Introduction to libnvme

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Linux Vault 2020

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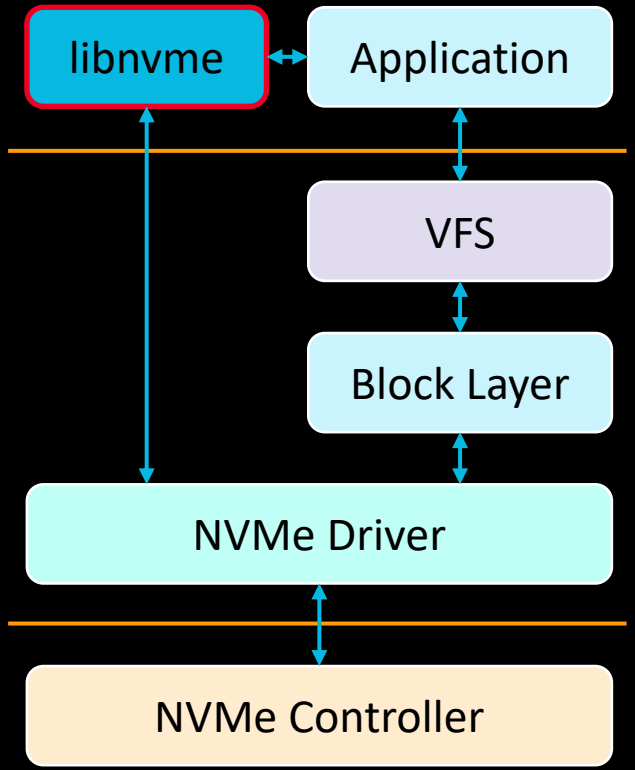
NVMe and Linux: Let's Make a Userspace Library

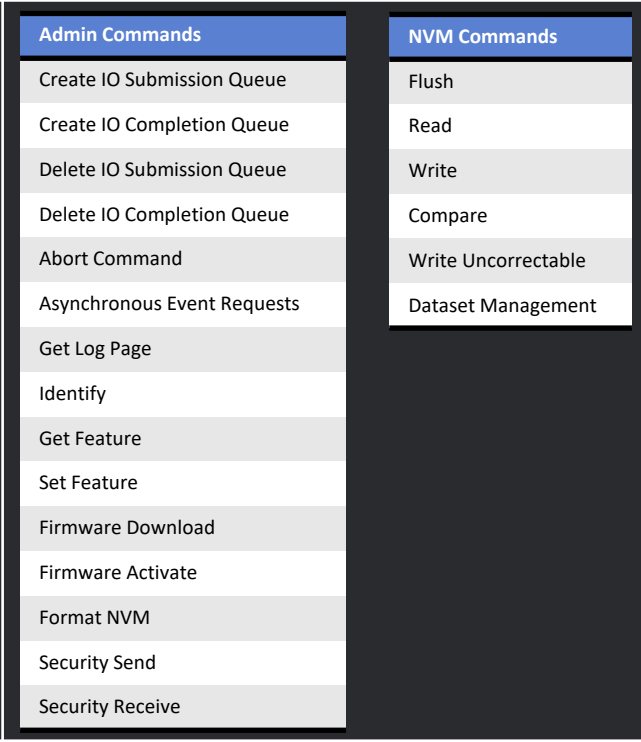
- NVM Express protocol and Linux features supporting it have grown significantly
- Open source and standard specification allows common software compatibility across a wide spectrum of devices
  - Host device drivers converge on common sources
  - But NVMe user space software often reimplements many of the same protocol'foundational core
- The nvme kernel user APIs are powerful, but too simple and abstract for easy use
- **libnvme**: Make all NVMe on Linux features conveniently reachable to developers

libnvme: Where it fits

- A place for all NVMe on Linux features: 0-day updates for ratified features and kernel driver changes
- Work with NVMe drivers (not around them)
  - The driver owns controller initialization, error recovery, transport specifics, command tagging, queuing and completion
  - libnvme provides methods to scan devices, connect to new targets, dispatch arbitrary commands to them and setup or decode data payloads



