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Korea Electronics Technology Institute

Accelerating I/O Performance for AI Frameworks on DAOS

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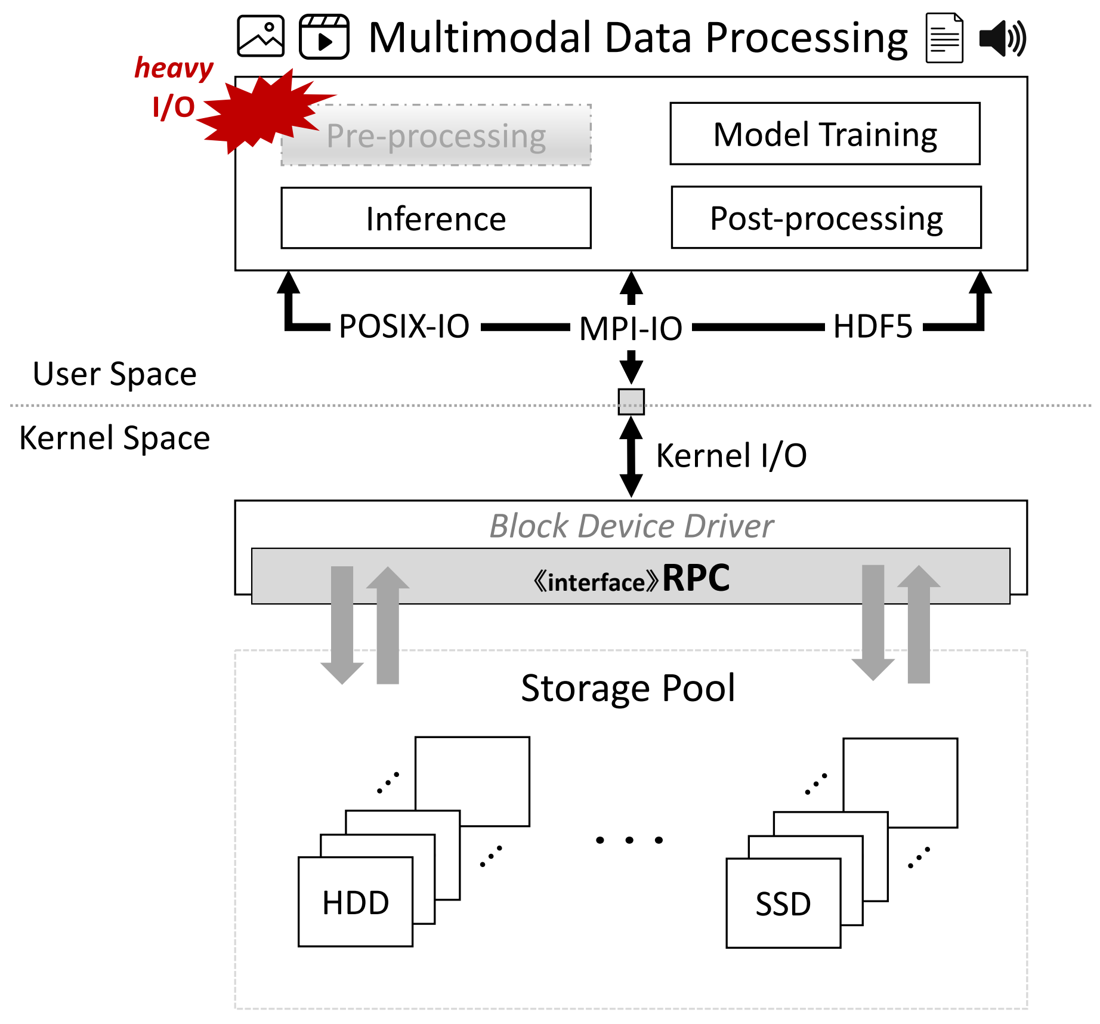
Aurora-FS

Overview



<Legacy Distributed Storage System>

As-is

❑ **Heavy I/O overhead**

- Modern AI and HPC workloads require intensive data preprocessing.

