SDC 19

September 23-26, 2019
Santa Clara, CA

Programming Emerging Storage Interfaces

Simon A. F. Lund
Samsung / SSDR

Programming Emerging Storage Interfaces

- Block Storage
- Zoned Block Storage
- Object Storage
- Computational Storage

Programming Emerging Storage Interfaces

- Block Storage
- Zoned Block Storage
- Object Storage
- Computational Storage

Command (sq-entry)

64 bytes to form an NVMe Command (Submission Entry)

Dword	Byte 3								Byte 2								Byte 1								Byte 0							
	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	Command Identifier																PSDT								Opcode							
1																																
2																																
3																																
4																																
5																																
6																																
7																																
8																																
9																																
10																																
11																																
12																																
13																																
14																																
15																																

Response (cq-entry)

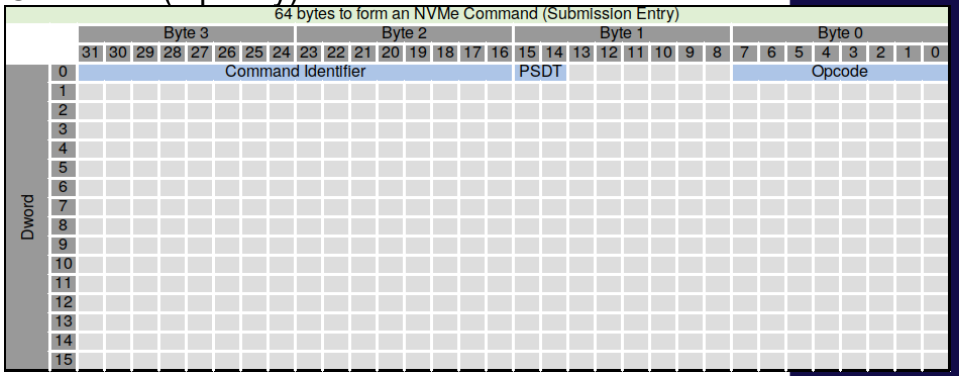
At least 16 bytes forming an NVMe Command Response (completion entry)

Dword	Byte 3								Byte 2								Byte 1								Byte 0							
	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0																																
1																																
2																																
3	Status Field																Command Identifier															

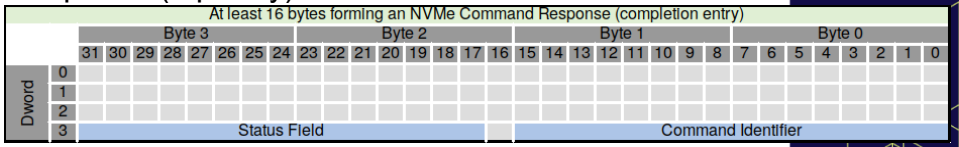
Programming Emerging Storage Interfaces

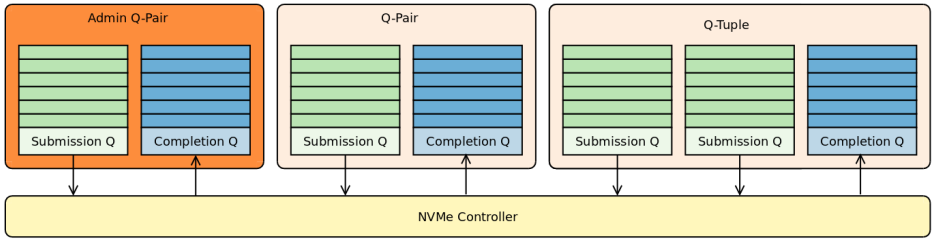
- Block Storage
- Zoned Block Storage
- Object Storage
- Computational Storage

Command (sq-entry)



Response (cq-entry)

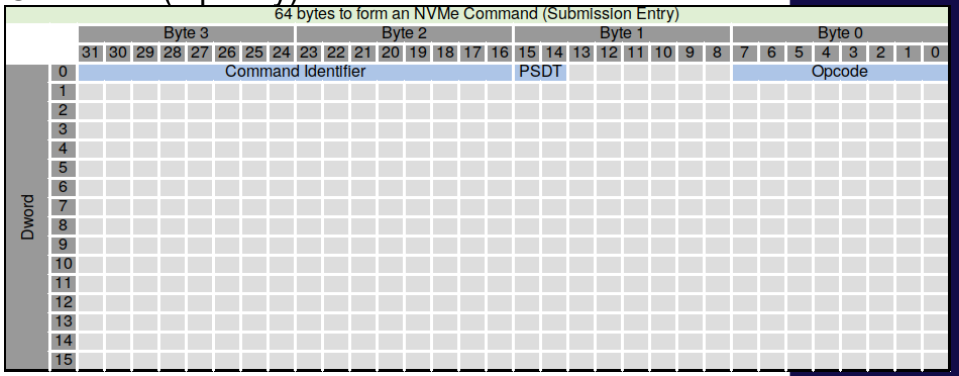




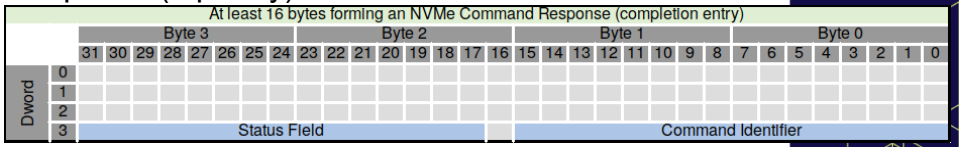
Programming Emerging Storage Interfaces

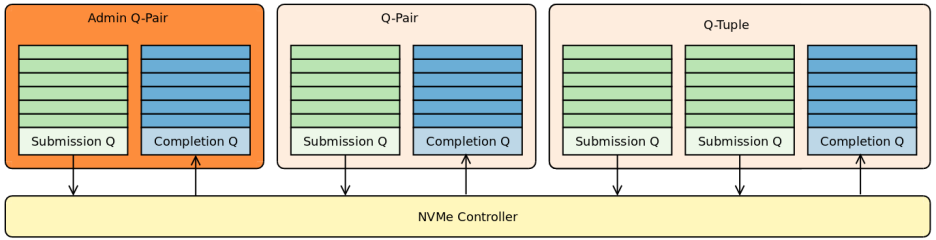
- Block Storage
- **Zoned Block Storage**
- Object Storage
- Computational Storage

Command (sq-entry)



Response (cq-entry)





Programming Emerging Storage Interfaces

- Host responsibilities for Zoned Block Storage

Programming Emerging Storage Interfaces

- Host responsibilities for Zoned Block Storage
- Setup virtual NVMe devices

Programming Emerging Storage Interfaces

- Host responsibilities for Zoned Block Storage
- Setup virtual NVMe devices
- User Space tools and libraries

Programming Emerging Storage Interfaces

- Host responsibilities for Zoned Block Storage
- Setup virtual NVMe devices
- User Space tools and libraries
- Example library and tool usage

Host Responsibilities From Open-Channel to ZNS

Host Responsibilities

- Device media represented as
  - **Physical blocks** (OCSSD 1.2)
  - **Chunks** (OCSSD 2.0 + Denali)
  - **Zones** (Zoned Namespaces)

Host Responsibilities

- Device media represented as
  - **Physical blocks** (OCSSD 1.2)
  - **Chunks** (OCSSD 2.0 + Denali)
  - **Zones** (Zoned Namespaces)
- Nomenclature: **zone**

Host Responsibilities: Zones

- Zone Layout

Host Responsibilities: Zones

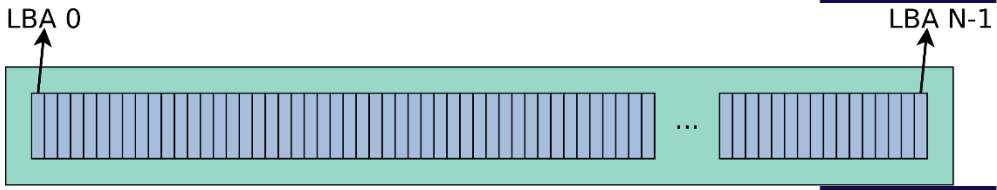
- Zone Layout
- Zone Attributes and Condition

Host Responsibilities: Zones

- Zone Layout
- Zone Attributes and Condition
- Zone Constraints
  1. Write contiguously (within a zone)
  2. Reset before write (again)