NVMe 1.0: The Early Days, circa 2011

Specifications	Transports	Commands
		

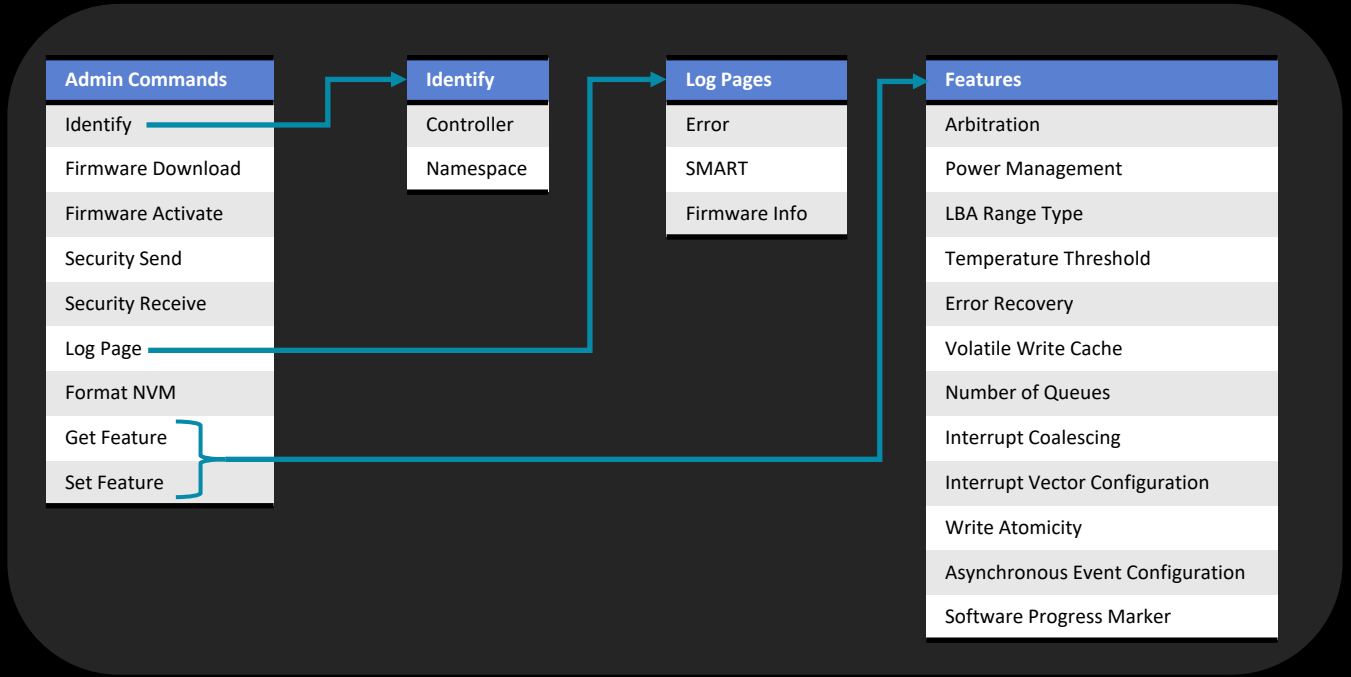
libnvme doesn't support harmful commands

Specifications	Transports	Commands

Admin Commands
~~Create IO Submission Queue~~
~~Create IO Completion Queue~~
~~Delete IO Submission Queue~~
~~Delete IO Completion Queue~~
~~Abort Command~~
~~Asynchronous Event Requests~~
Get Log Page
Identify
Get Feature
Set Feature
Firmware Download
Firmware Activate
Format NVM
Security Send
Security Receive

