What's the Story in EBS Glory: Evolutions and Lessons in Building Cloud Block Store

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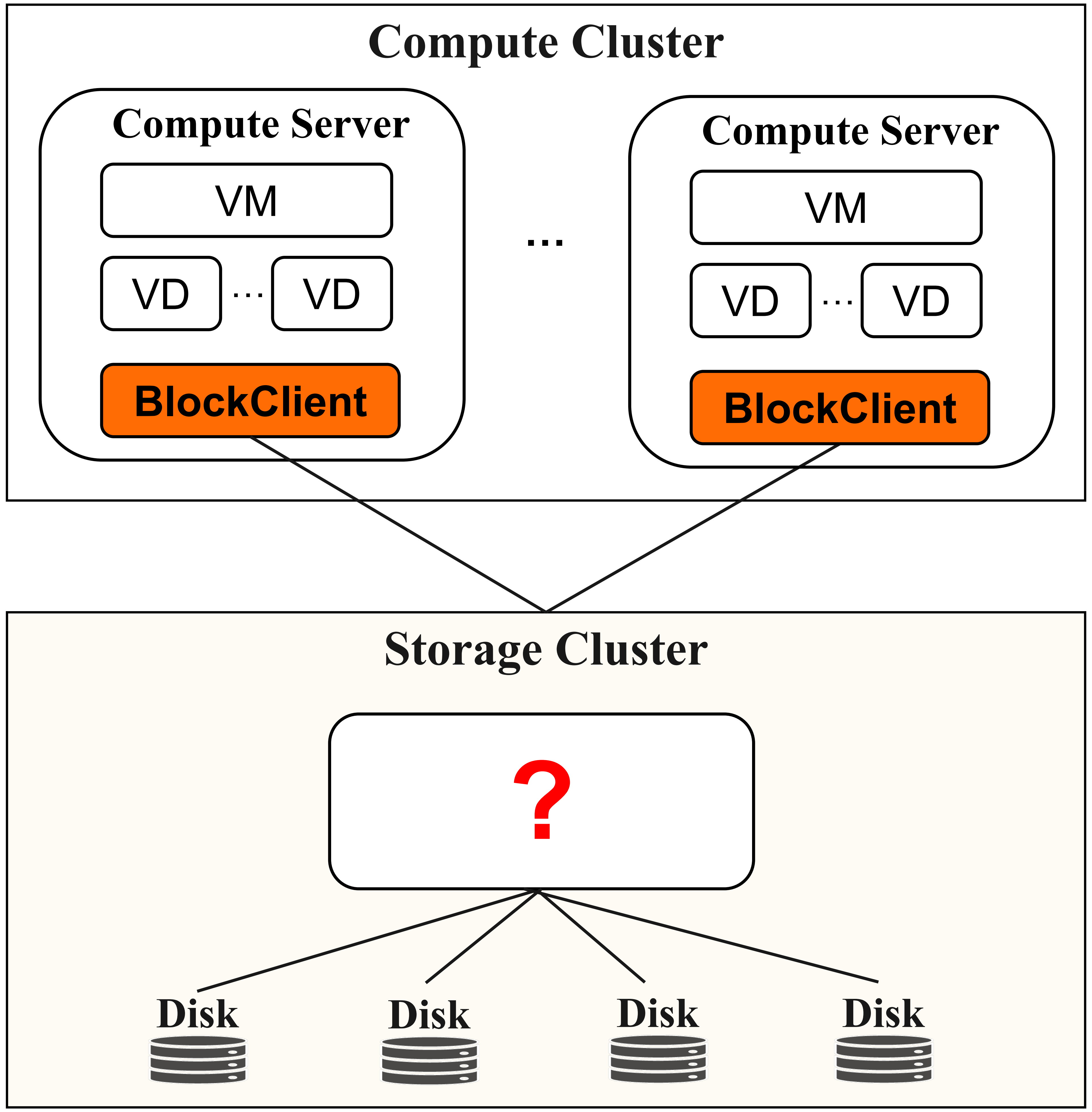
Alibaba Group

29 Feb 2024

Background: Elastic Block Store

- **EBS**
  - ✓ **VM: Virtual Machine**
  - ✓ **VD: Virtual Disk**
- **Goal**
  - ✓ **High Performance**
  - ✓ **High Elasticity**
  - ✓ **High Availability**
- **Compute-Storage Disaggregation**
  - ✓ **VMs and VDs are on different clusters**



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Evolutions of EBS

Elasticity: A Tale of Four Metrics

Other Topics

EBS1: an Initial Foray

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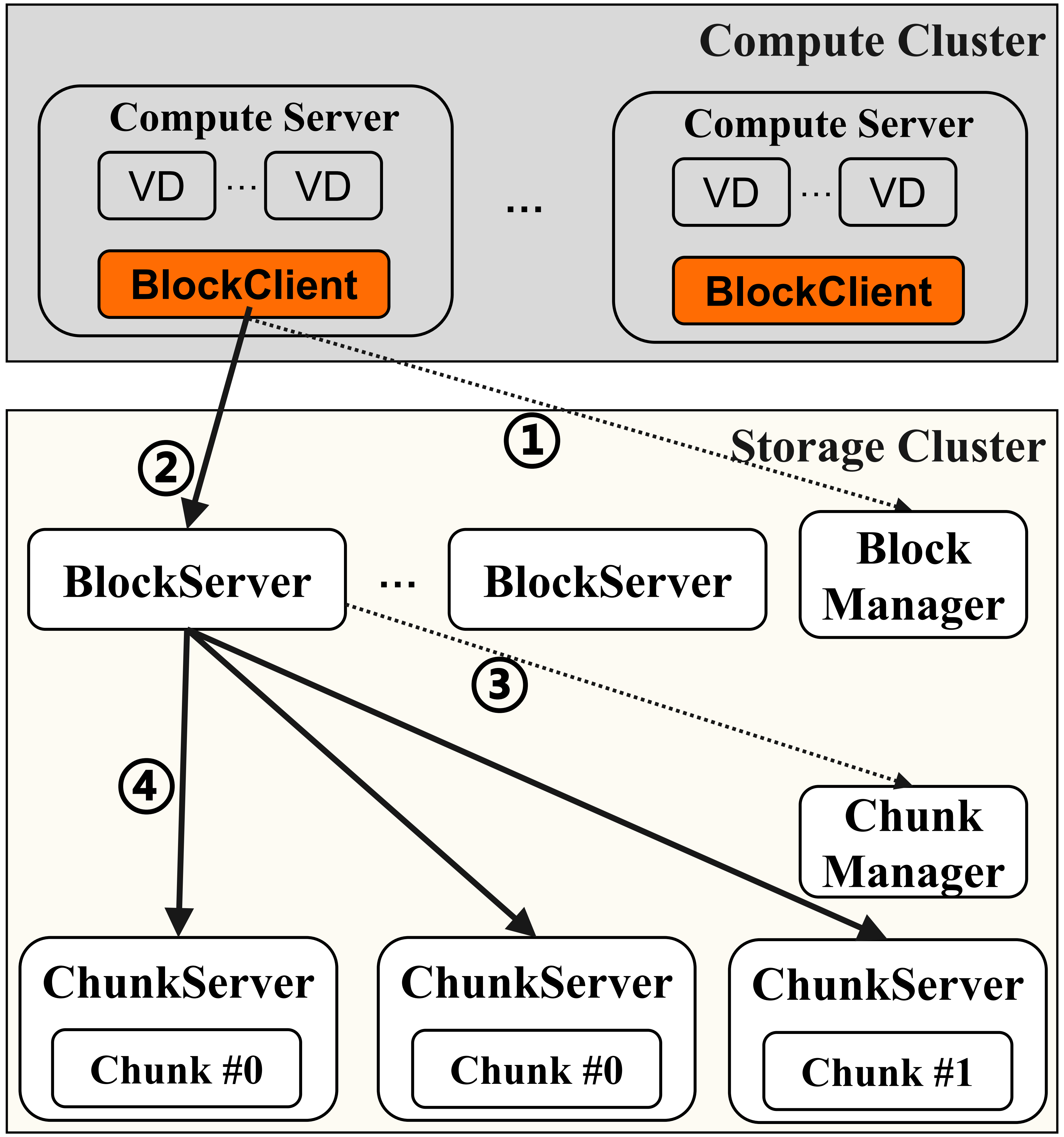
- **Design Goals**
  - ✓ Straightforward design for fast development/deployment
- **Architecture**
  - ✓ VD space is partitioned into fixed-size Chunks (64 MiB)
  - ✓ Two-layer: Blockserver + Chunkserver
  - ✓ Each Chunk is an Ext4 file
- **Features**
  - ✓ In-place updates: VD = Ext4 files
  - ✓ N(VDs)-to-1(blockserver) binding



