cores; 8 cores for SPDK polling
  - Each mounts one EBS/EBSX cloud disk
- Customized SPDK FTL
  - Mount Latte as an SPDK Block Device in VM
- FIO
  - Micro-benchmarks and trace replay

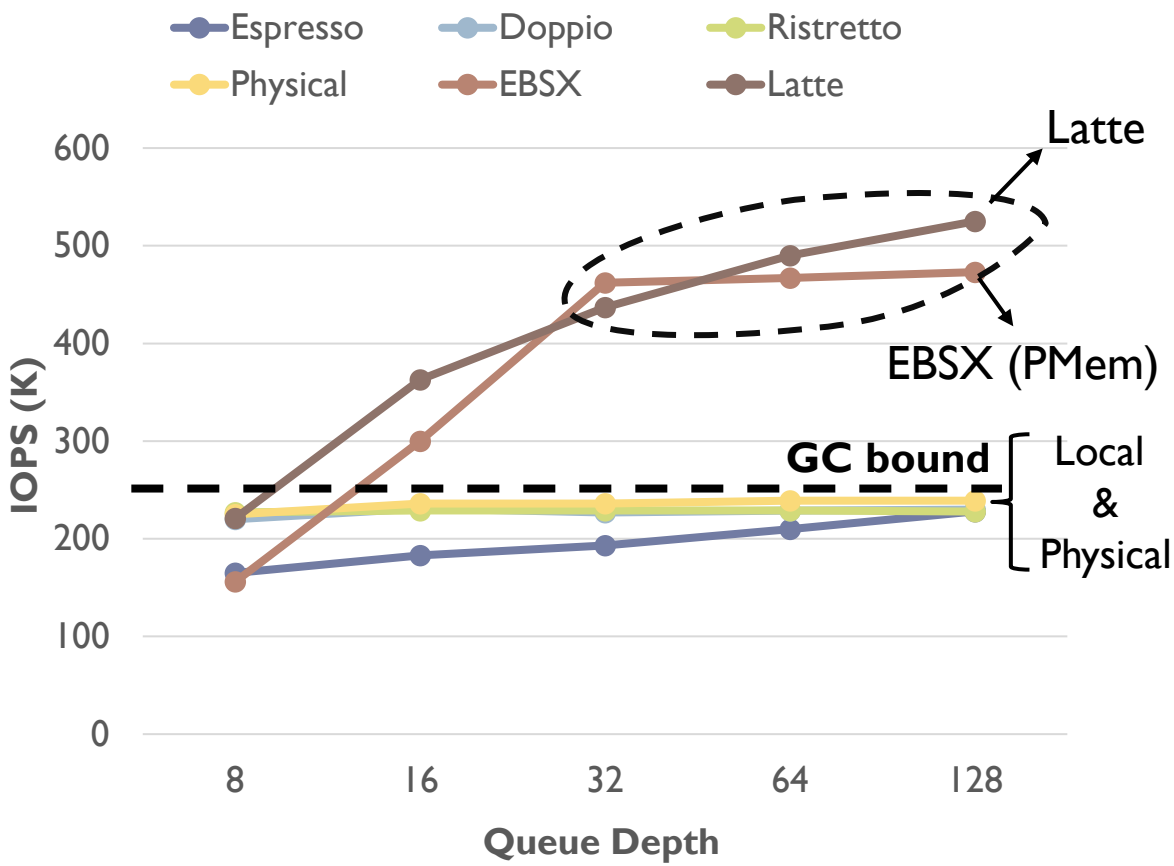
Micro-benchmark



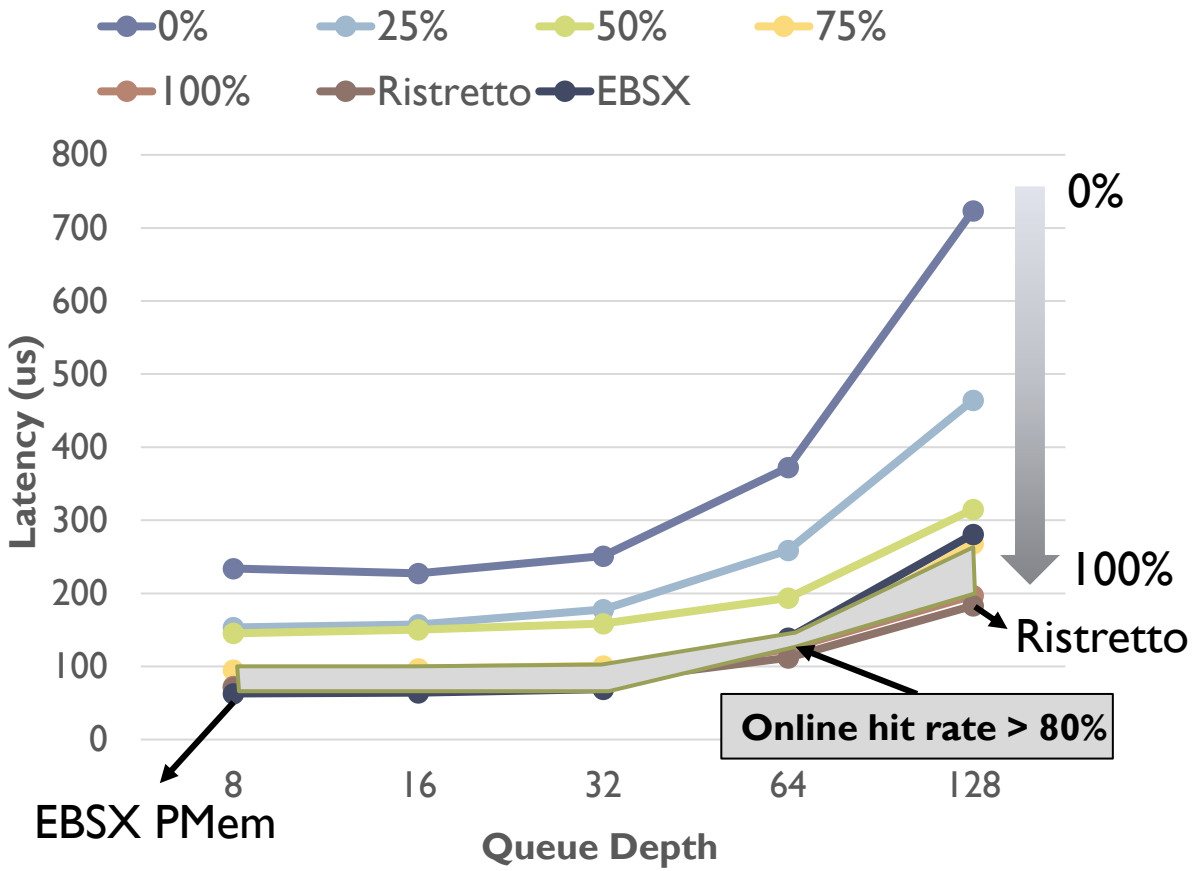
❑ **Avg. Latency**

❑ **P99.9 Latency**

Micro-benchmark

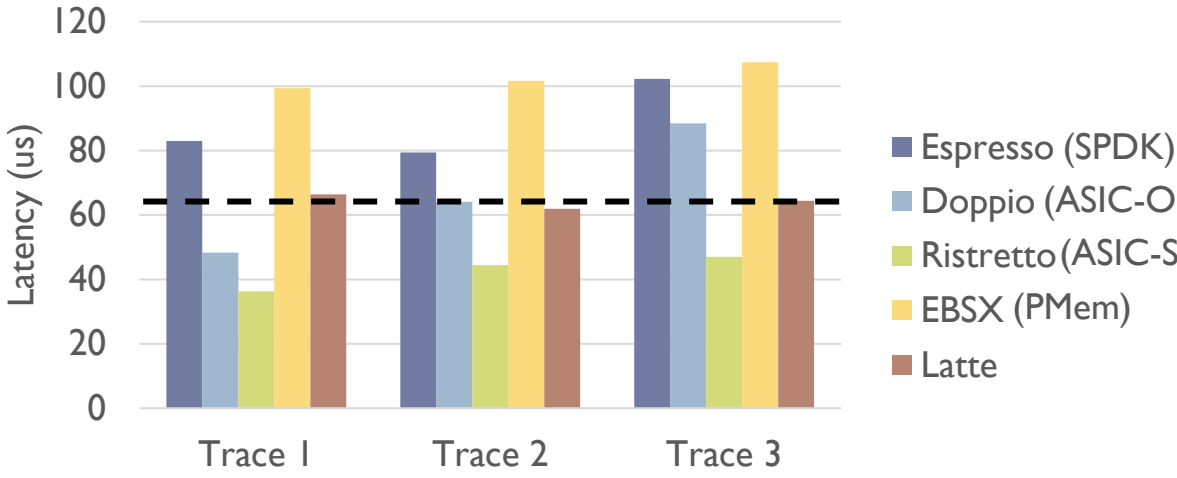


❑ **Write IOPS w/ GC**