NVM Commands
Flush
Read
Write
Compare
Write Uncorrectable
Dataset Management

A few commands have subtypes



NVMe 1.4: Today

Specifications

Transports

PCI EXPRESS®

RDMA

Remote Direct Memory Access

FIBRE CHANNEL

TCP

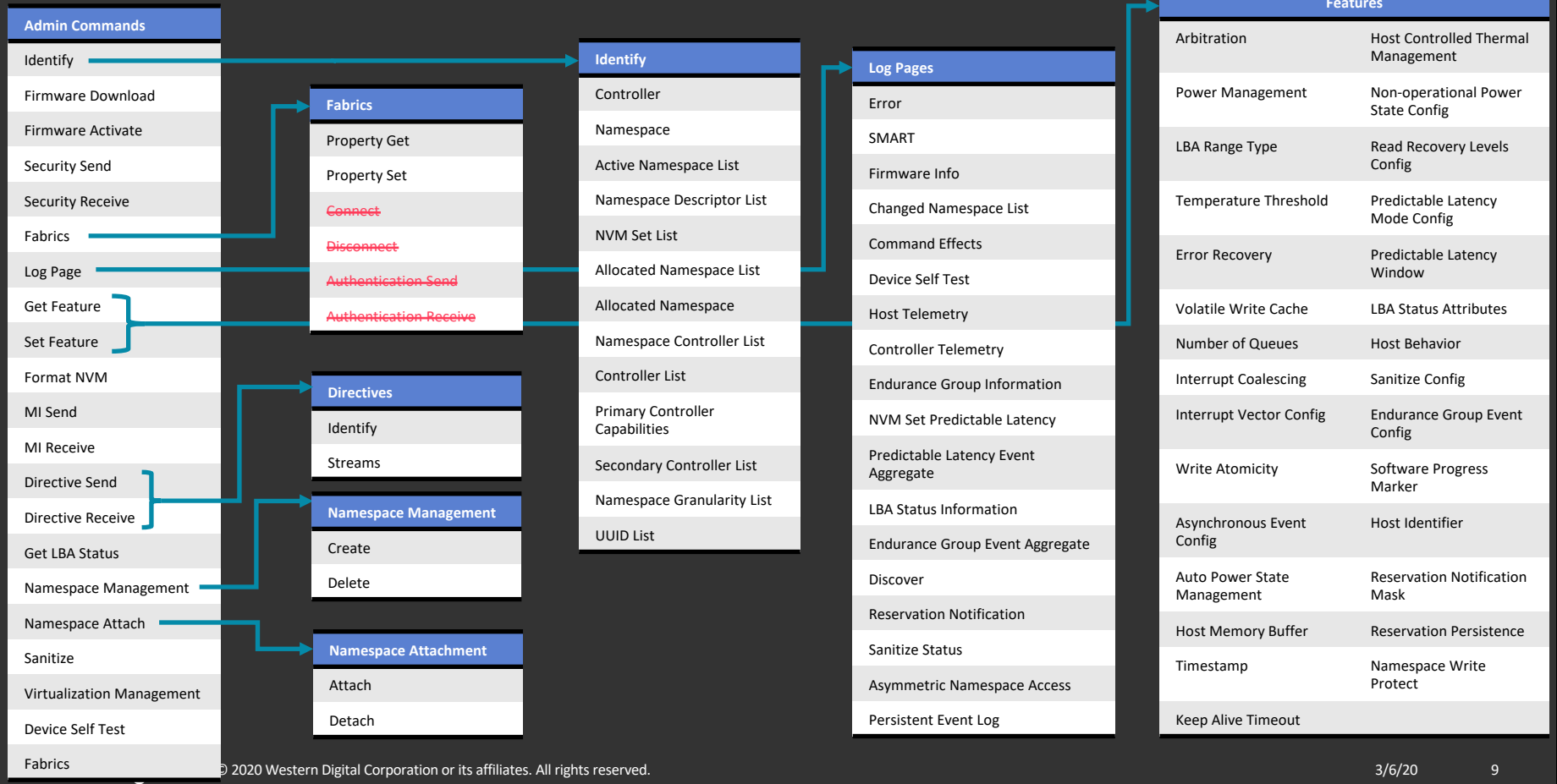
Other/Loop-back

Commands

Admin Commands	
Identify	Directive Send
Firmware Download	Directive Receive
Firmware ~~Activate~~Commit	Get LBA Status
Security Send	Namespace Management
Security Receive	Namespace Attach
Log Page	Sanitize
Format NVM	Virtualization Management
Get Feature	Device Self Test
Set Feature	Fabrics
MI Send	~~Keep Alive~~
MI Receive	

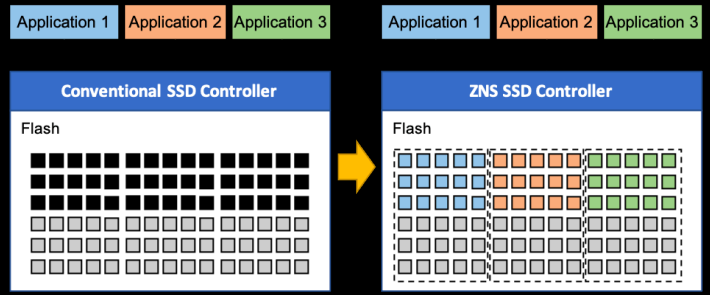
IO Commands
Flush
Read
Write
Compare
Write Uncorrectable
Dataset Management
Write Zeroes
Verify
Reservation Register
Reservation Acquire
Reservation Release
Reservation Report

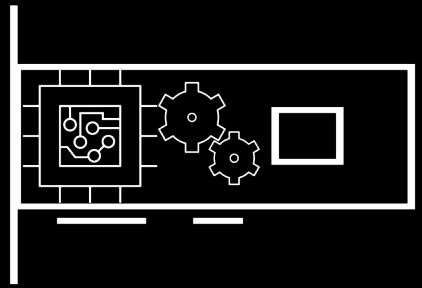
Many more command subtypes!