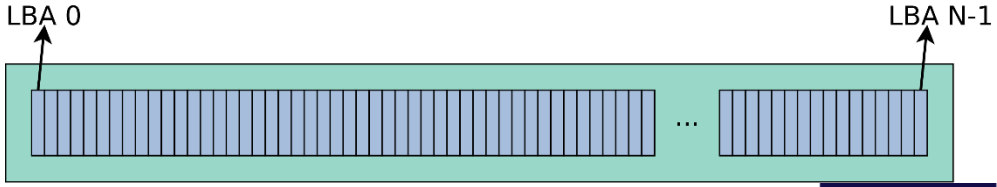
Host Responsibilities: Zone Layout

- Block Storage
  - How many LBAs
  - Size of an LBA

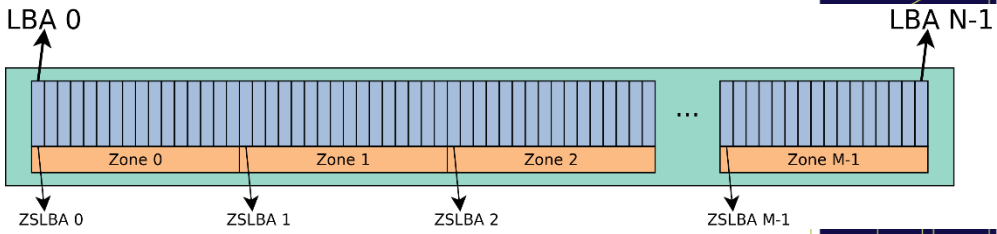


Host Responsibilities: Zone Layout

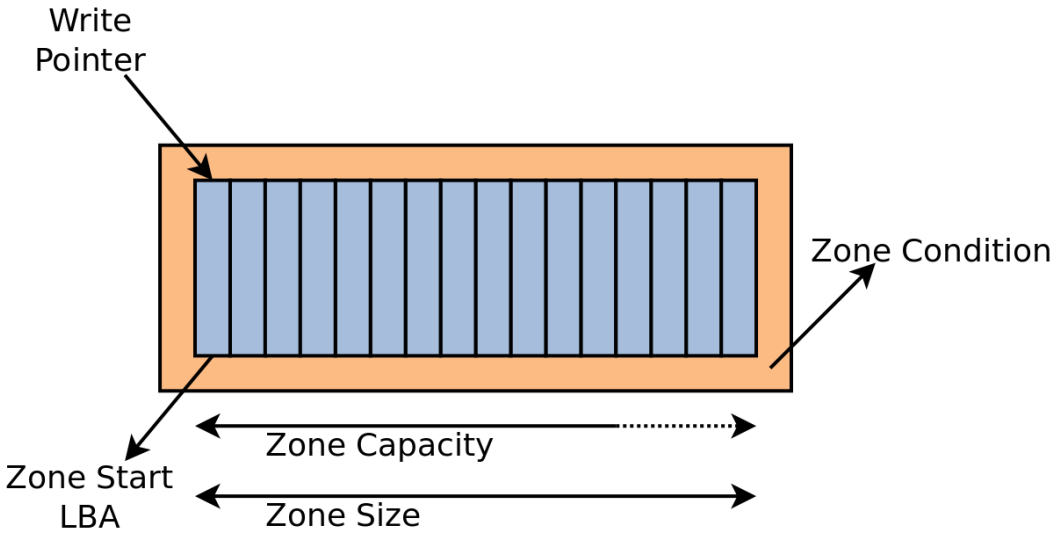
- Block Storage
  - How many LBAs
  - Size of an LBA



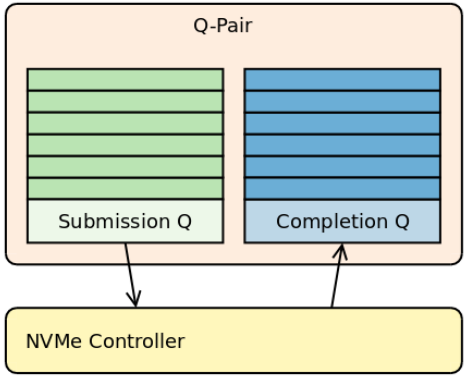
- Zoned Block Storage
  - How many Zones
  - Attributes and Condition

