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Improving Longhorn Performance With SPDK

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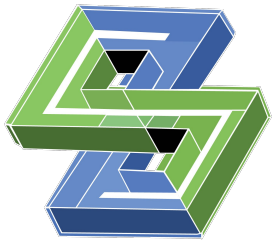
Agenda

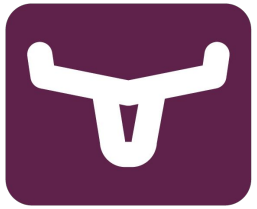
- What is Longhorn
- How Current Longhorn Works
- What Challenges Current Longhorn Has

- What is SPDK
- How New Longhorn Works
- What Benefits New Longhorn Introduces

- Preliminary Performance Benchmark
- Further Areas for Improvement
- What Is Next? Longhorn SPDK



SPDK



LONGHORN

What is Longhorn

- Highly available, software-defined persistent block storage for Kubernetes
- Lightweight, reliable, and easy-to-use
- Adds persistent volume support to any certified K8s cluster
- Storage Agnostic – any ext4/xfs filesystem can be added to a Longhorn cluster
- NFS and S3 compatible (backup storage)
- Kubernetes-first design implemented in CRDs and controller pattern
- Open source and owned by the CNCF

How Current Longhorn Works

Volume Elements

- Volume Frontend (iSCSI)
- Volume (Engine)
- Volume replica (Replica)

Volume Lifecycle

- CSI
- PVC/PV

Data Placement

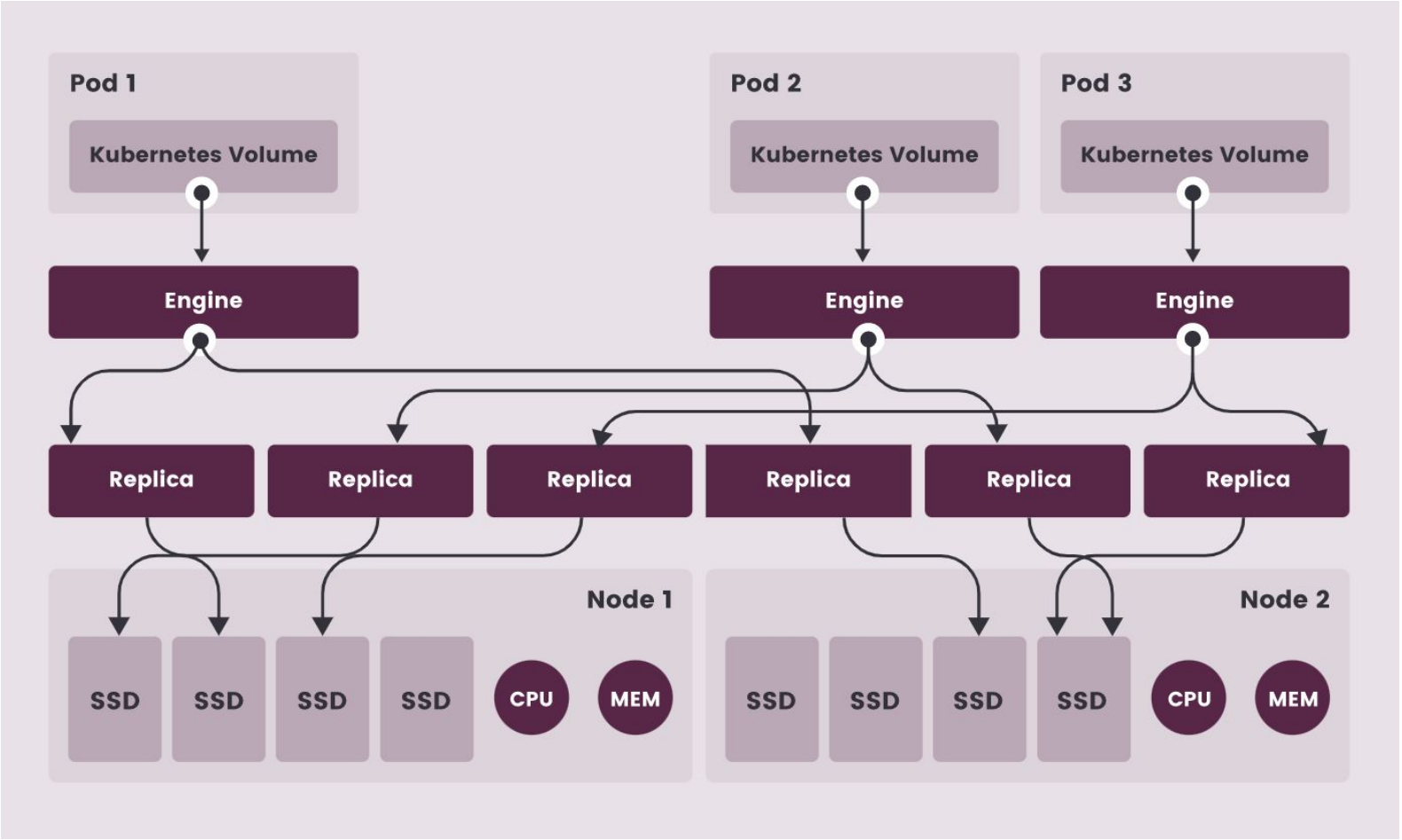
- Longhorn disk (FS on host)