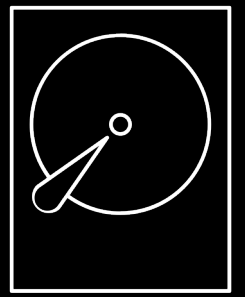


NVMe: New features under development

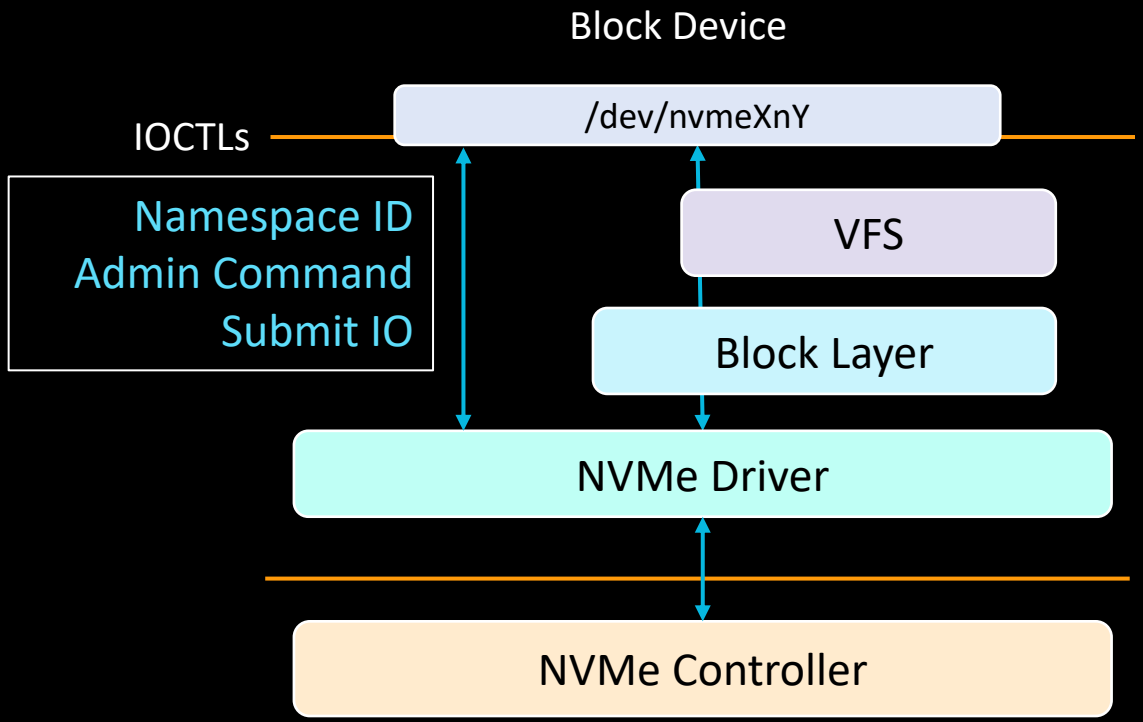
- New Namespace Types
  - Computational
  - Key-Value
  - Zone
- More logs, identifications and features
- New Commands and Command Sets
- Spinning media
- More Specifications: Refactoring effort to introduce transport specific standards