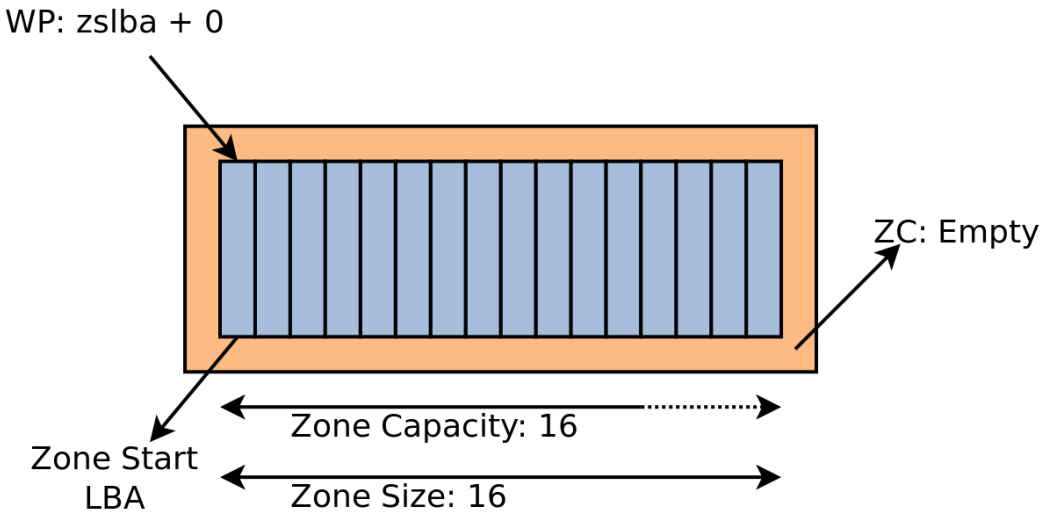


Host Responsibilities: Zone Attributes

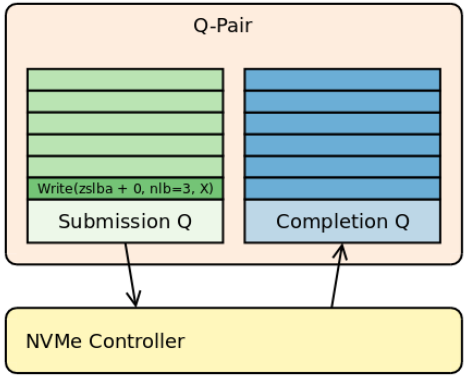


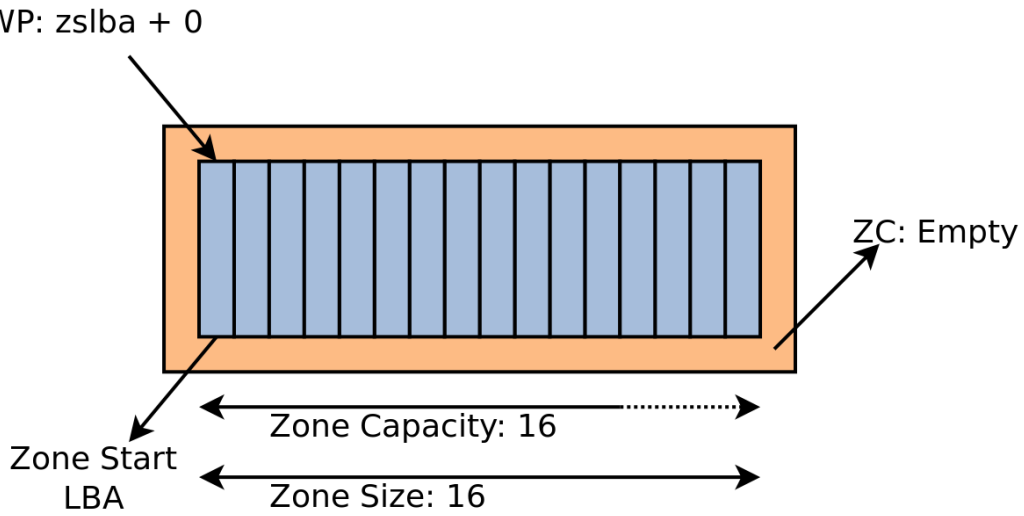
Host Responsibilities: Zone Attributes



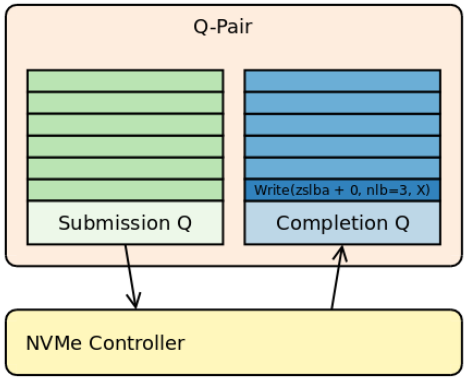


Host Responsibilities: Zone Write

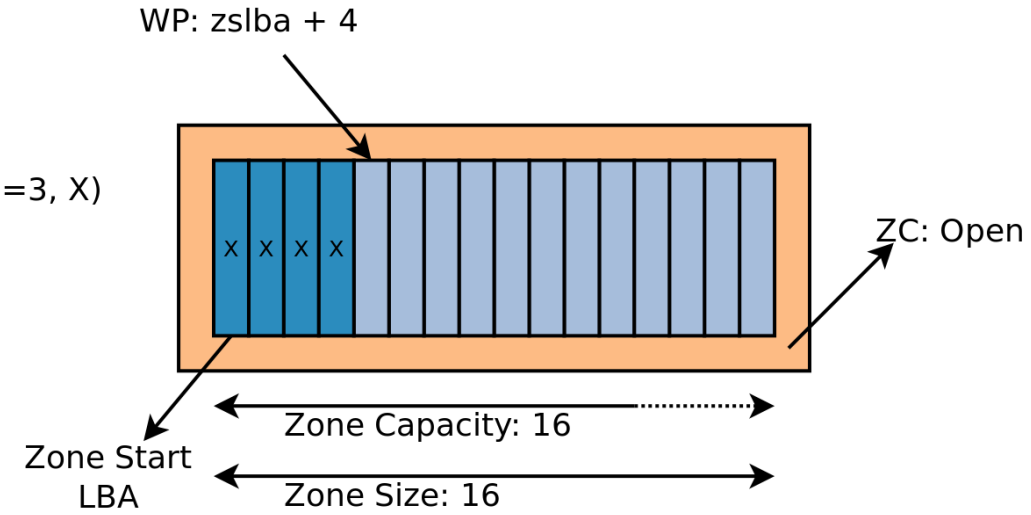




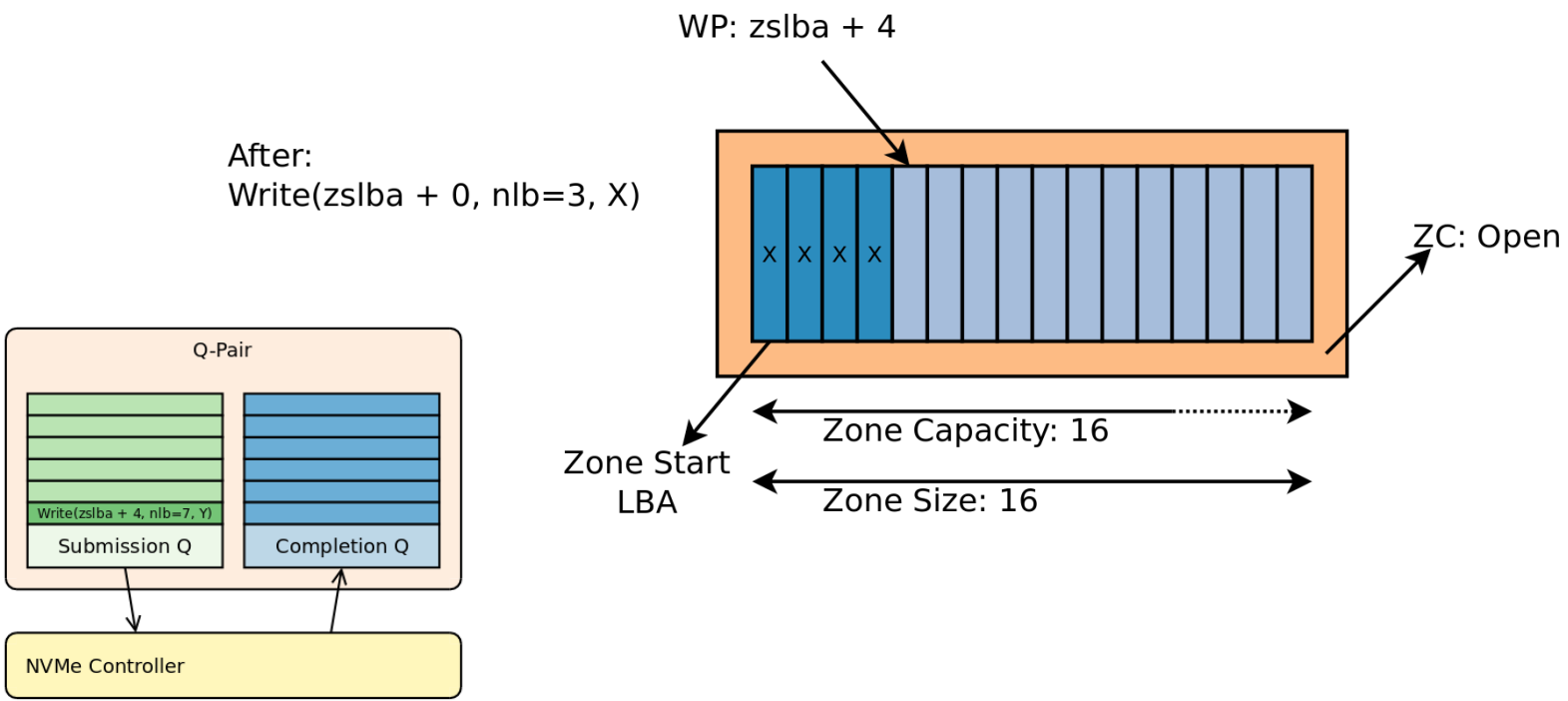
Host Responsibilities: Zone Write



After:
Write(zslba + 0, nlb=3, X)

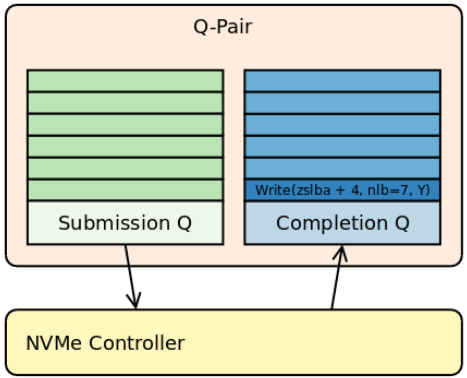


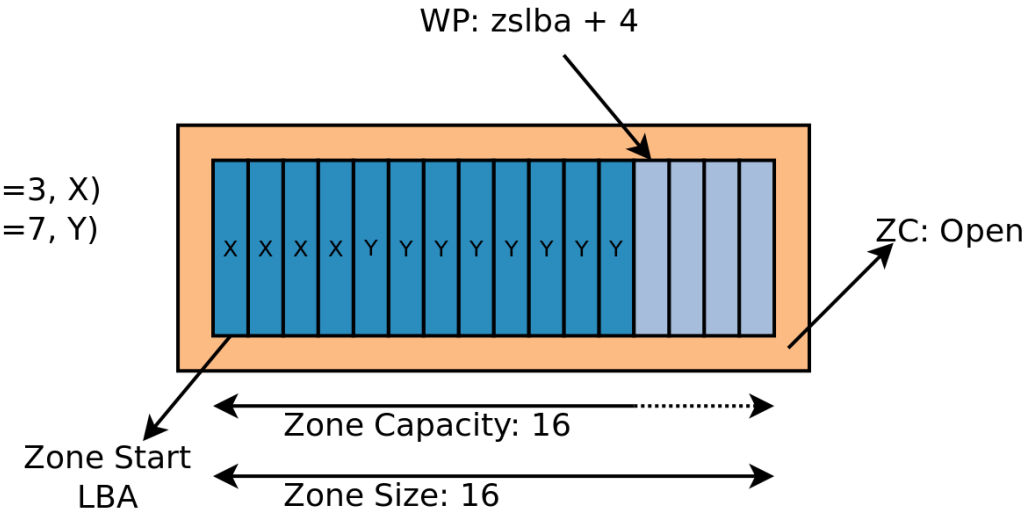
Host Responsibilities: Zone Write



Host Responsibilities: Zone Write

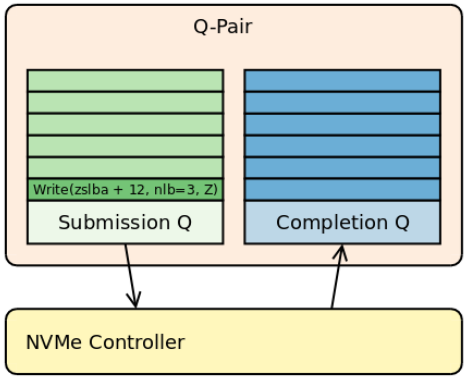
After:
Write(zslba + 0, nlb=3, X)
Write(zslba + 4, nlb=7, Y)