EBS1: An Initial Foray

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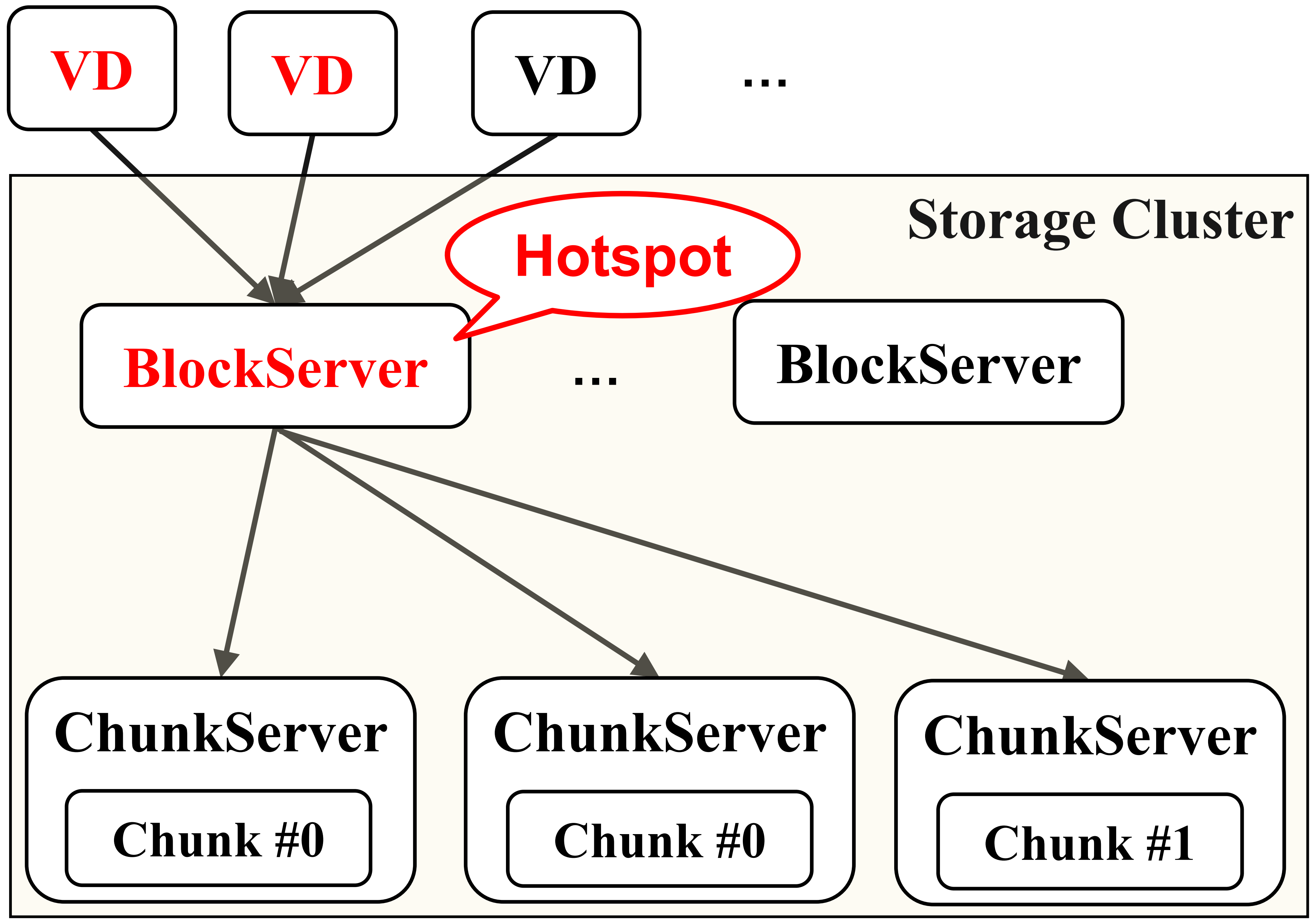
Deployment

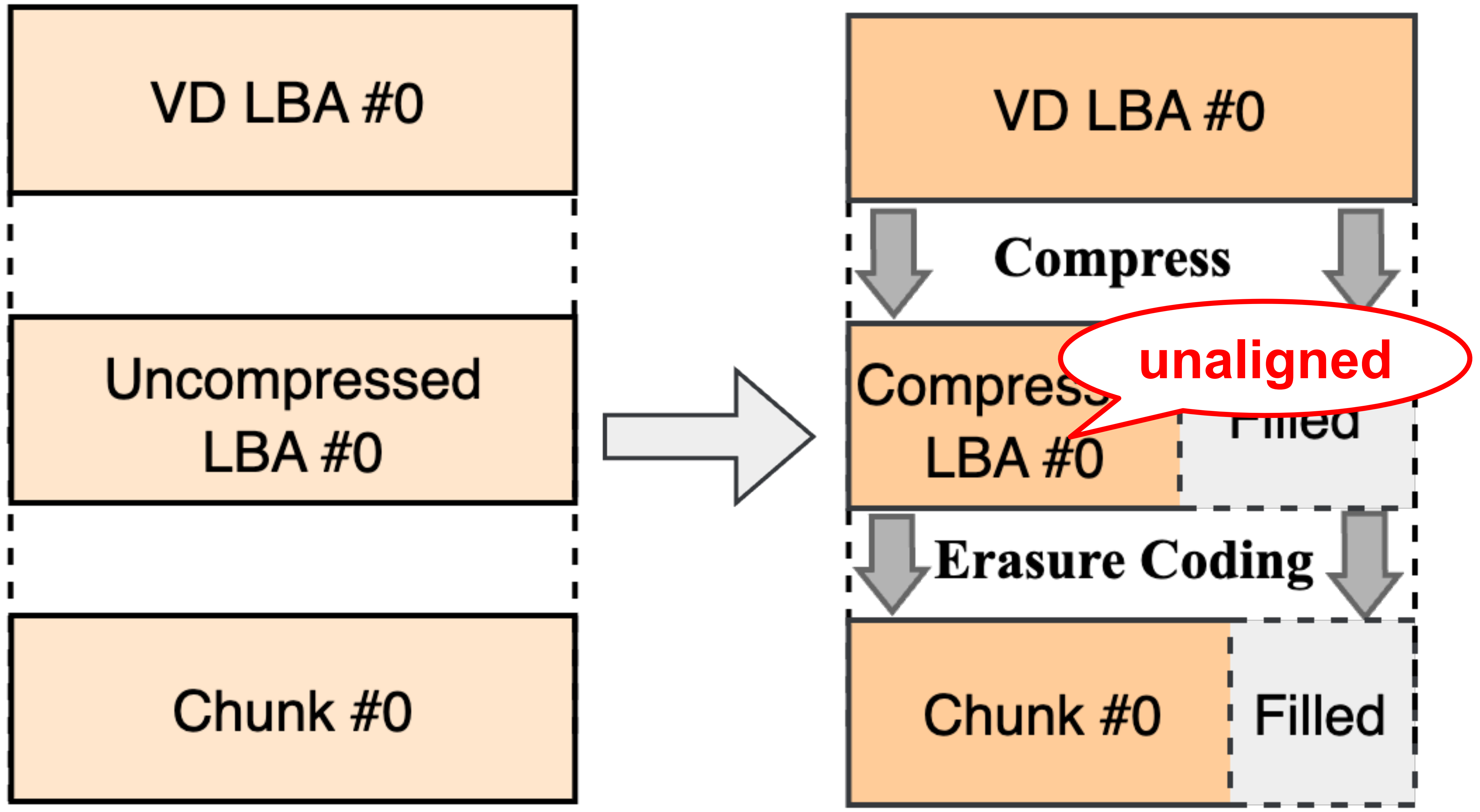
✓ Released in 2012, served over 1 million VDs and stored hundreds of PBs of data across hundreds of clusters