Deployment

- Segregated Microservice

Control Plane

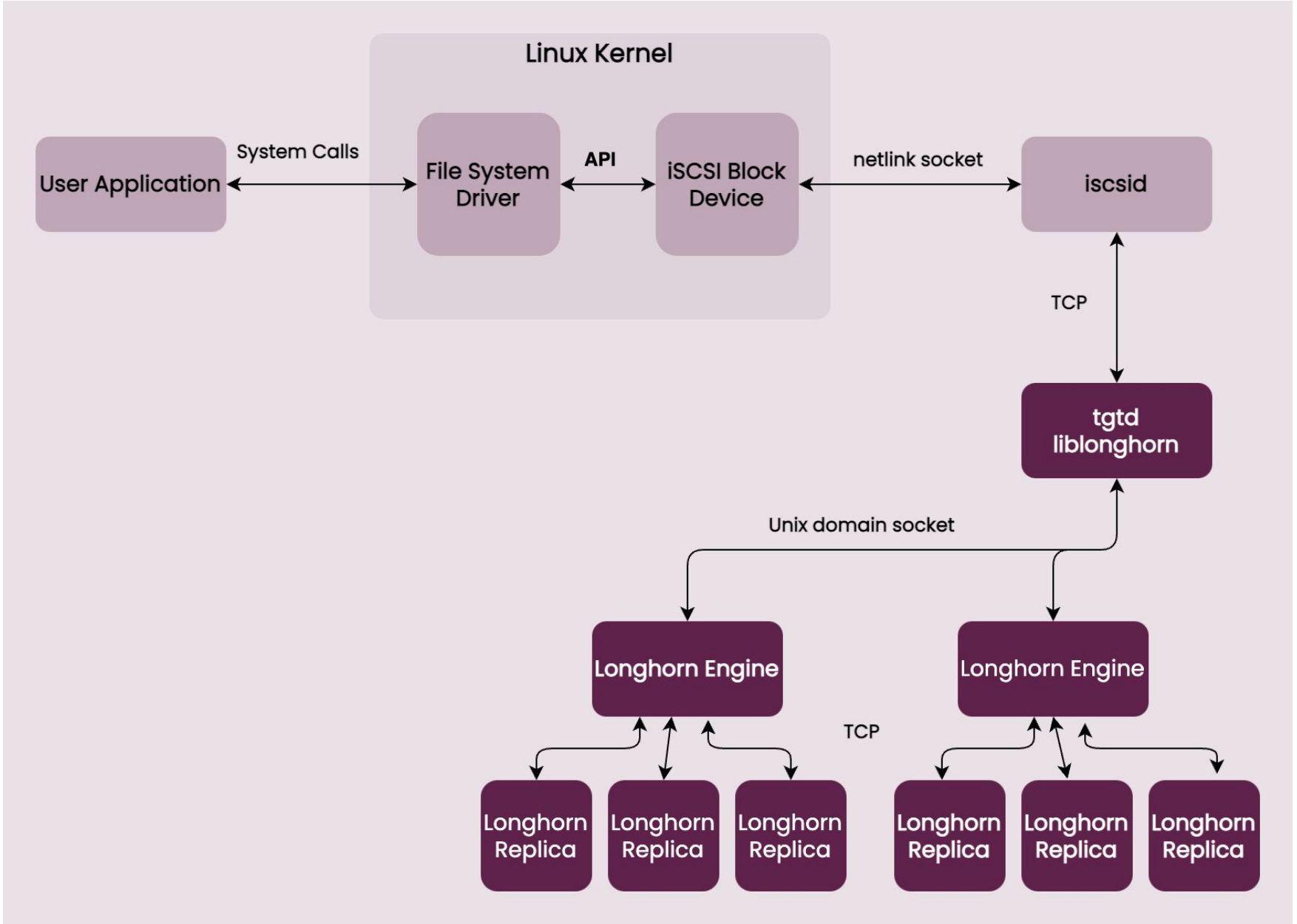
- Kubernetes Controller + CR



Longhorn Engine & Replica

- Volume Frontend (iSCSI)
  - open-iscsi (iSCSI initiator)
- Volume (Engine)
  - longhorn tgtd (iSCSI target)
  - longhorn engine (TCP data server and volume controller)
- Volume replica (Replica)
  - longhorn replica (local, remote TCP data server and replica controller)
  - Data operation (snapshot, rebuild, coalesce/merge, prune, purge, backup, etc)

Longhorn Engine & Replica - Data Path



What Challenges Current Longhorn Has

- Too many components
  - iscsid, longhorn tgtd and longhorn engine process for each volume
- Longhorn engine (data plane) & tgtd, 2 hops extra cost
  - Method allocation and garbage collection for each I/O operation
- I/O model limitation, difficult to change the implementation