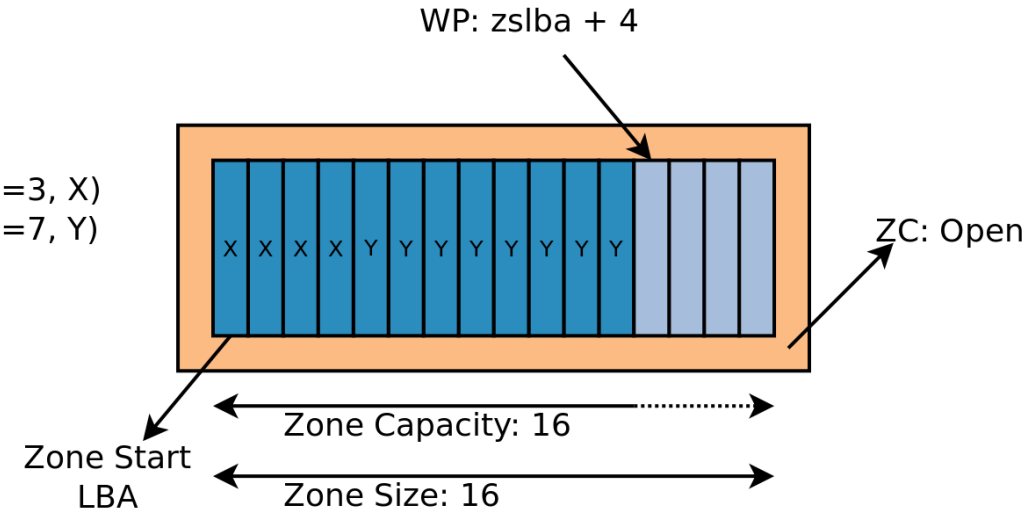




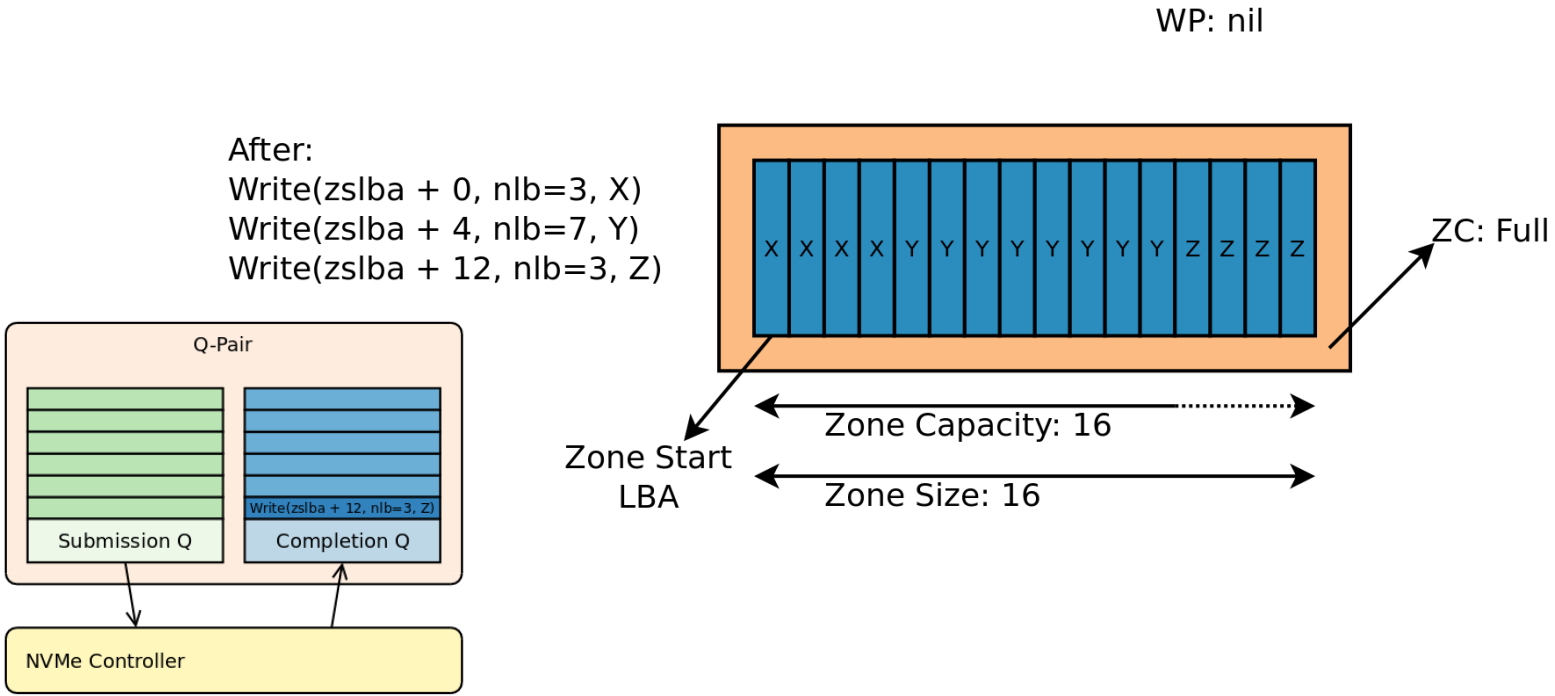
Host Responsibilities: Zone Write

After:
Write(zslba + 0, nlb=3, X)
Write(zslba + 4, nlb=7, Y)