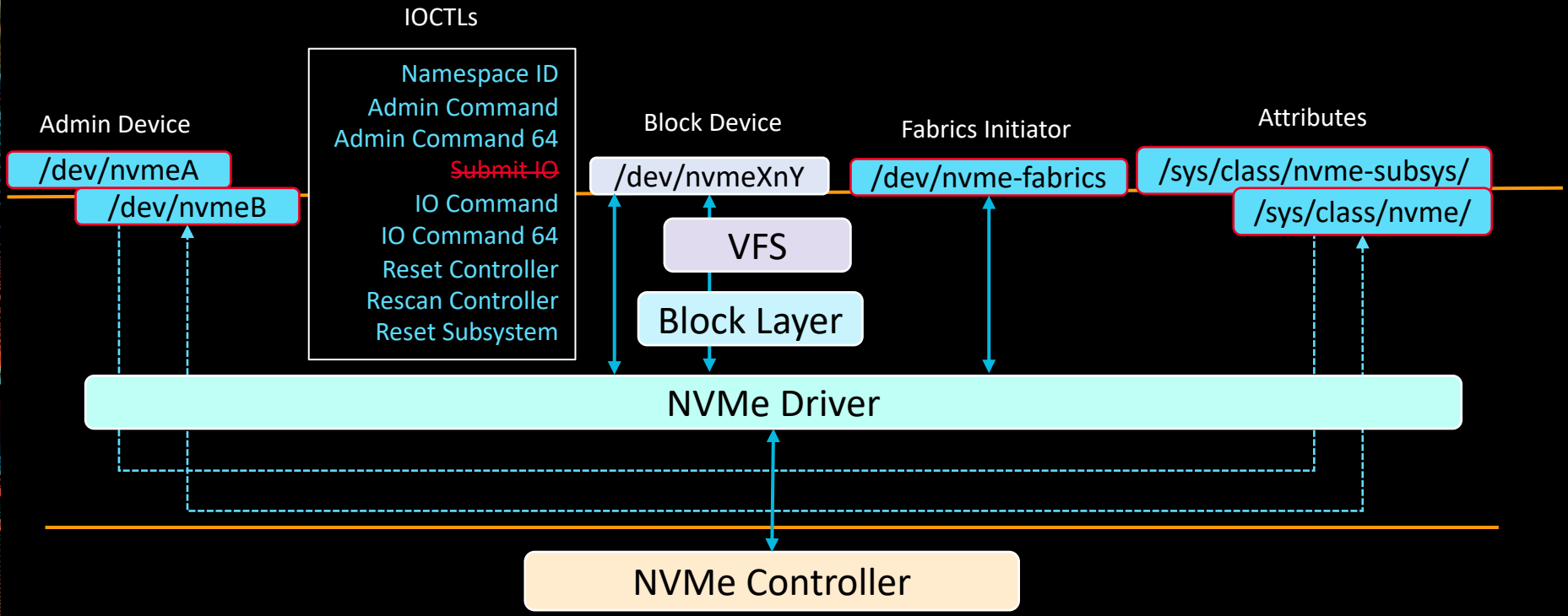




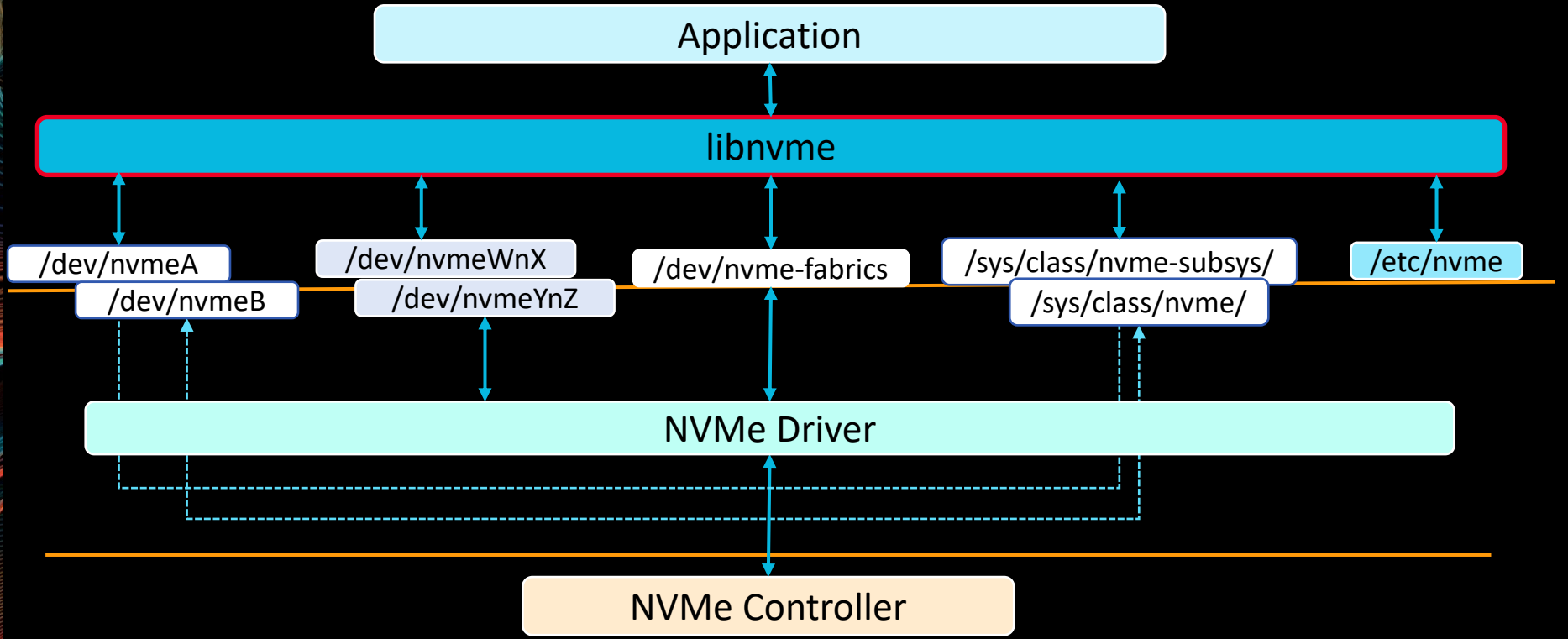
Original Linux Kernel's NVMe User Interfaces