  - I/O model is based on filesystem sparse files opened with O_DIRECT, blocking read and write system calls.
  - Significant changes would be needed for newer I/O methods in Linux like libaio or io_uring
  - Lack of library support for these methods in Go.
- Number of processes increases with each block device

What is SPDK

SPDK - Software Performance Development Kit

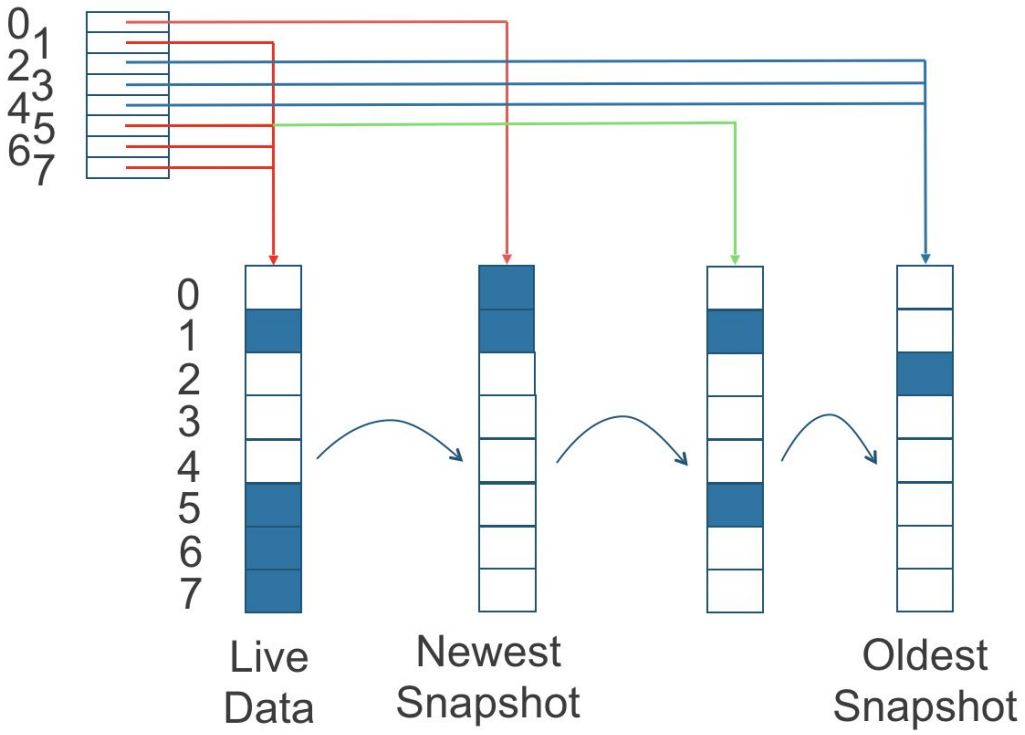
- Used in high performance cloud applications
- Has a generic “block device” application layer with many different implementations, easy to implement new block devices
- Has support for exposing block devices over several widely supported network protocols for remote block devices: iSCSI and NVMe over Fabrics
- Has a logical volume feature which stores data in a series of sparse snapshots
- Designed for asynchronous programming
- Uses memory pools to minimize memory allocation