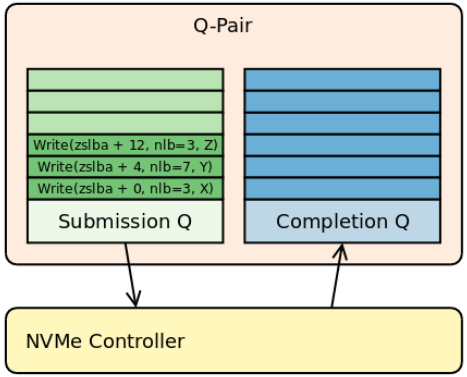


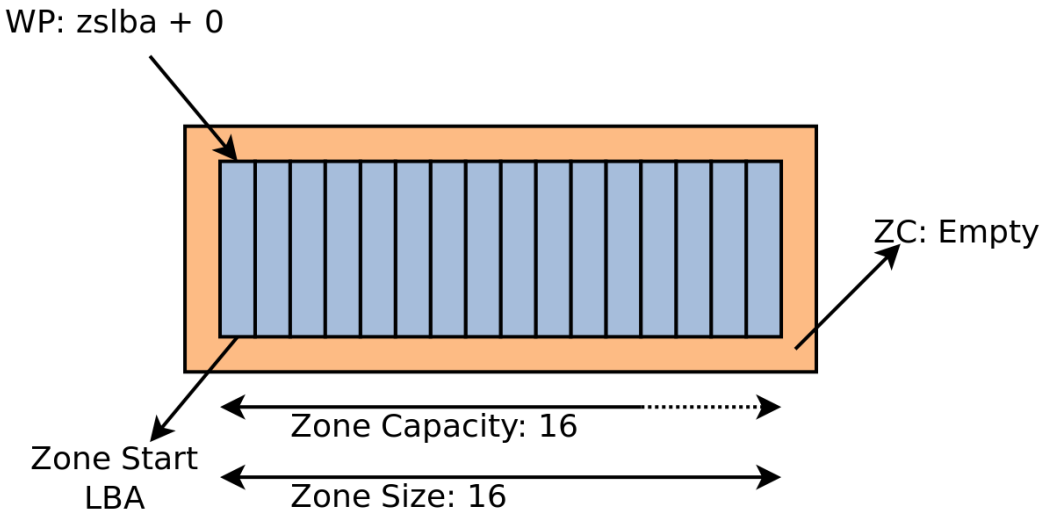


Host Responsibilities: Zone Write

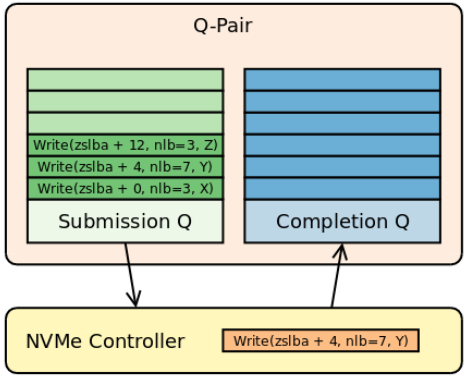


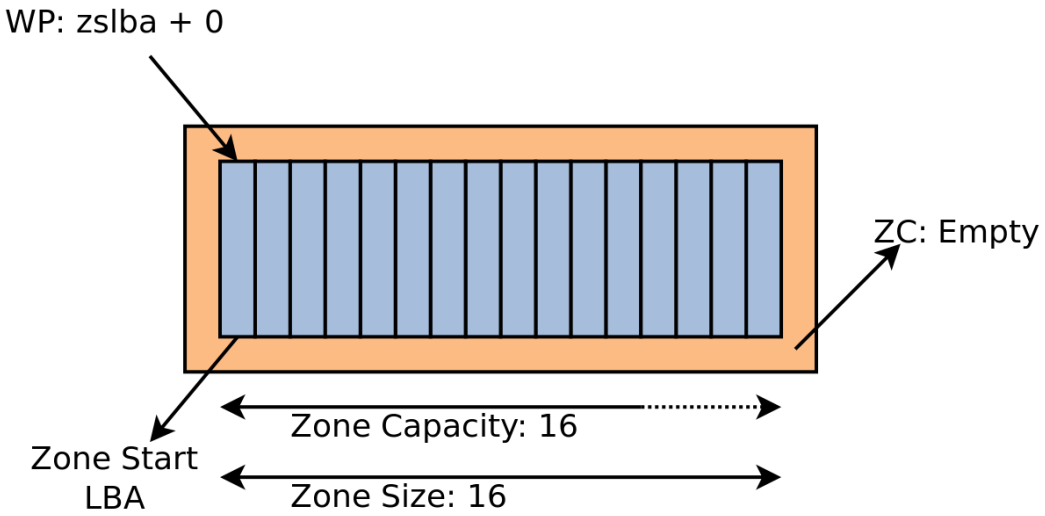
Host Responsibilities: Zone Write QD > 1