Limitations

✓ N-to-1 mapping leads to a single hot-point bottlenecks and restricts performance



✓ In-place updates hinder the implementation of compression and EC, thereby reducing cost-efficiency



EBS2: Speedup with Space Efficiency

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● Design Goals

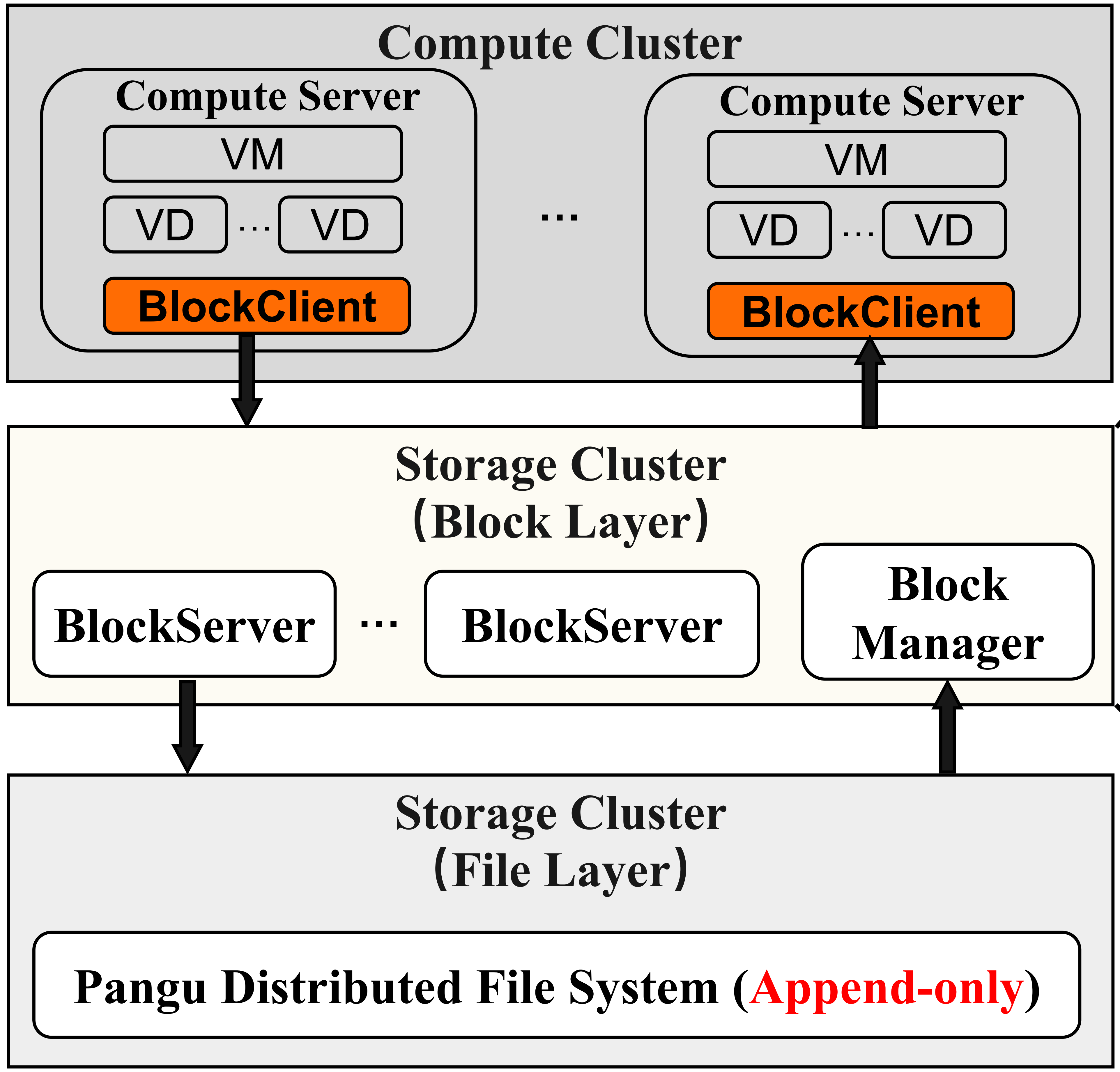
✓ High **performance** and high **space efficiency**

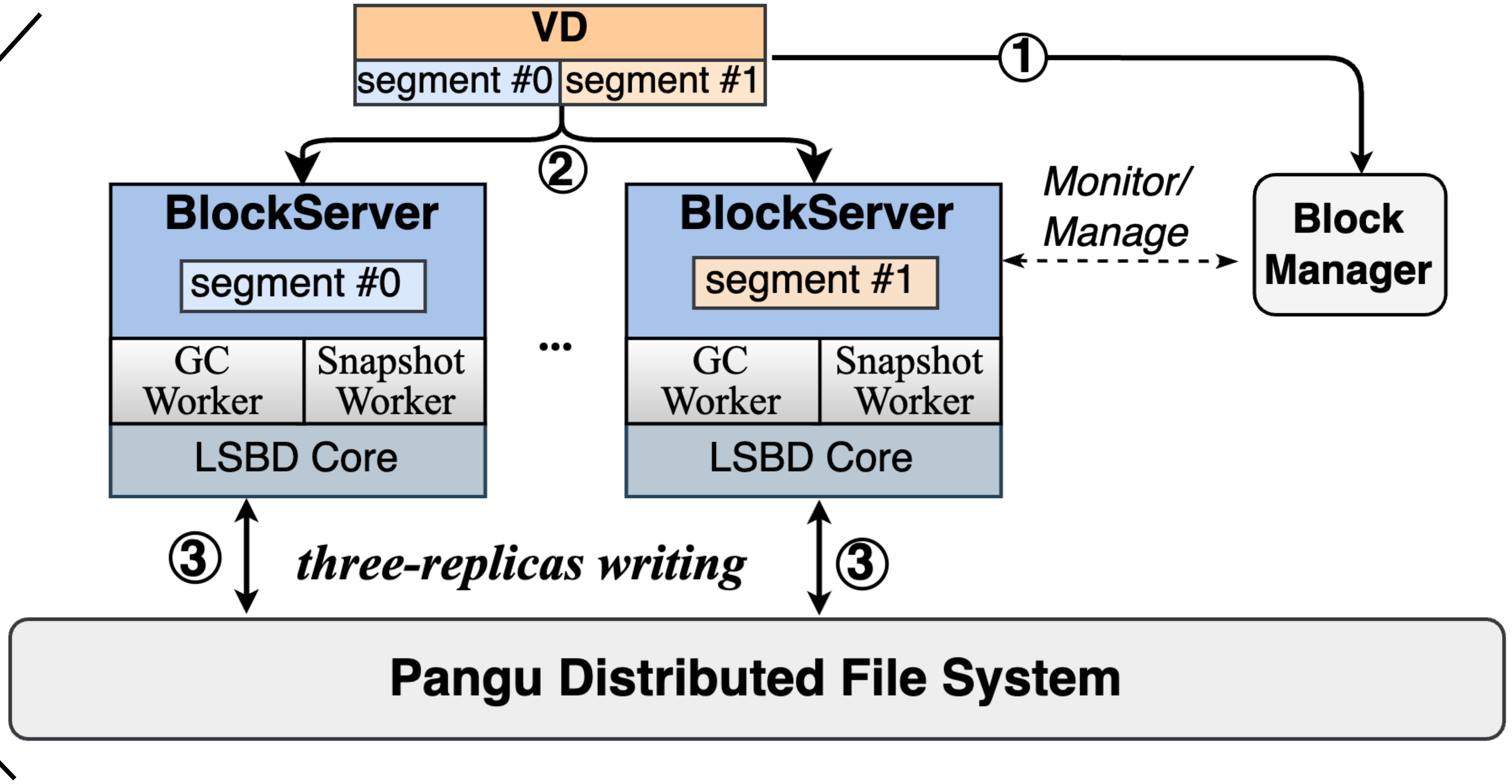
● Key Designs

✓ Disk segmentation

✓ Log-structured Block Device (LSBD)