Longhorn Sparse Provisioning vs SPDK Logical Volumes

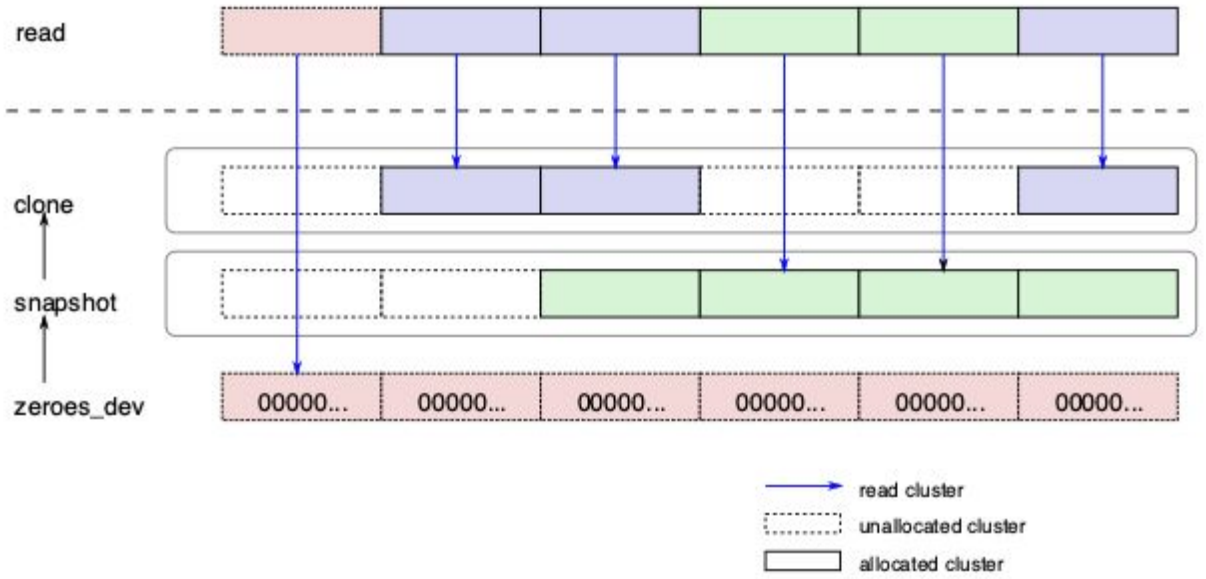
- Longhorn uses sparse files for thinly provisioning volumes and for snapshots
  - A hierarchy of sparse snapshot files represent a volume
  - Each volume is in a separate directory on the file system
- SPDK has logical volumes
  - One SPDK block device can host multiple logical volume block device
  - Each logical volume is also a hierarchy of sparse “blobs”