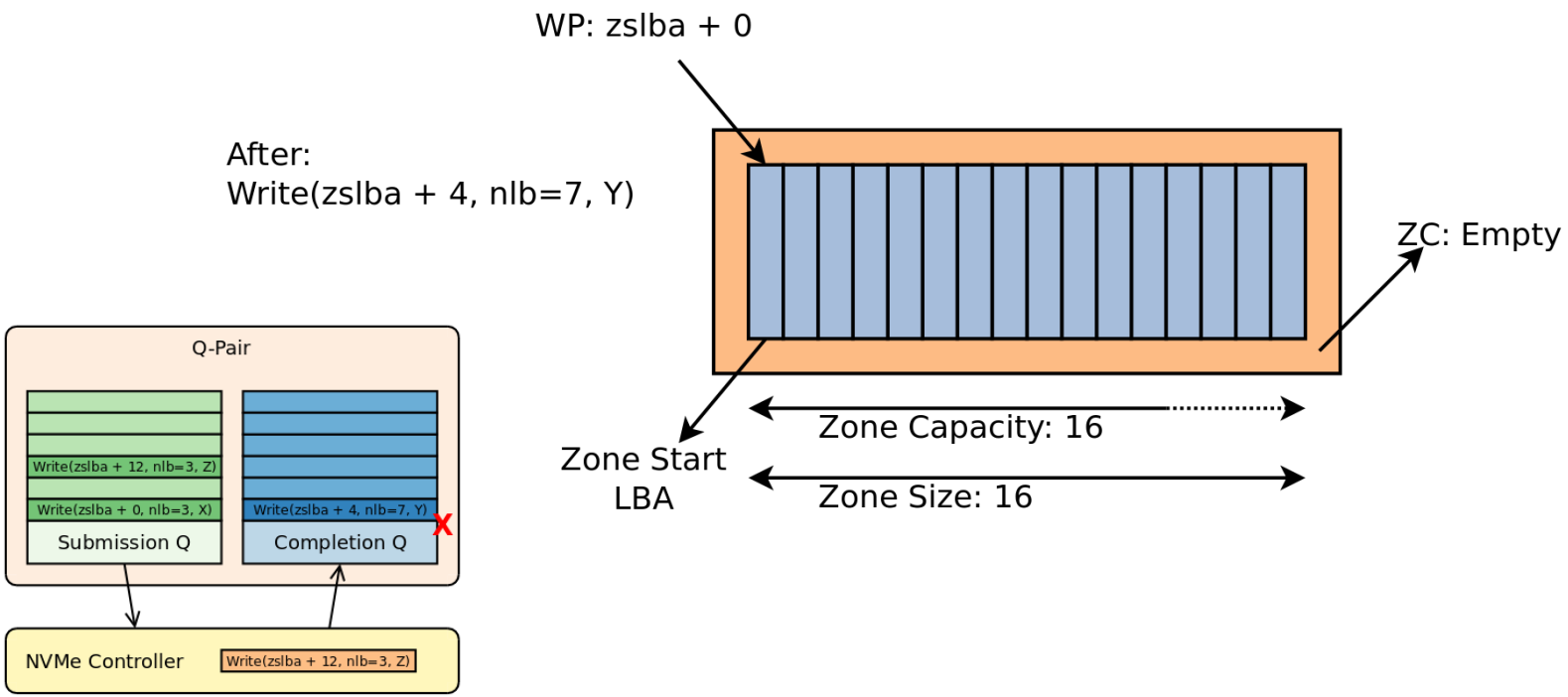


Host Responsibilities: Zone Write QD > 1

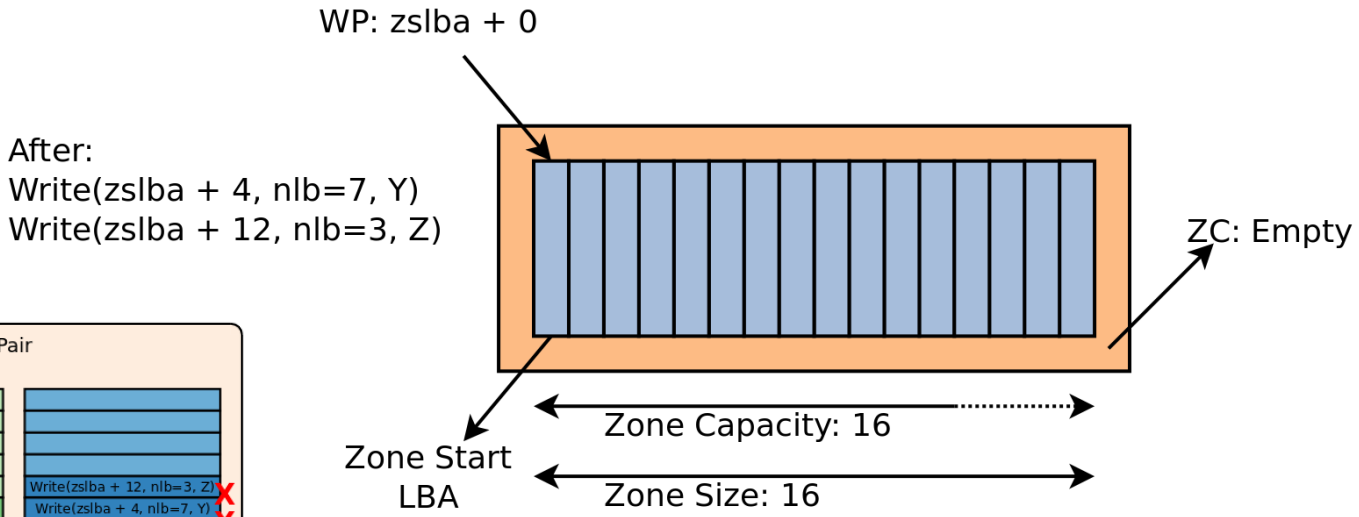


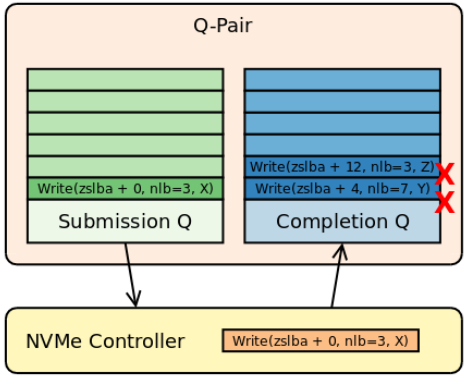


Host Responsibilities: Zone Write QD > 1



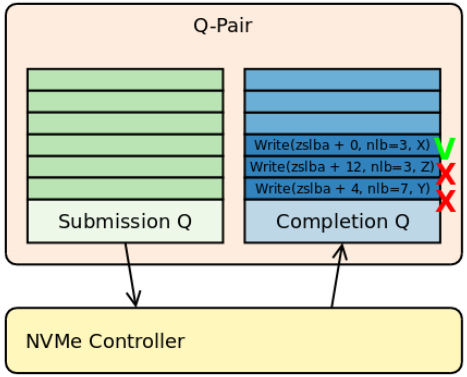
Host Responsibilities: Zone Write QD > 1

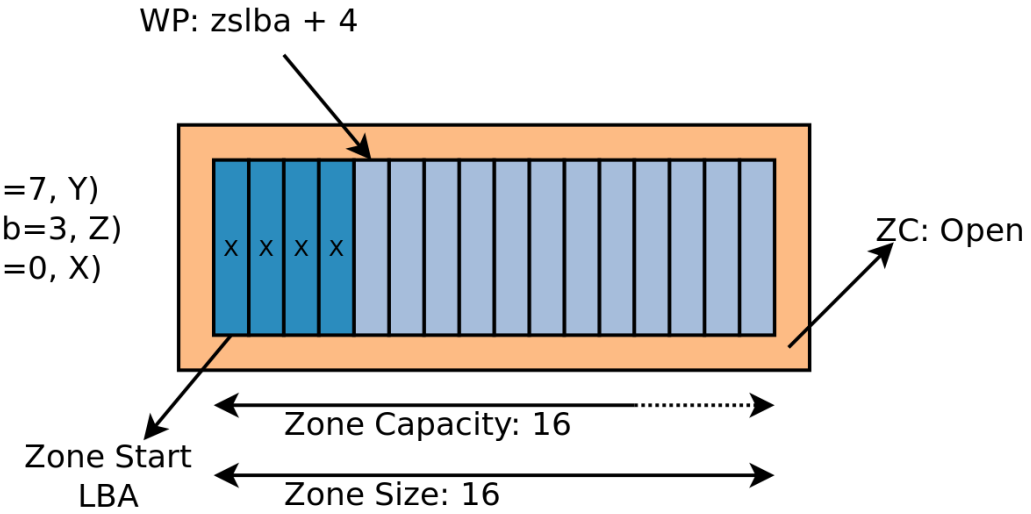




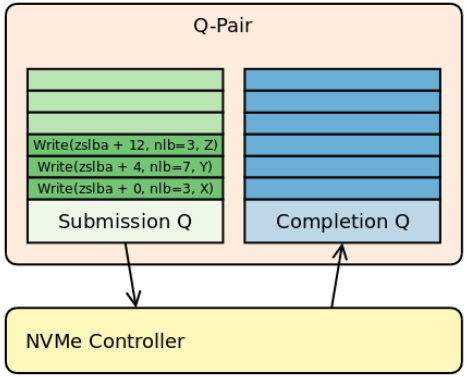
Host Responsibilities: Zone Write QD > 1

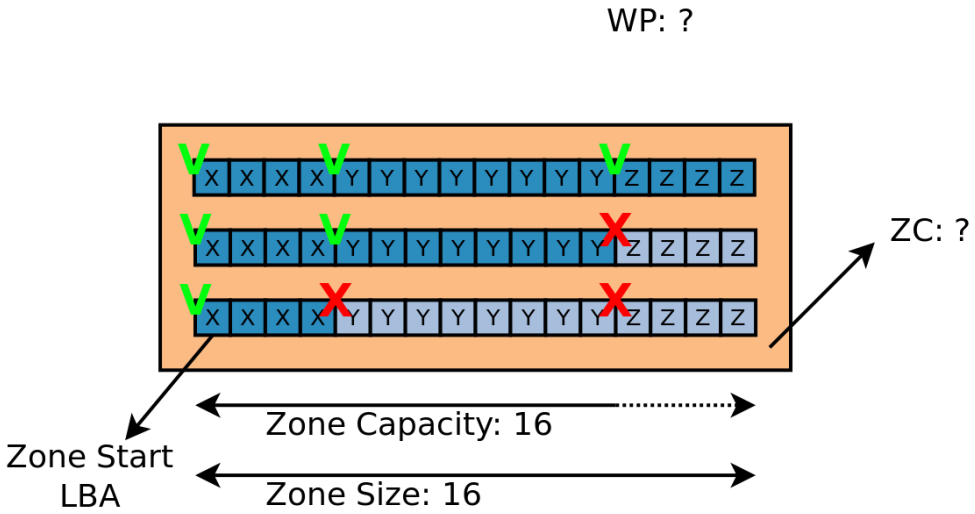
After:
Write(zslba + 4, nlb=7, Y)
Write(zslba + 12, nlb=3, Z)
Write(zslba + 0, nlb=0, X)





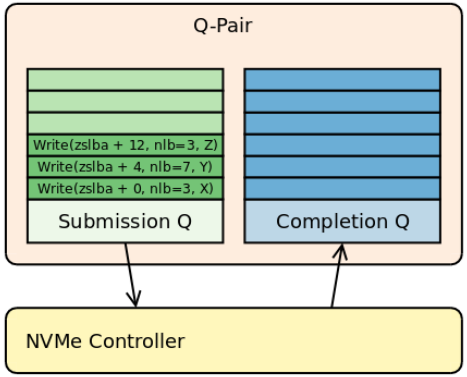
Host Responsibilities: Zone Write QD > 1

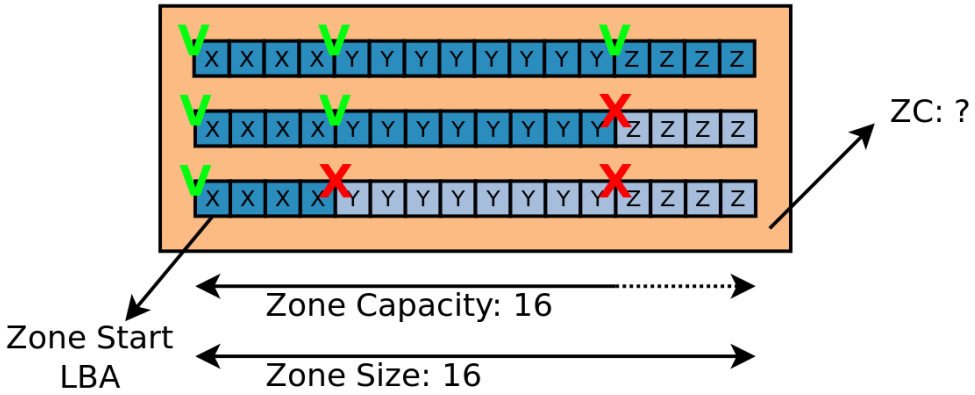




Host Responsibilities: Zone Write QD > 1

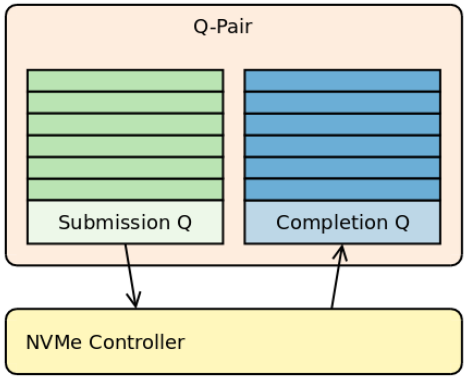
Submission Order != Execution / Completion Order