Linux Kernel's NVMe User Interfaces Today



libnvme: One library to rule them all



Current libnvme snapshot

- Source Code Repository: https://github.com/linux-nvme/libnvme
- Language: C (extern “C” for C++)
- Code stats (approximates)
  - 20k lines of C code (mostly comments for documentation)
  - 250 exported functions
  - 170 enumerations define over 800 nvme values
  - 90 specification defined structures
- Install Artifacts:
  - Header files of API methods, structures and enumerations
  - Statically linkable archive (libnvme.a)
  - Dynamically linkable shared object (libnvme.so)
  - Documentation (html and man)

nvme/types.h

- Defines nvme data structures, fields, enumerations and bit fields
  - Currently 85 structures, and 80 enumeration types (540 unique values) defined
- Updated to match the nvme specification and ratified proposals
- Documentation describes all types and cross links to related functions, structures and enumerations

struct nvme_telemetry_log

Retrieve internal data specific to the manufacturer.

Definition

```
struct nvme_telemetry_log {
  __u8 lpi;
  __u8 rsvd1[4];
  __u8 ieee[3];
  __le16 dalb1;
  __le16 dalb2;
  __le16 dalb3;
  __u8 rsvd14[368];
  __u8 ctrlavail;
  __u8 ctrldgn;
  __u8 rsnident[128];
  __u8 data_area[];
};
```

Members

`lpi`

Log Identifier, either `NVME_LOG_LID_TELEMETRY_HOST` or `NVME_LOG_LID_TELEMETRY_CTRL`

`ieee`

IEEE OUI Identifier is the Organization Unique Identifier (OUI) for the controller vendor that is able to interpret the data.

`dalb1`

Telemetry Controller-Initiated Data Area 1 Last Block is the value of the last block in this area.

nvme/ioctl.h: Generic passthrough

- Provides ioctl definitions matching kernel UAPI
  - Except NVME_IOCTL_SUBMIT_IO: Kernel should deprecate this ioctl
- Generic method signatures provided at the lowest level of the command API
  - Provides everything needed to send any NVMe command and payload, including vendor specifics
  - Not very coder friendly

```
int nvme_admin_passthru(int fd, __u8 opcode, __u8 flags, __u16 rsvd,
                        __u32 nsid, __u32 cdw2, __u32 cdw3, __u32 cdw10, __u32 cdw11,
                        __u32 cdw12, __u32 cdw13, __u32 cdw14, __u32 cdw15,
                        __u32 data_len, void *data, __u32 metadata_len, void *metadata,
                        __u32 timeout_ms, __u32 *result);
```

nvme/ioctl.h: Command specific functions

- Parameterized for every command with fields and types specific to the commands' construction define usage
  - Easier to use compared to setting bits and bytes into unconstrained parameters
- Some commands, like logs, have many variations
  - Another layer will make it easier to reach the desired features

int **nvme_get_log**(int *fd*, enumnvme_cmd_get_log_lid *lid*, __u32 *nsid*, __u64 *lpo*, __u8 *lsp*, __u16 *lsi*, bool *rae*, __u8 *uuidx*, __u32 *len*, void * *log*)