✓ GC with EC/Compression

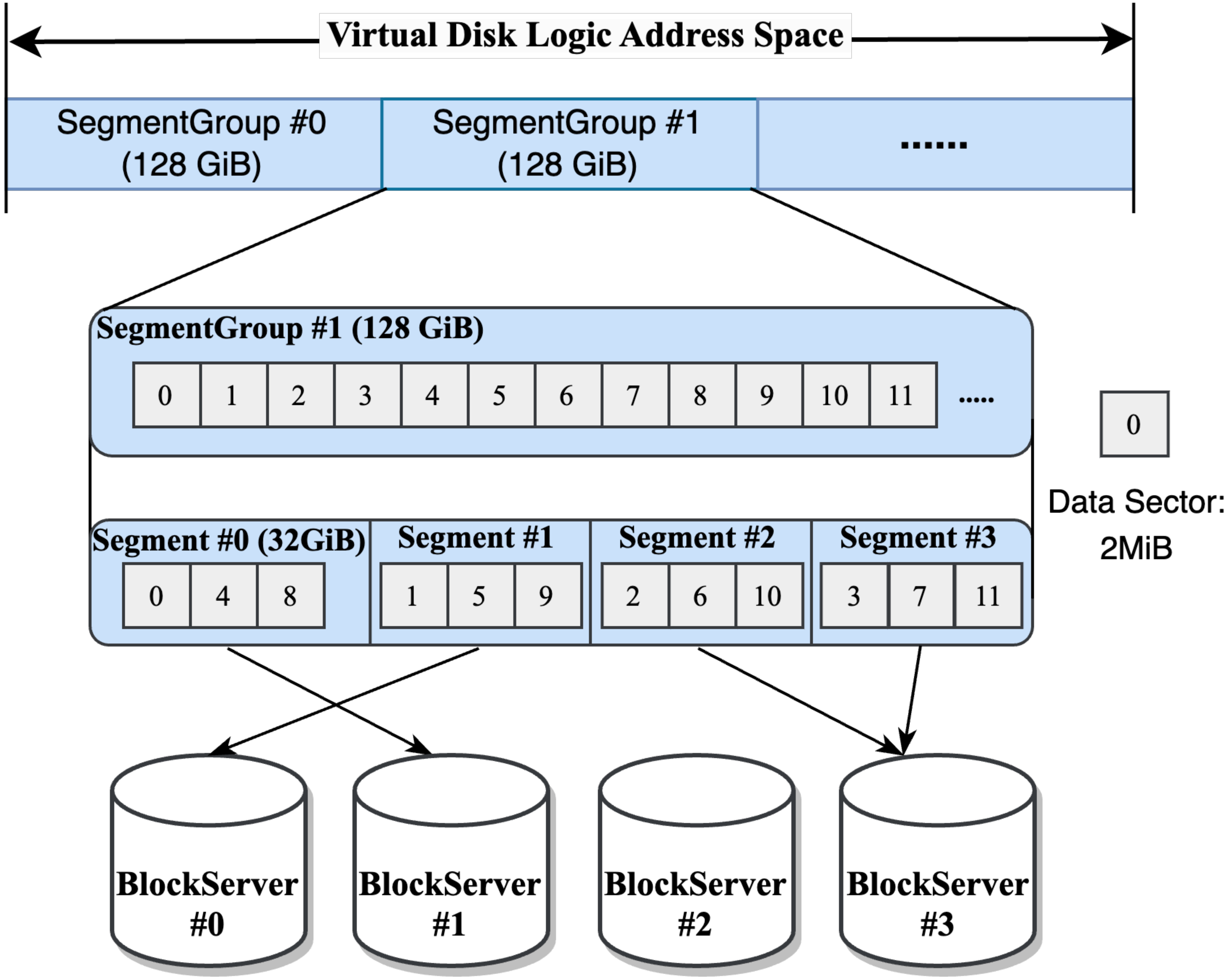




EBS2: Speedup with Space Efficiency

Disk Segmentation

- ✓ The entire VD logic space is divided into multiple contiguous **SegmentGroups**
- ✓ Each **SegmentGroup** is organized as a series of **Data Sectors**
- ✓ Data Sectors are allocated to the **Segments** in a Round-Robin Fashion
- ✓ BlockServers operate at the granularity of **Segments**



EBS2: Speedup with Space Efficiency

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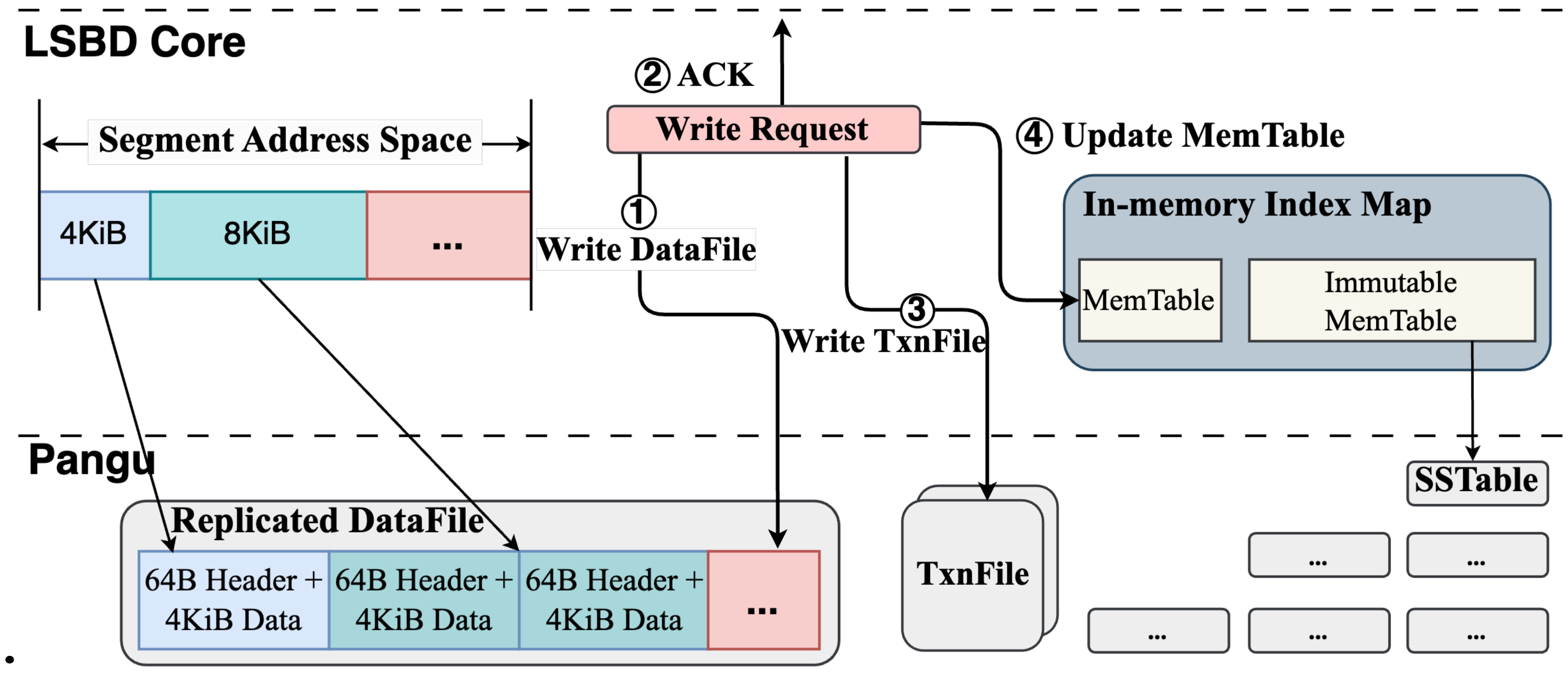
● Log-structured Block Device

- ✓ DataFile = (4KB data +64B Header) x N
- ✓ Txnfile for speeding up failover
- ✓ In-memory Index Map for speeding up read.