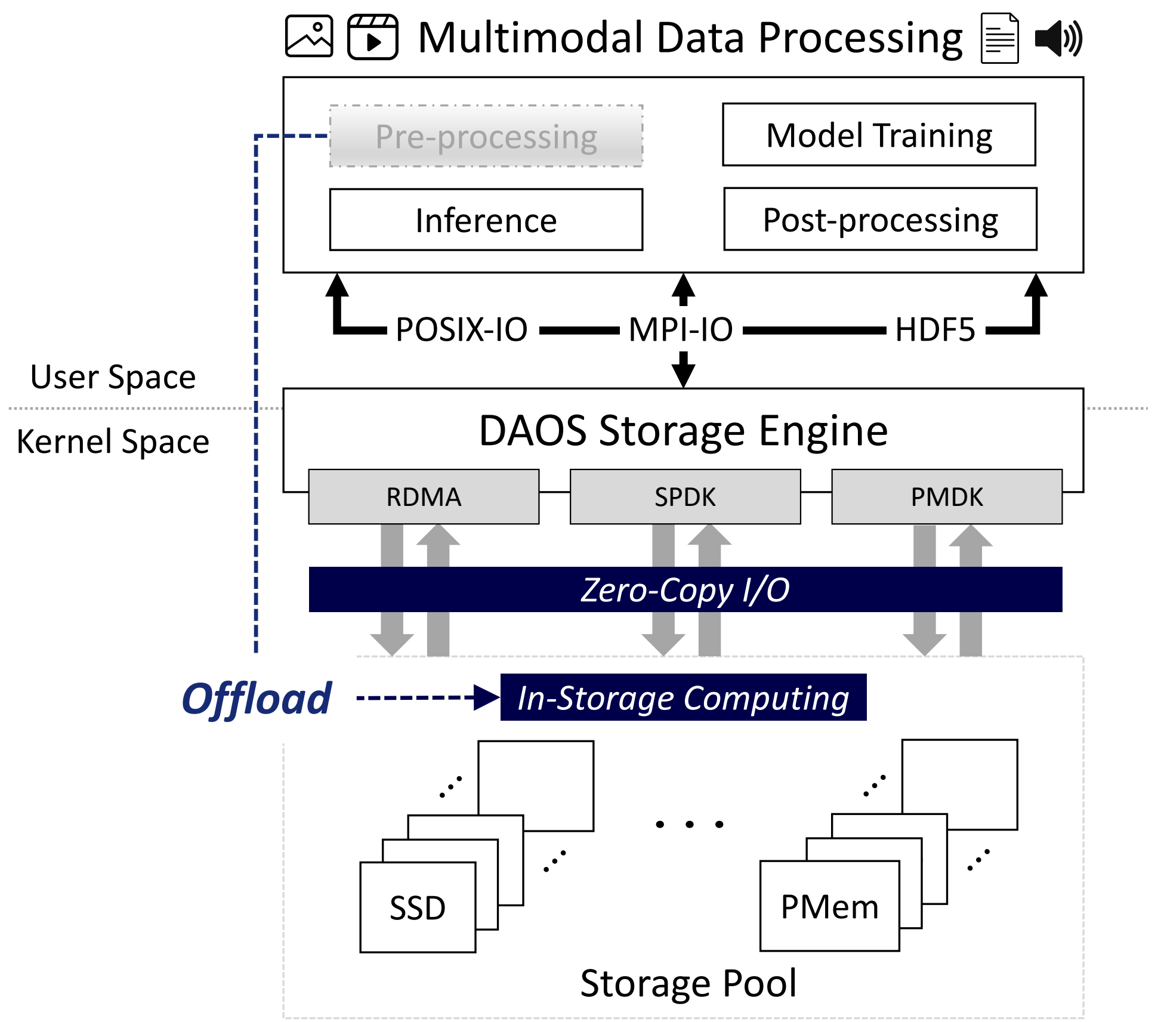
❑ **Excessive redundant copies and context switches**

- The default DAOS I/O path traverses between user space and kernel space via block drivers and RPC.

To-be

❑ **Two solutions for accelerating I/O performance**

- To reduce unnecessary data movement: ***Zero-copy I/O***
- To move computation closer to data: ***In-Storage Computing***