NVMe Admin Get Log command

Parameters

`int fd`

File descriptor of nvme device

`enum nvme_cmd_get_log_lid lid`

Log page identifier, see `enum nvme_cmd_get_log_lid` for known values

`__u32 nsid`

Namespace identifier, if applicable

`__u64 lpo`

Log page offset for partial log transfers

`__u8 lsp`

Log specific field

nvme/ioctl.h: Command subtype specific

- Commands with subtypes: Get Log Page, Identify, Get/Set Features, Get/Set Directives
- Provide easy access to each sub-type of command by further parameterizing each
  - Constraining parameters is easier to use and provides type safety
  - 140 unique command functions for their specific command mode and payload
  - 85 enumerations for command parameters

int nvme_get_log_telemetry_ctrl(int *fd*, bool *rae*, __u64 *offset*, __u32 *len*, void * *log*)

Parameters

`int fd`

File descriptor of nvme device

`bool rae`

Retain asynchronous events

`__u64 offset`

Offset into the telemetry data

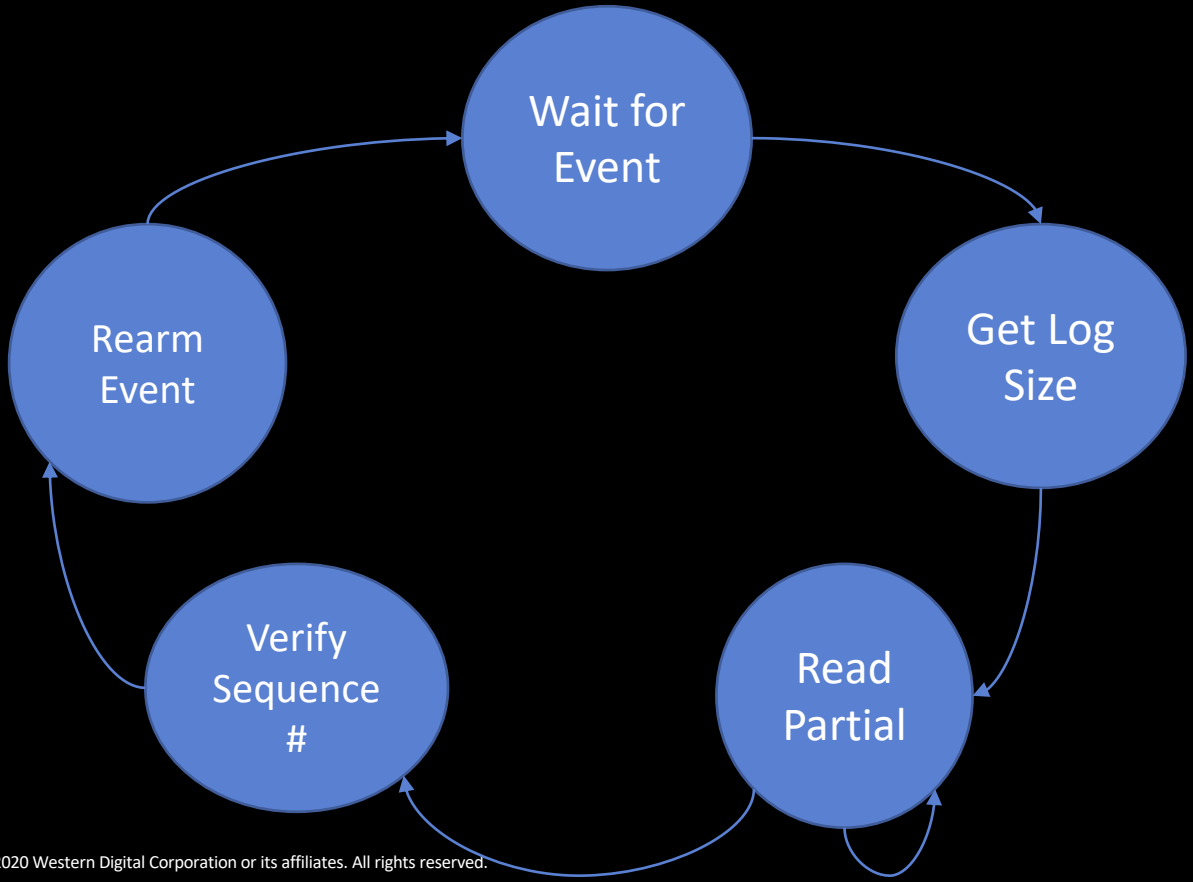
`__u32 len`

Length of provided user buffer to hold the log data in bytes

`void * log`

User address for log page data

nvme/util.h: Complex command sequences



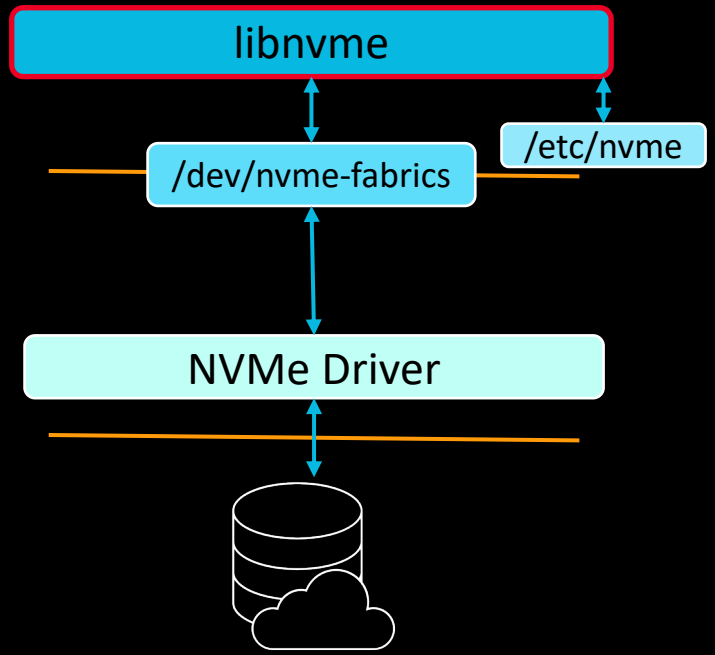
nvme/util.h: Complex command sequences

- Some information types require a longer or more complex sequence to successfully transact data: another layer to the rescue
- An incorrect sequence risks collecting a torn or stale payload
- libnvme's utils provide helper functions to manage some of complex sequences

```
int nvme_get_ctrl_telemetry(int fd, bool rae, struct nvme_telemetry_log **log);
```

nvme/fabrics.h

- Initiating connections to NVMeOF targets uses a special device handle: `/dev/nvme-fabrics`