EBS2: Speedup with Space Efficiency

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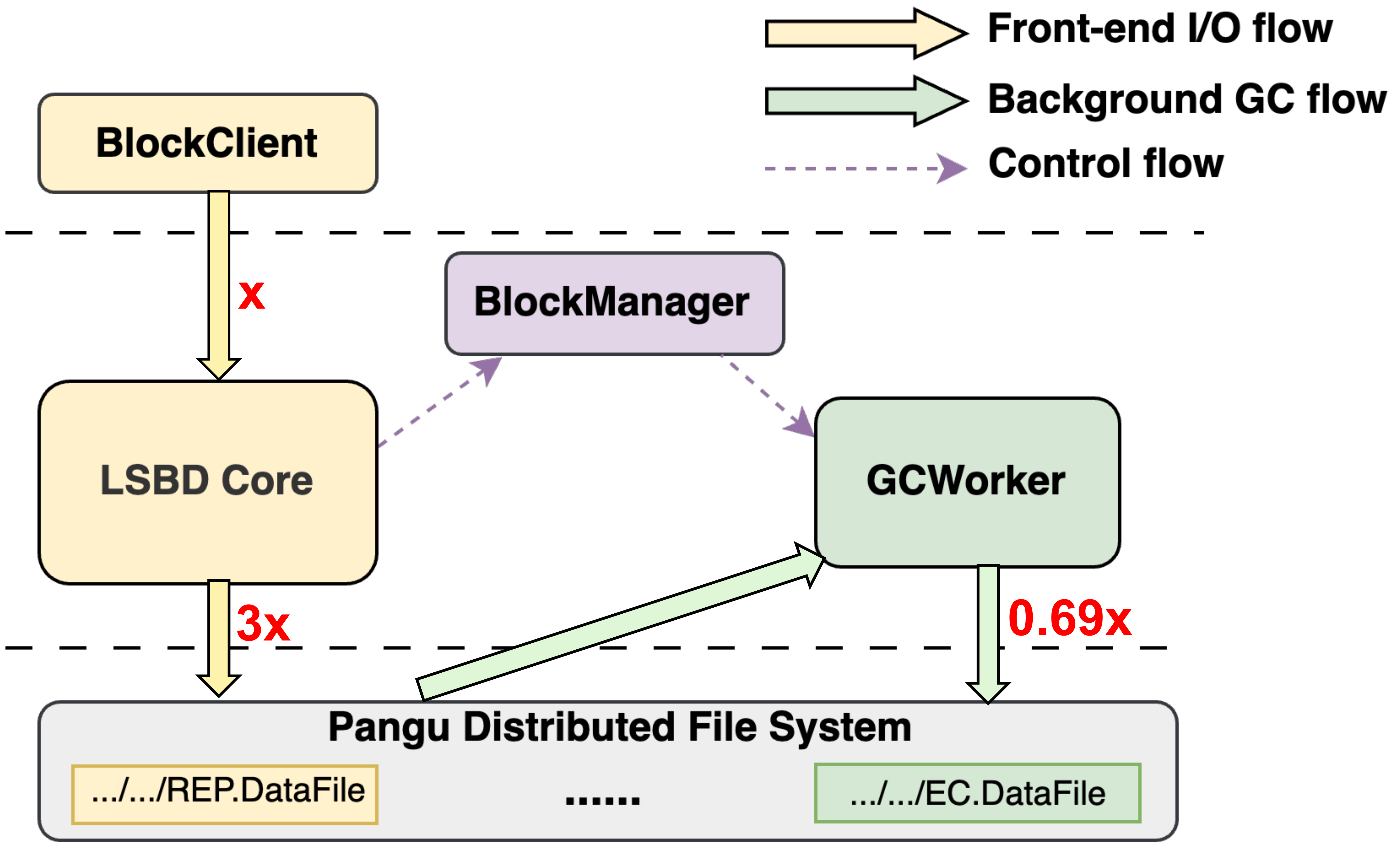
● GC with EC/Compression

- ✓ LSBD splits traffic into **frontend** (i.e., client I/Os) and **backend** (i.e., GC and compression)
- ✓ GC runs at the granularity of **DataFiles**
- ✓ GC converts the "REP.DataFiles" to "EC.DataFiles" with **EC(8, 3)** and **LZ4/ZSTD** compression algorithms



$$SpaceCost_{EBS1} = 3$$

$$SpaceCost_{EBS2} = 1(\text{original}) \times 0.5(\text{compressed}) \times \frac{8+3}{8}(\text{EC}) = 0.69$$

EBS2: Speedup with Space Efficiency

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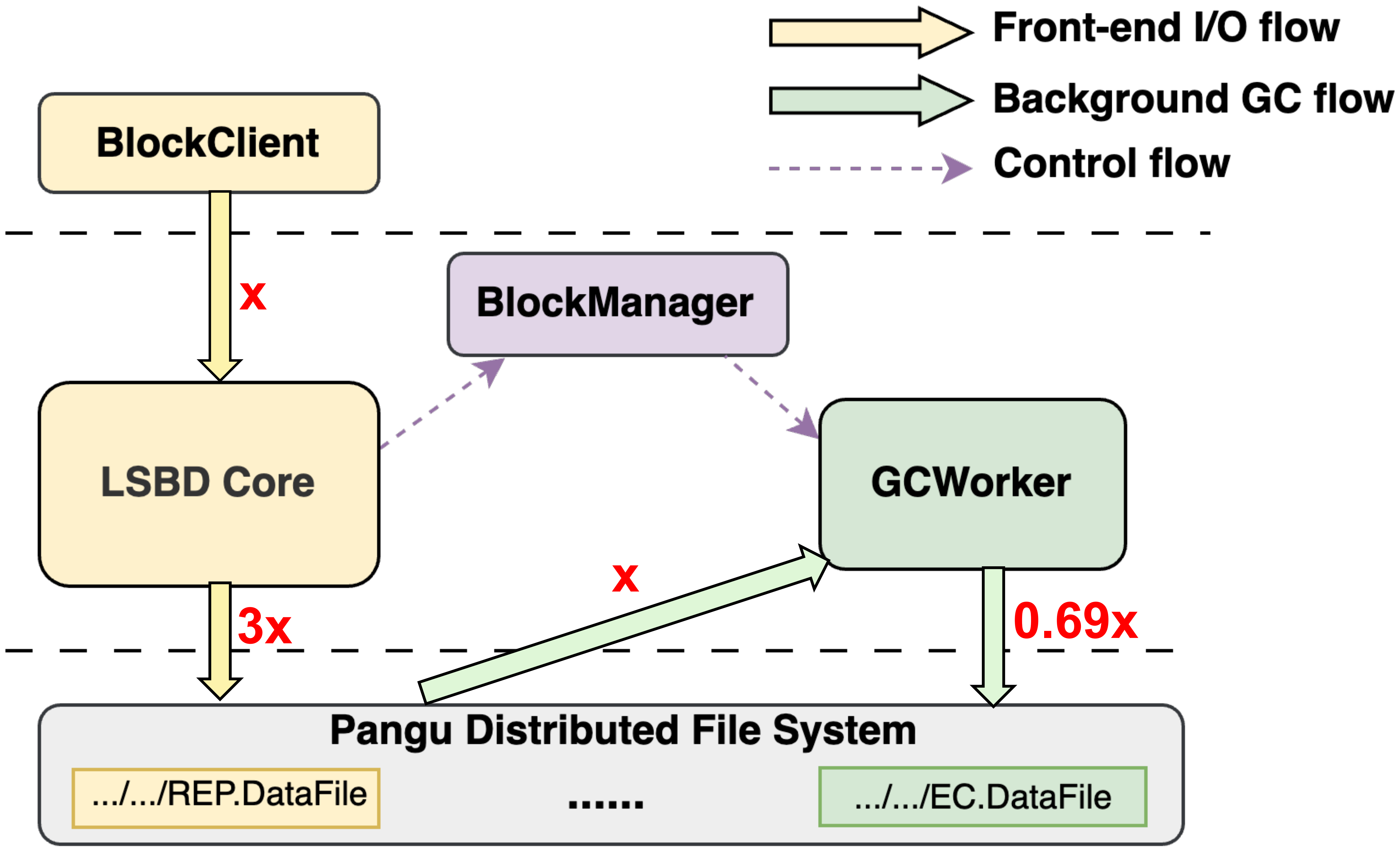
Deployment