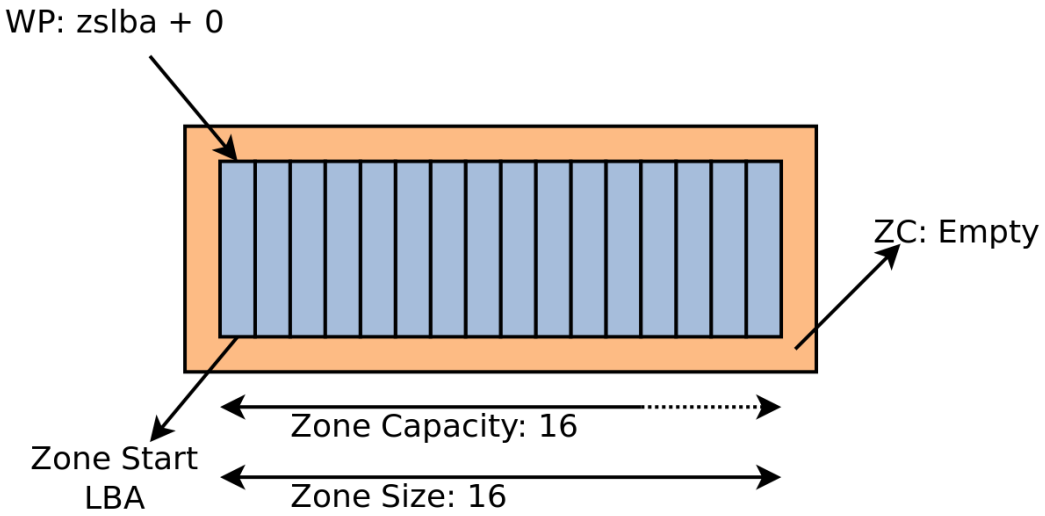




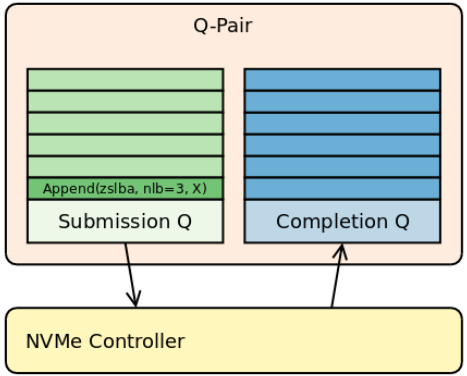
Synchronize:
Wait for a write to WP finish before writing to WP + k