- User API: Write magic strings to initiate
- libnvme provides helpers to:
  - Generate and submit the magic strings
  - Recursively discover and connect to targets
  - Decoding host and target configuration files in /etc/nvme/
- Updated in sync with linux-nvme driver's fabric UAPI



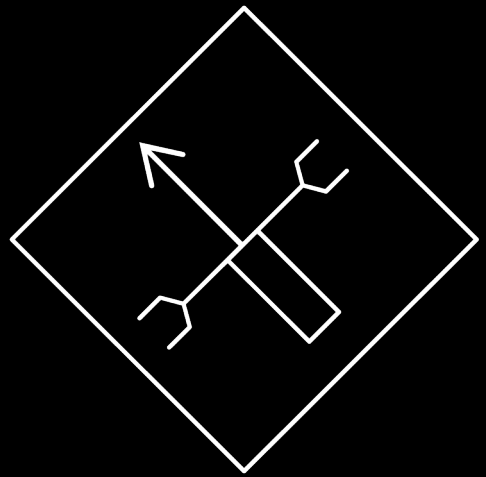
nvme/tree.h

- Establishes controller and namespace relations with each other, their parent devices, subsystem groups, and multi-path statuses
- Creates handles to all nvme objects in the system hierarchy and APIs to traverse, search, filter, retrieve attributes, and submit commands
- Filtering examples:
  - Find all controllers from vendor “ACME”
  - Find all controllers connected with RDAM transport
- Updated as needed to match the Linux driver’s sysfs hierarchy

```
|-- nvme-subsys5 - NQN=testnqn
|   |-- nvme5n1 lba size:512 lba max:488397168
|   |-- nvme7 loop  live
|   |   `-- nvme5c7n1 optimized
|   |-- nvme6 loop  live
|   |   `-- nvme5c6n1 optimized
`-- nvme-subsys0 - NQN=nqn.2018-01.com.wdc:nguid:19190E802017-0001-001B448B44AF756C
    `-- nvme0 pcie 0000:09:00.0 live
        `-- nvme0n1 lba size:512 lba max:488397168
```

Remaining work

- A few specifications features remain to be implemented
  - Persistent event log
  - Management Interface (MI) send/receive
- Uncommon features remain untested
  - Need to be verified with real hardware to confirm the library's types and commands are correctly implemented
  - Finding target support for some features can be difficult!
- New NVMe specification features are coming soon: will need to implement these
- Complete integration with nvme-cli
  - Release and request package support in our favorite Linux distributions



The End