- ✓ 100μs avg. write latency and 1 million IOPS per VD.
- ✓ Over 500 clusters and served for 2 million VDs.
- ✓ Low to 1.29 data replicas.

Limitations

- ✓ Traffic amplification up to 4.69.
- ✓ As the cost per GiB of SSD decreases, cloud storage has shifted from space-sensitive to traffic-sensitive.



$$TrafficAmplification_{EBS1} = 3x \div x = \mathbf{3}$$

$$TrafficAmplification_{EBS2} = (3x + x + 0.69x) \div x = \mathbf{4.69}$$

EBS2 with Foreground EC/Compression?

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- **Fragmented requests prevent Online Compress-EC**
  - ✓ EC requires the raw data blocks to typically be at least 16KB
  - ✓ Nearly 70% of write requests are smaller than 16KB
  - ✓ Waiting for merging incurs extra latency (ranging from 10us to 100ms)

- **CPU-based compression is slow**
  - ✓ 16KB-sized data blocks compression = 25us for CPUs
  - ✓ CPU resource contention leads to lower throughput

EBS3: Foreground EC/Compression

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Design Goals

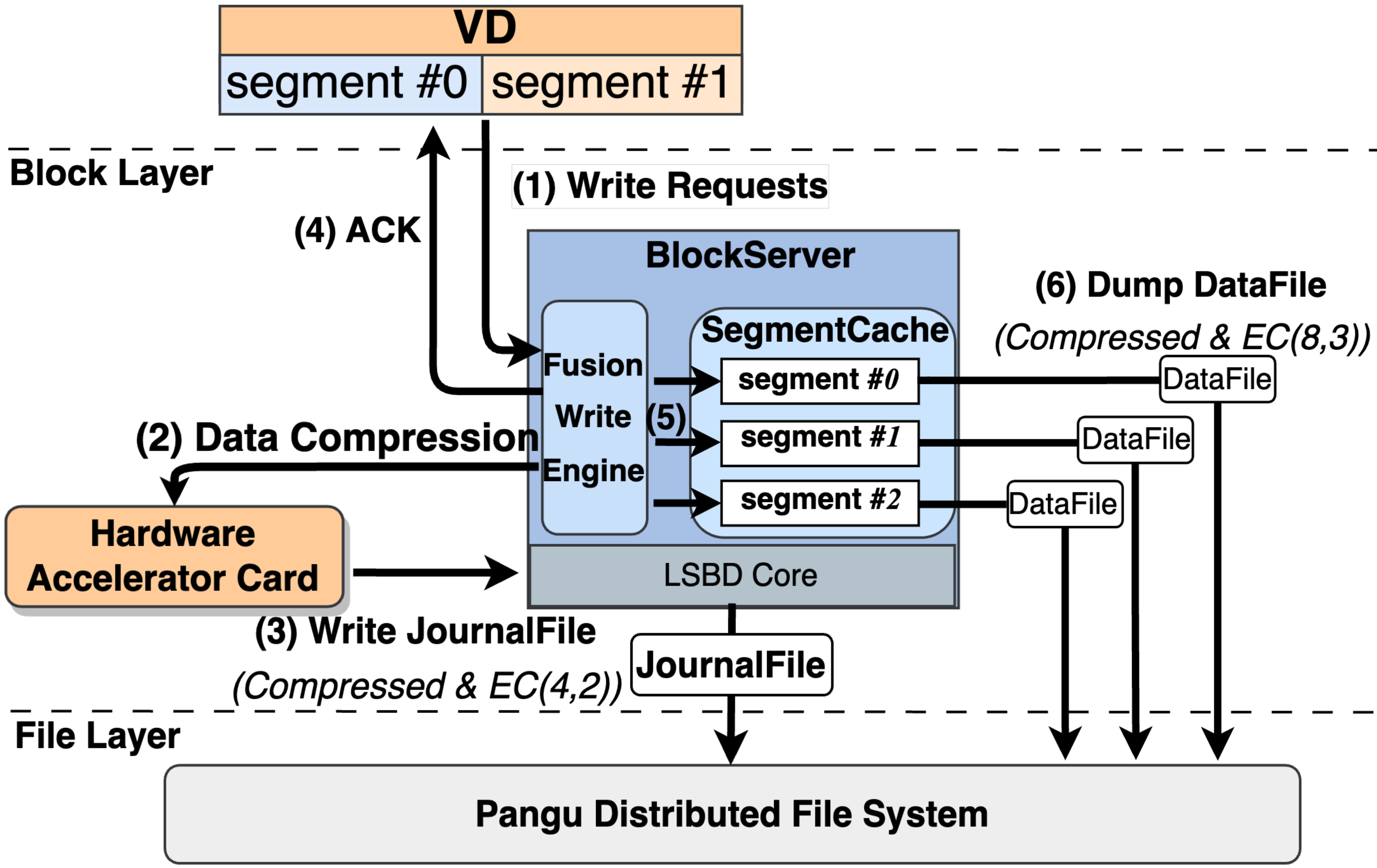
- ✓ Lower traffic consumption and storage space costs
- ✓ No performance loss

Key Designs

- ✓ Bifurcated write path
- ✓ Fusion Write Engine
- ✓ FPGA-based compression offloading