Longhorn Sparse Provisioning vs SPDK Logical Volumes

Longhorn Sparse Provisioning



SPDK Logical Volumes



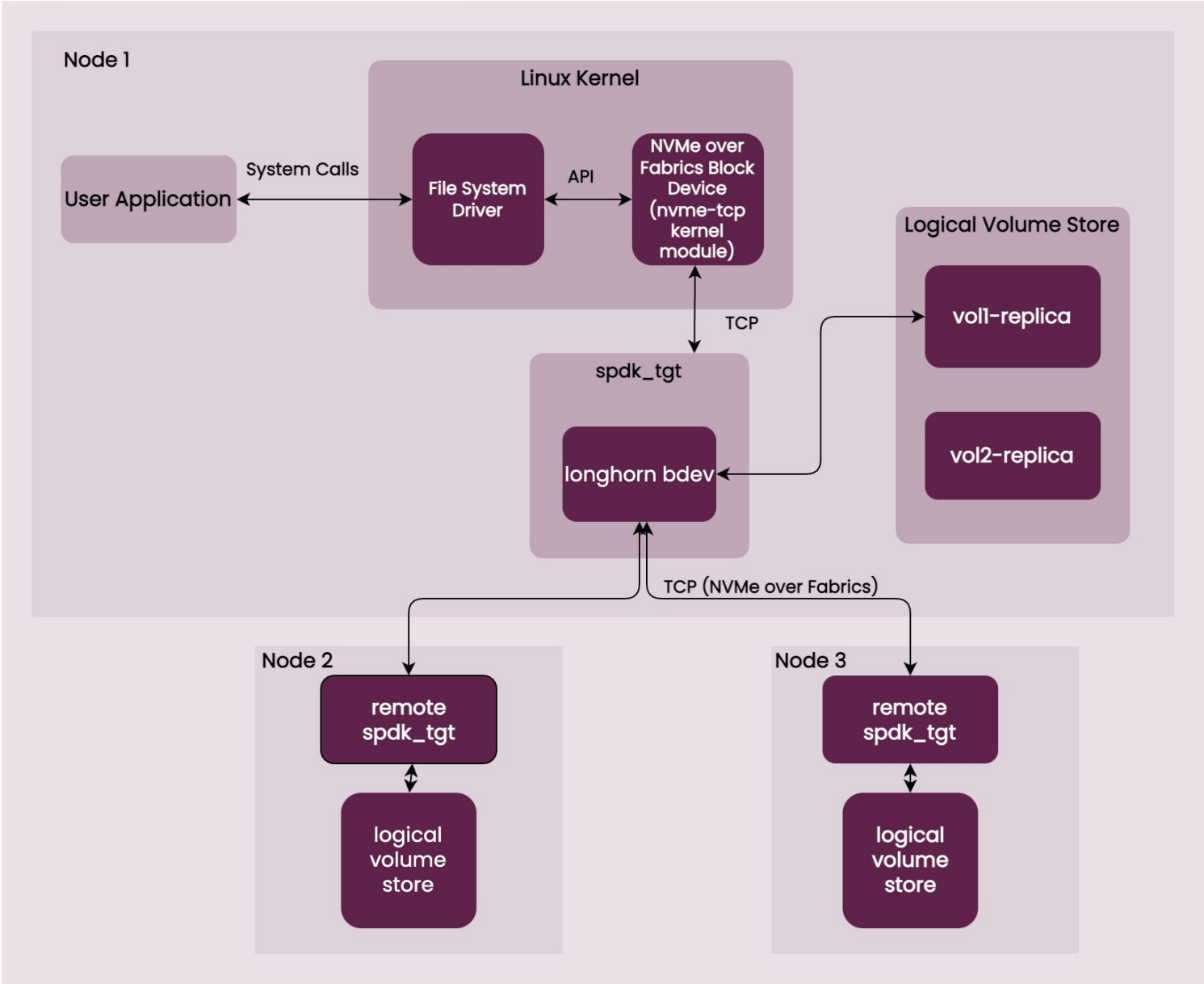
SPDK's Asynchronous Programming Model

- API functions don't block
- API is asynchronous and event driven
  - Schedule an operation to be performed
  - Main loop checks status of all pending operations continuously
  - Notify via a callback when the operation is complete
- Achieves better performance than traditional blocking I/O

How New Longhorn Works - Longhorn with SPDK

- Use SPDK's NVMe over Fabrics for Longhorn's block device instead of iSCSI.
  - Linux has mature NVMe over Fabrics device support
  - The Linux kernel has direct NVMe over Fabrics support without the need for an iscsid equivalent.
- Implement the core Longhorn engine functionality as a custom "block dev" in SPDK.
  - Consists of a set of replicas which are local logical volume bdevs or remote NVMe over Fabrics logical volume bdevs (these are akin to current longhorn replicas)
  - Distributes all write operations to a replicas.
  - Chooses one of the replicas for read operations.
  - Supports snapshots and rebuilding new volumes when added.
- One SPDK process per Kubernetes node. Each SPDK process can handle multiple block devices.