<Proposed Distributed Storage System>

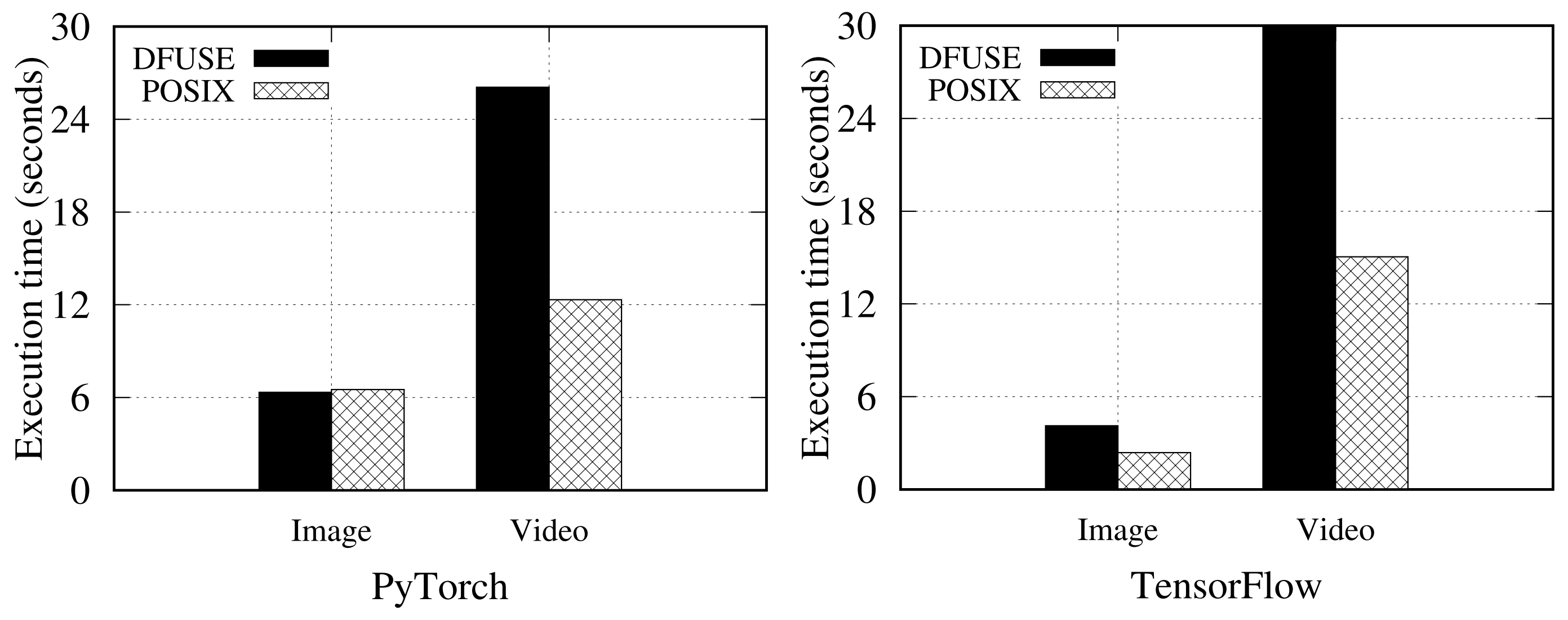
Motivation

❑ **Setup** – Evaluated PyTorch and TensorFlow preprocessing pipelines on DFUSE (DAOS FUSE) vs. POSIX filesystem (xfs) using image (CIFAR-10) and video (UCF101) datasets