Deployment

- ✓ Over 100 clusters for 500K VDs
- ✓ Data replicas reduced to 0.77



EBS3: Foreground EC/Compression

Alibaba Cloud

Design Goals

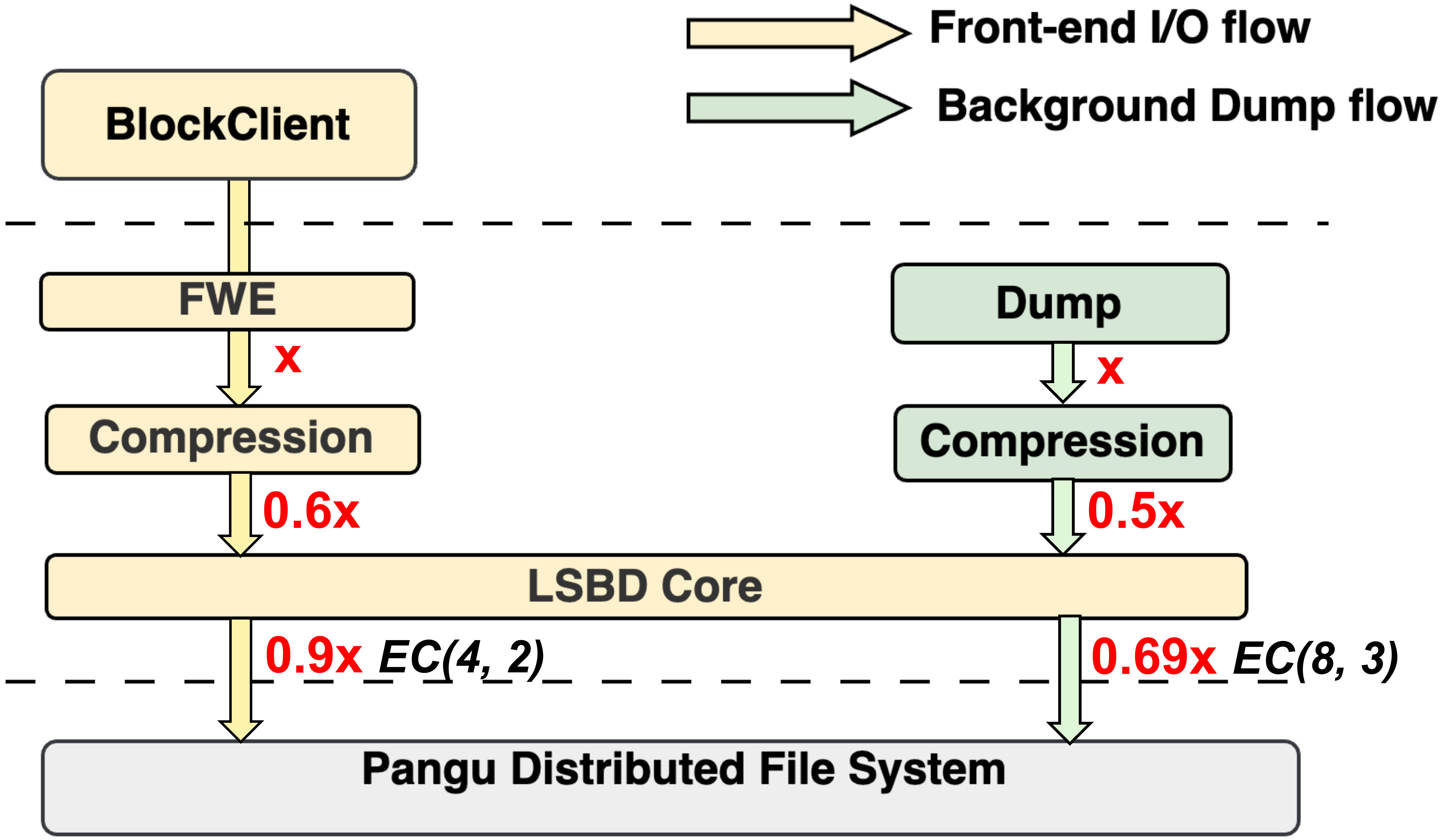
- ✓ Lower traffic consumption and storage space costs
- ✓ No performance loss

Key Designs

- ✓ Fusion Write Engine
- ✓ FPGA-based compression offloading
- ✓ Traffic reduced from 4.69 to 1.59

Deployment

- ✓ Over 100 clusters for 500K VDs
- ✓ Data replicas reduced to 0.77



$$TrafficAmplification_{EBS2} = (3x + x + 0.69x) \div x = \mathbf{4.69}$$

$$TrafficAmplification_{EBS3} = (0.9x + 0.69x) \div x = \mathbf{1.59}$$

Comparison of Three Generations of EBS

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	EBS1	EBS2	EBS3
Avg. Latency	Millisecond Level	Hundred-microsecond Level	Hundred-microsecond Level
MAX. IOPS / Throughput	25,000	1,000,000	1,000,000
Key Features	**In-place updates N-to-1mapping**	**Background EC & Compression**	**Foreground EC & Compression**
Space Cost (Replicas per Data)	**3**	**1.29**	**0.77**
Traffic Amplification	**3**	**4.69**	**1.59**

Evolving Journey of EBS

Elasticity: A Tale of Four Metrics

Other Topics

Metrics #1: Latency

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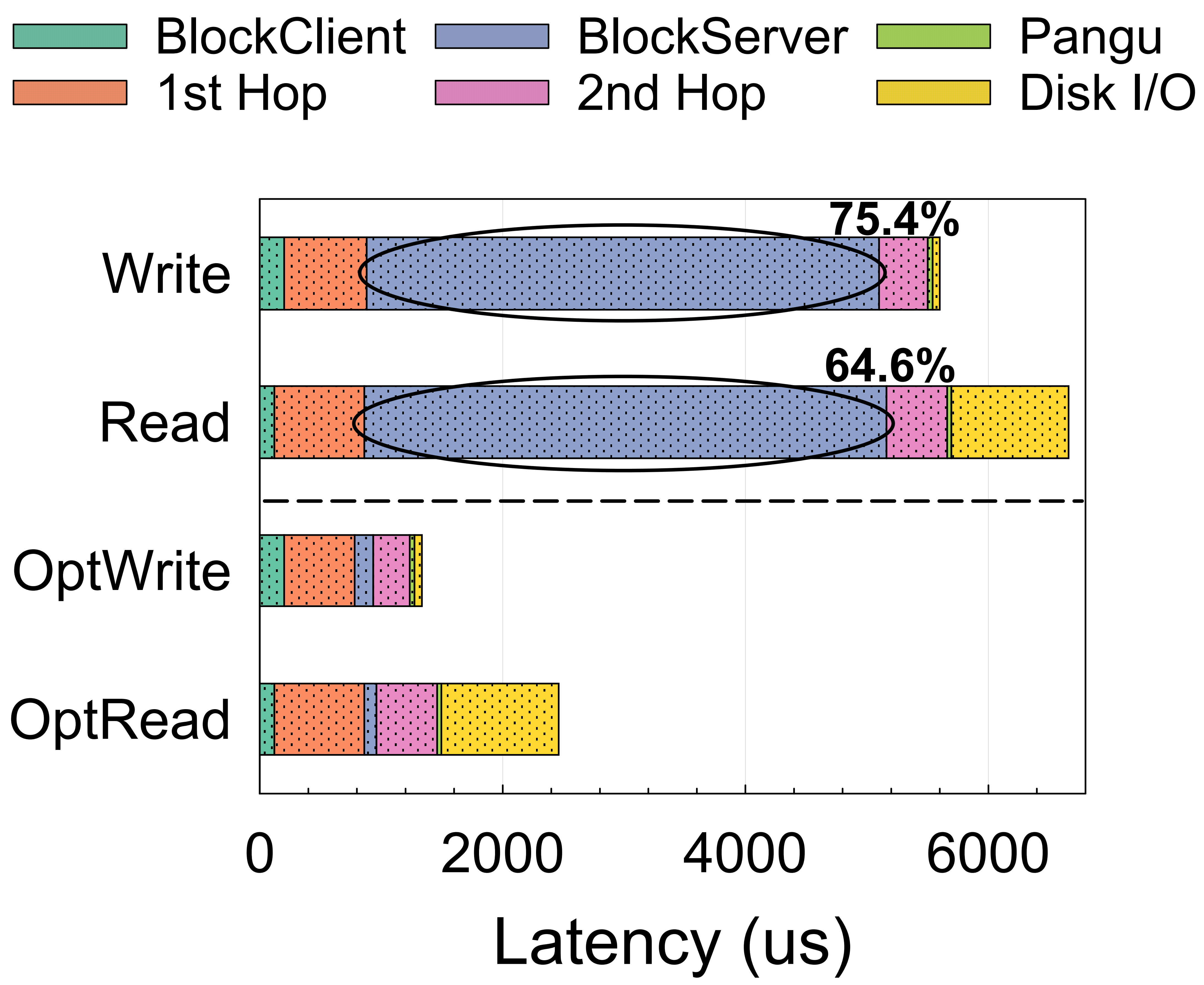
- **Elasticity of latency is coarse-grained**
  - ✓ **Defined by the architectures**