How New Longhorn Works - Longhorn Components with SPDK



Preliminary Performance Benchmark

- Test Environment
  - CPU: 1 x AMD EPYC 7402P 24-Core Processor
  - RAM: 64GB
  - DISK: 2 x 240GB SSD, 2 x 480GB SSD
  - NIC: 2 x 10Gbps Bonded Ports

- Test Methodology
  - Uses the Longhorn developed kbench utility
  - Uses the fio command to test IOPS, bandwidth, and latency
  - Tested single node using raw disk, the existing Longhorn, and Longhorn with SPDK
  - Tested three nodes with the existing Longhorn and Longhorn with SPDK

Single Node Performance Comparison

Disk

	Read	Write
IOPS Random	88,298	66,998
IOPS Sequential	107,598	89,425
Bandwidth Random I/O	545,822 KiB/sec	506,418 KiB/sec
Bandwidth Sequential I/O	552,562 KiB/sec	517,037 KiB/sec
Latency Random I/O	102,024 ns	35,664 ns
Latency Sequential I/O	30,674 ns	32,998 ns

Current Longhorn

	Read	Write
IOPS Random	41,710	15,557
IOPS Sequential	62,332	27,707
Bandwidth Random I/O	500,057 KiB/sec	360,538 KiB/sec
Bandwidth Sequential I/O	494,365 KiB/sec	397,190 KiB/sec
Latency Random I/O	266,264 ns	248,349 ns
Latency Sequential I/O	224,166 ns	254,604 ns

Longhorn with SPDK

	Read	Write
IOPS Random	67,700	66,964
IOPS Sequential	97,954	82,704
Bandwidth Random I/O	544,774 KiB/sec	506,642 KiB/sec
Bandwidth Sequential I/O	552,061 KiB/sec	510,585 KiB/sec
Latency Random I/O	128,691 ns	60,968 ns
Latency Sequential I/O	57,724 ns	56,785 ns

Single Node Performance Key Points

- Single Node performance with SPDK improves in all categories
- Bandwidth with SPDK close to Disk
- Overall latency with SPDK compared to disk is 25-30 µs versus over 100 µs with Longhorn.

Three Node Performance Comparison

Existing Longhorn

	Read	Write
IOPS Random	50,022	8,377
IOPS Sequential	77,361	22,717
Bandwidth Random I/O	1,145,030 KiB/sec	278,256 KiB/sec
Bandwidth Sequential I/O	652,087 KiB/sec	355,622 KiB/sec
Latency Random I/O	269,326 ns	254,559 ns
Latency Sequential I/O	227,172 ns	253,791 ns

Longhorn with SPDK

	Read	Write
IOPS Random	105,532	66,964
IOPS Sequential	131,949	82,704
Bandwidth Random I/O	1,272,529 KiB/sec	365,686 KiB/sec
Bandwidth Sequential I/O	1,274,302 KiB/sec	366,601 KiB/sec
Latency Random I/O	194,131 ns	169,507 ns
Latency Sequential I/O	190,013 ns	168,261 ns

Three Node Performance Key Points

- SPDK also performs better on a three node scenario over the existing Longhorn Engine
- Latency is worse than single node in the three node scenario because of networking
- Read operations and bandwidth are improved because reads are distributed among the three nodes

Further Areas for Improvement

- User space NVMe support
  - Access NVMe drives from user space driver instead of Linux kernel driver
  - SPDK's claim to fame
  - Initially didn't support this because we wanted to support any kind of disk
- io_uring and other new I/O technologies used in SPDK can be tried easily
- RDMA - A different network transport for NVMe over Fabrics using special NIC drivers

What is Next? Longhorn SPDK

- Longhorn SPDK changes the how the rest of Longhorn will work
  - Change from multiple Longhorn engine processes per node to one Longhorn SPDK process
    - Eliminate Instance Manager which manages all these processes
    - Longhorn CRDs reflect current process model and need update
    - Remove iSCSI and tgt
- New communication mechanism between Longhorn Manager and SPDK
- Develop backup and restore functionality
- Working on technology preview of Longhorn integrated with SPDK

Thank You 🙏

Q & A 🙋

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