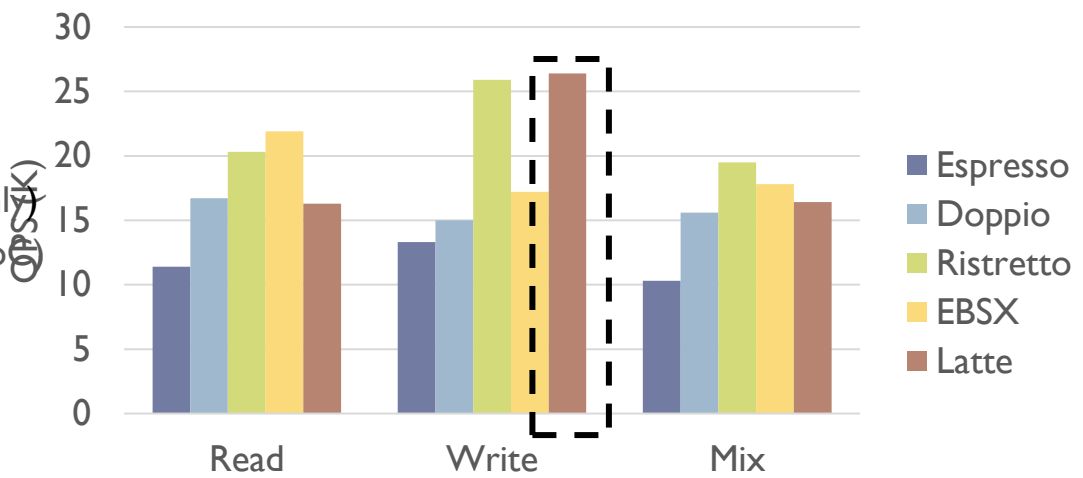


❑ **Read Latencies of various hit rates**

Macro-benchmark



- **Online Traces Replay Latency**



- **MySQL Sysbench Test**

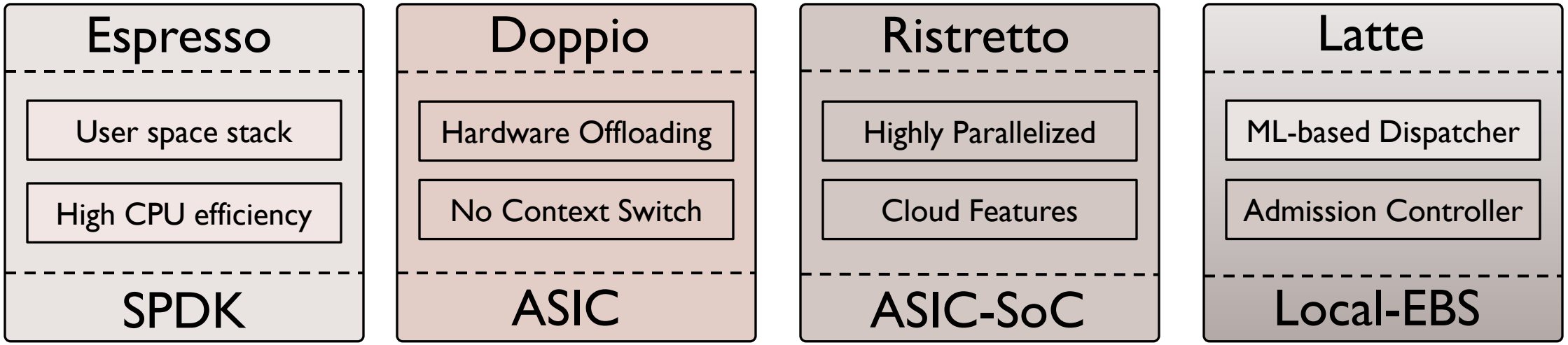
CapEx

Type	Max. IOPS	Max. Throughput	Unit Price
Ristretto	550K	6.7GB/s	1
EBSX	450K	6.0GB/s	~ 20$
Latte	750K	8.9GB/s	2.1 ~ 4.0

- **Local storage** is cheap with limitations
- **EBSX** has much larger CapEx than **local**
- **Latte** reduces unit price with higher perf

Conclusion

- **Evolution of Local Storage Stack**
  - SPDK for Espresso
  - ASIC-only for Doppio
  - ASIC-SoC Design for Ristretto
- **Latte: Future of local storage**
  - Local-cloud hybrid storage stack
  - ML-based dispatcher for write path
  - Admission controller for read path



Thank You!

Q & A

More details are in the paper