- **EBSX**
  - ✓ **Shorten the path** ***(e.g., skip a network hop)***
  - ✓ **Use faster devices** ***(e.g., PMem instead of SSD)***
  - ✓ **Simple and efficient data consistency protocol**

- **Tail latency**
  - ✓ **Software-induced tail latency can be the dominant**
  - ✓ **Separate client IOs from background tasks (e.g., GC)**



99.999th Percentile Latency

Metrics #2 & #3: IOPS and Throughput

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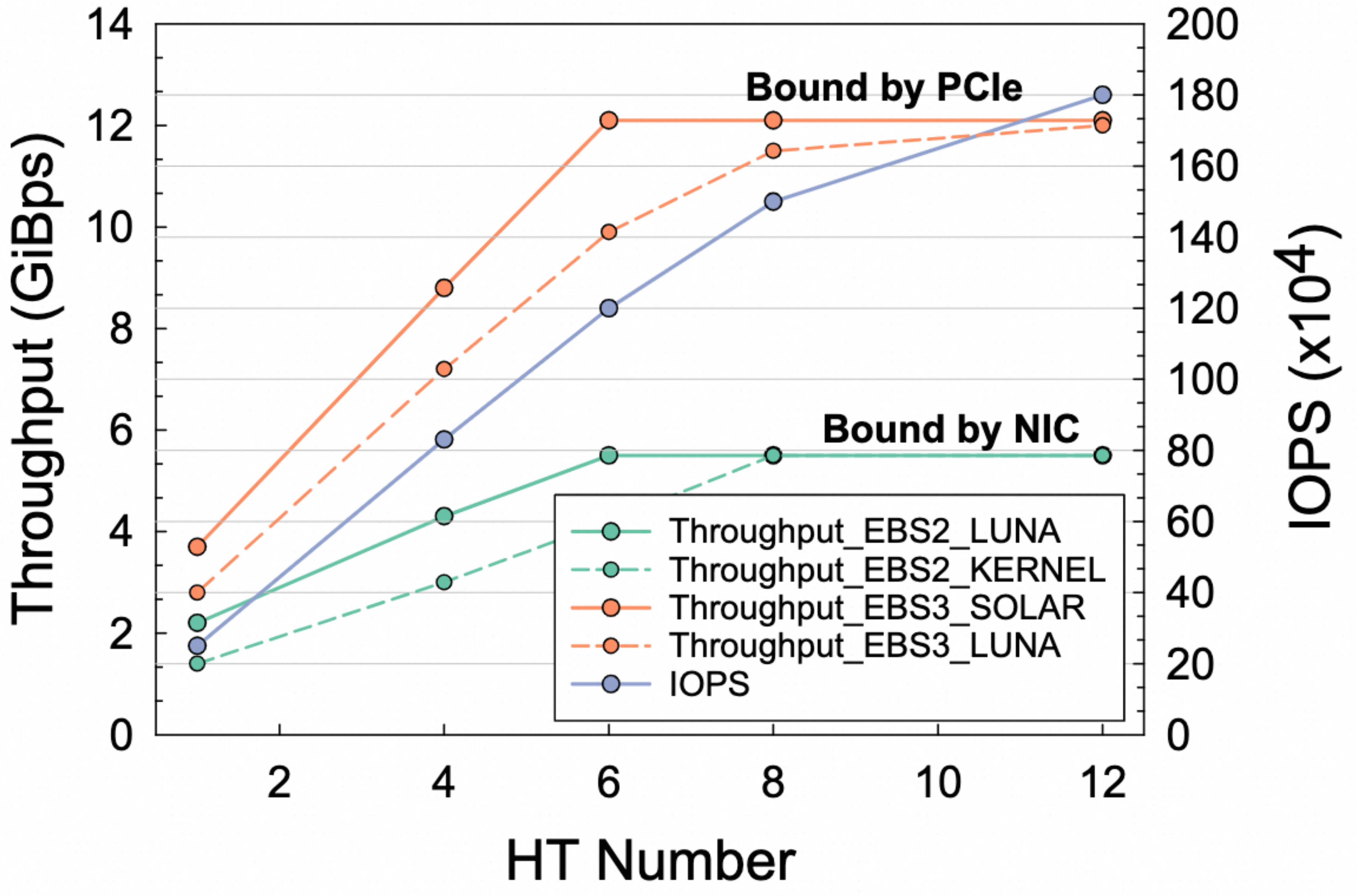
● Upper bound is determined by BlockClient

- ✓ Backend can be easily extended
- ✓ BlockClient is bound by processing and forwarding capability
- ✓ From kernel-space to user-space, then to hardware offloading



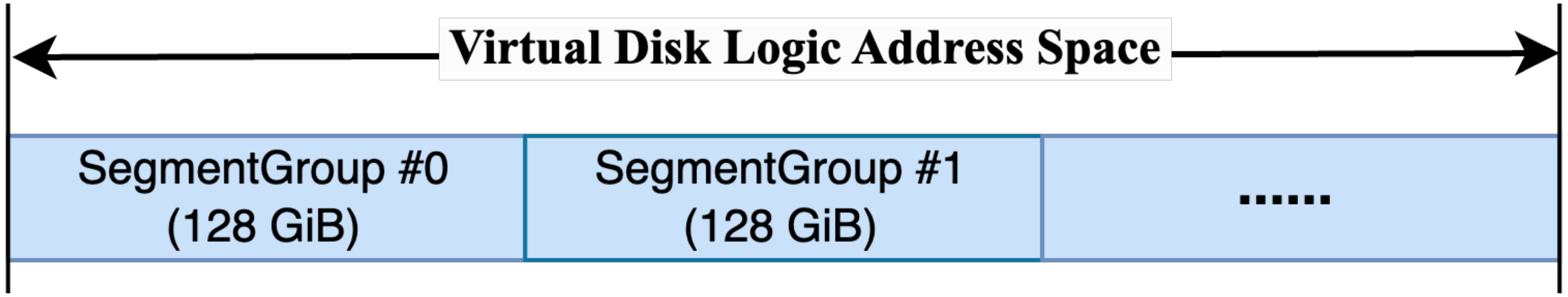
● High IOPS/Throughput is often desired but not always needed

- ✓ Auto performance level (AutoPL) Virtual Disk： on demand without altering the capacity
- ✓ Base + Burst strategy: efficiently allocating IOPS/ throughput to VDs
- ✓ Base throughput means can definitely be satisfied
- ✓ Burst throughput means trying my best to satisfy

Metrics #4: Capacity

Flexible space resizing

- ✓ Achieve resizing via adding or removing SegmentGroups
- ✓ Virtual disk sizes up to 64 TiB



Fast VD cloning

- ✓ *Hard Link* of Pangu files
- ✓ Up to 10,000 virtual disks (each 40 GiB) in 1 min

Evolving Journey of EBS

Elasticity: A Tale of Four Metrics

Other Topics

Other Topics

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Availability Threats and Solutions *(See Section 4)*

- ✓ **Challenge 1:** a BlockServer crash impacts more VDs
  Solution: Federated BlockManager (Two-layer control nodes)
- ✓ **Challenge 2:** Segment migration leads to cascading failures
  Solution: Logical Failure Domain (Limited migration)

EBS Offloading *(See Section 5)*

- ✓ **FPGA is not ideal: expensive, high failure rates**
- ✓ **Blockclient offloading: FPGA → ASIC**: 1. cost-friendly 2. a fixed set of functions
- ✓ **BlockServer offloading: FPGA → Many-core ARM**: 1. cost-friendly 2. comparable performance

What if? *(See Section 6)*

- ✓ **Q1: W/o log-structured design? Both cost and performance cannot move forward.**
- ✓ **Q2: EBS with open-source software? Co-design will be never possible.**
- ✓ **Q3: Not separating Pangu? Slow down the development of EBS.**

Please see more details in the paper.

Thanks
Q & A

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