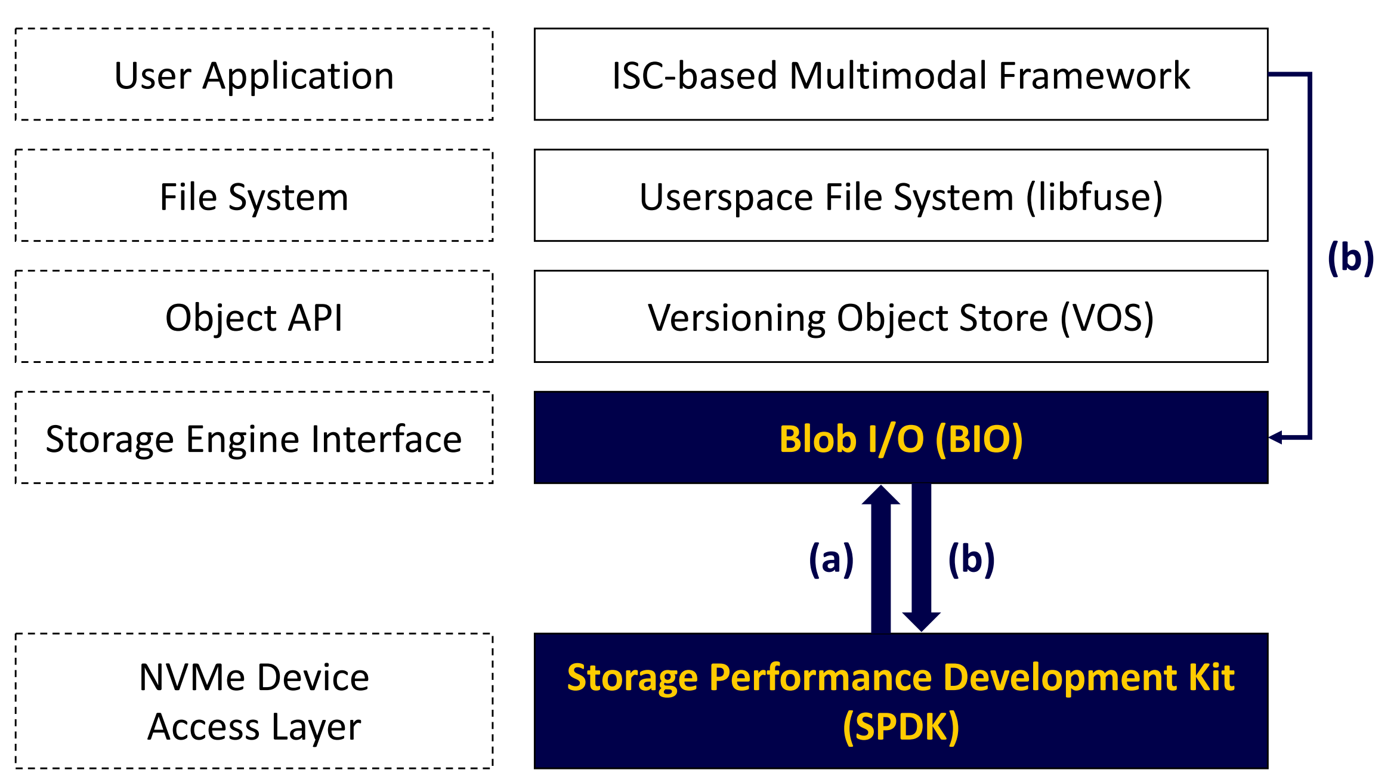
❑ **Result** – Up to ***3.3x slower*** preprocessing on DFUSE for video pipelines

❑ **Cause** – DFUSE introduces frequent user-kernel transitions, redundant copies, and heavy POSIX operations

❑ **Insight** – Bottleneck stems from ***data movement*** between compute and storage!



Proposed Design


User Application
ISC-based Multimodal Framework
File System
Userspace File System (libfuse)
Object API
Versioning Object Store (VOS)
Storage Engine Interface
Blob I/O (BIO)
(b)
(a)
(b)
NVMe Device Access Layer
Storage Performance Development Kit (SPDK)

< Redesigned DAOS I/O Stack>

Redesigned DAOS I/O Path

(a) Zero-Copy I/O

- **BIO → SPDK**: Submits DMA-ready user buffers directly to SPDK's NVMe channels
- **BIO ← SPDK**: Returns completion events and signals the DMA transfer to devices

(b) In-Storage Computing

- **User → BIO**: Sends ISC requests to BIO by specifying the target object extents
- **BIO → SPDK**: Issues targeted block-access requests to SPDK

(a) Zero-Copy I/O

Limitation

- The software I/O path (user ↔ DFUSE ↔ kernel ↔ device) dominates latency.

Design Proposal

- Direct data transfer without kernel

Design Elements

❑ **DAOS storage engines**

- **BIO**: Acts as the zero-copy entry point that receives DMA-ready buffers from the DAOS client

❑ **SPDK modules**

- **Blobstore**: Manages physically contiguous I/O regions that can be directly mapped from user buffers
- **Bdev**: Provides DMA-capable I/O channels and NVMe queue pair management
- **SPDK memory module**: Handles hugepage-based physical address to make user buffers DMA-ready

(b) In-Storage Computing

Limitation

- Preprocessing workloads repeatedly transfer large volumes of I/O from compute to storage.

Design Proposal

- Offloading preprocessing pipelines to the storage layer

Design Elements

❑ **DAOS storage engines**

- **VOS**: Manages versioned object metadata and transactional consistency-guaranteed epochs
- **BIO**: Hosts ISC execution and enables SPDK-driven I/O

❑ **SPDK modules**

- **Blobstore**: Executes ISC with block-granular access to NVMe-backed objects
- **Bdev**: Provides I/O channel control with block-level extent

❑ **HW emulation**

- **QEMU**: Provides a *controllable* NVMe device environment