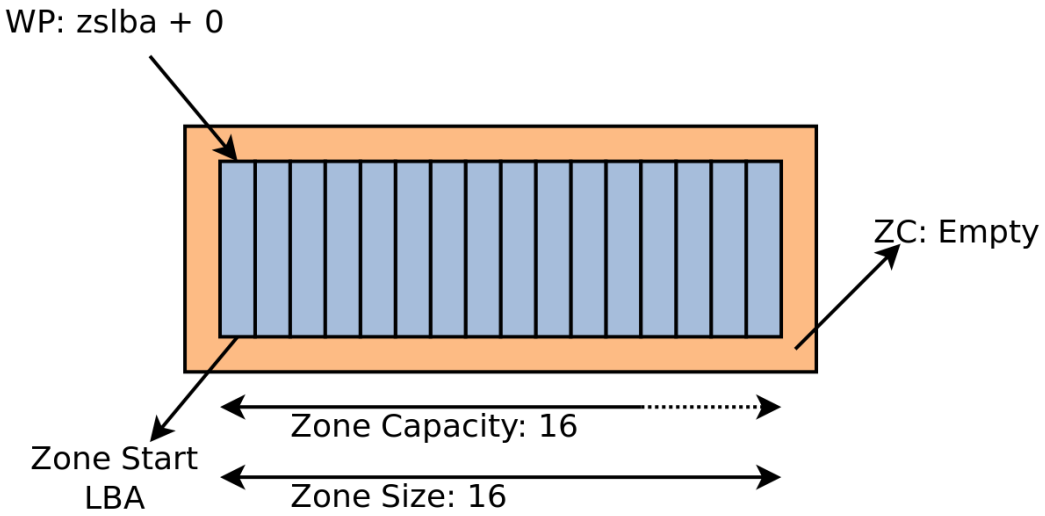
Host Responsibilities: Zone Append



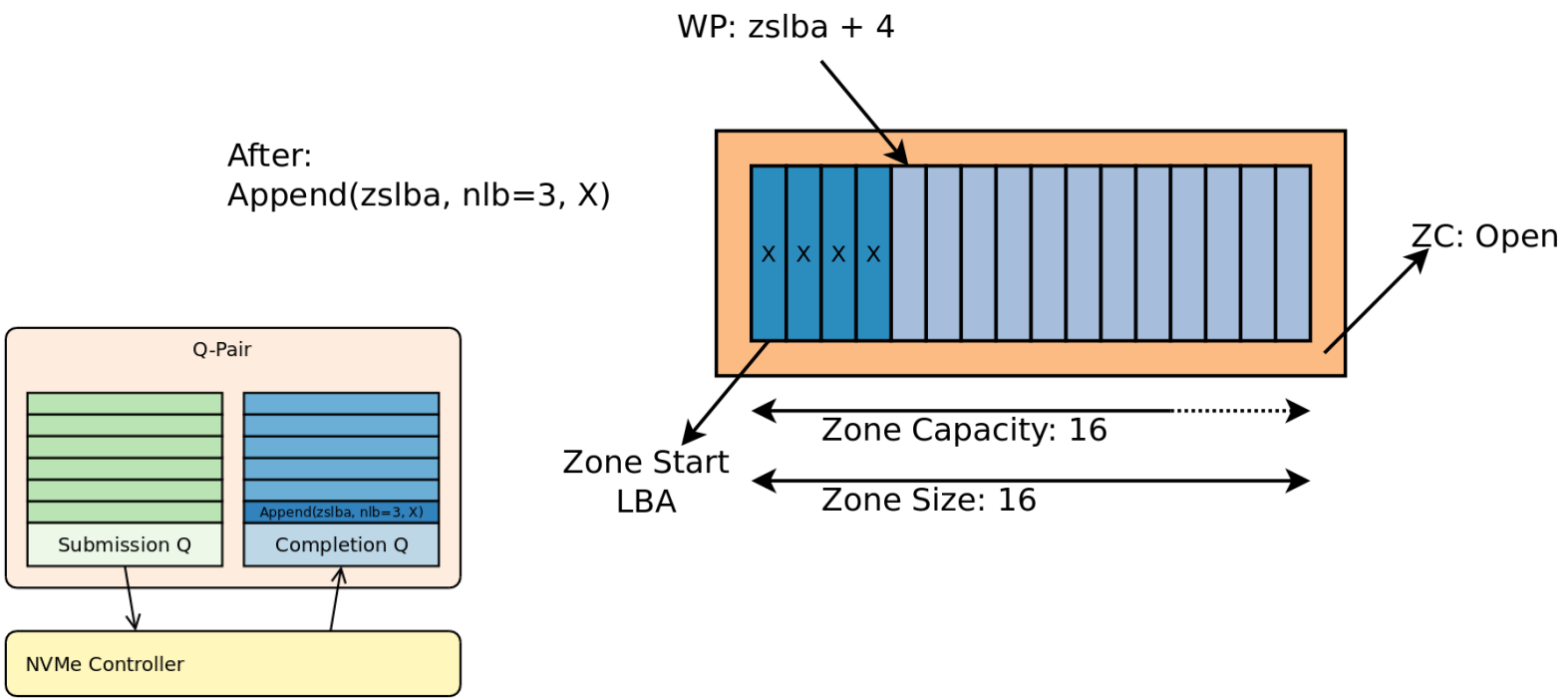


Host Responsibilities: Zone Append

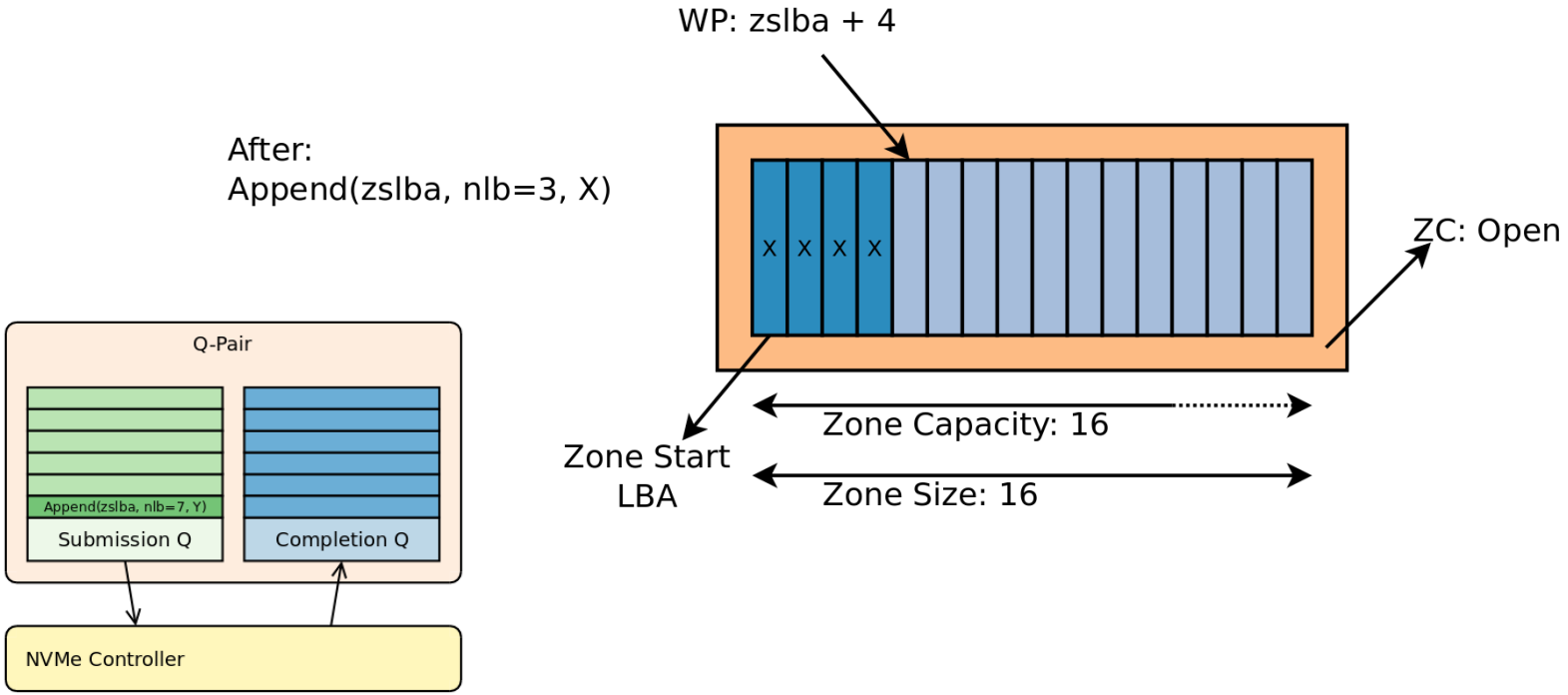




Host Responsibilities: Zone Append

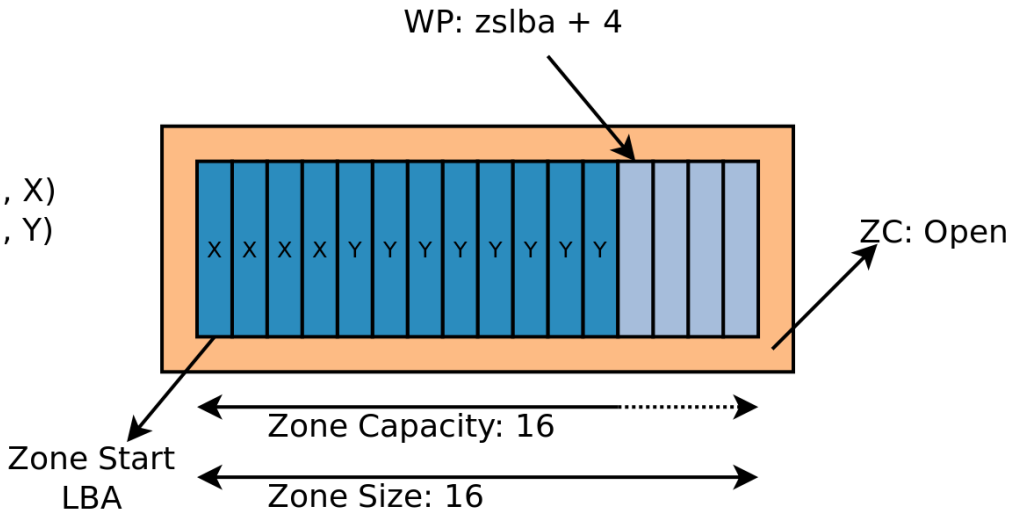


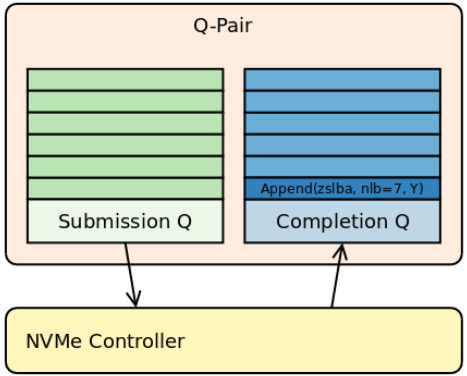
Host Responsibilities: Zone Append



Host Responsibilities: Zone Append

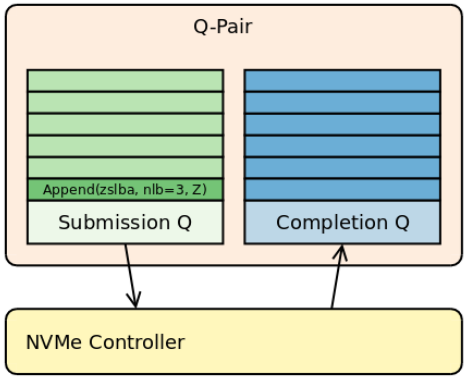
After:
Append(zslba, nlb=3, X)
Append(zslba, nlb=7, Y)

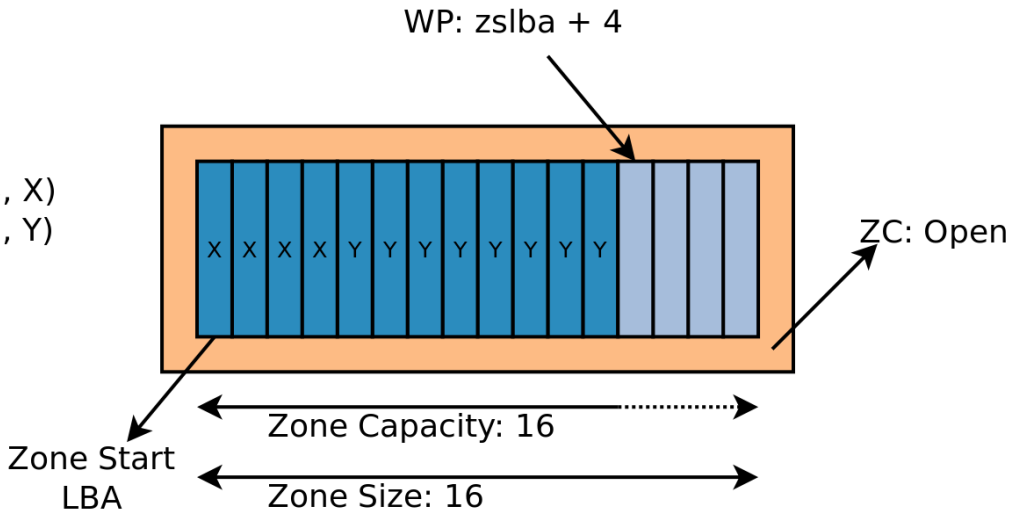




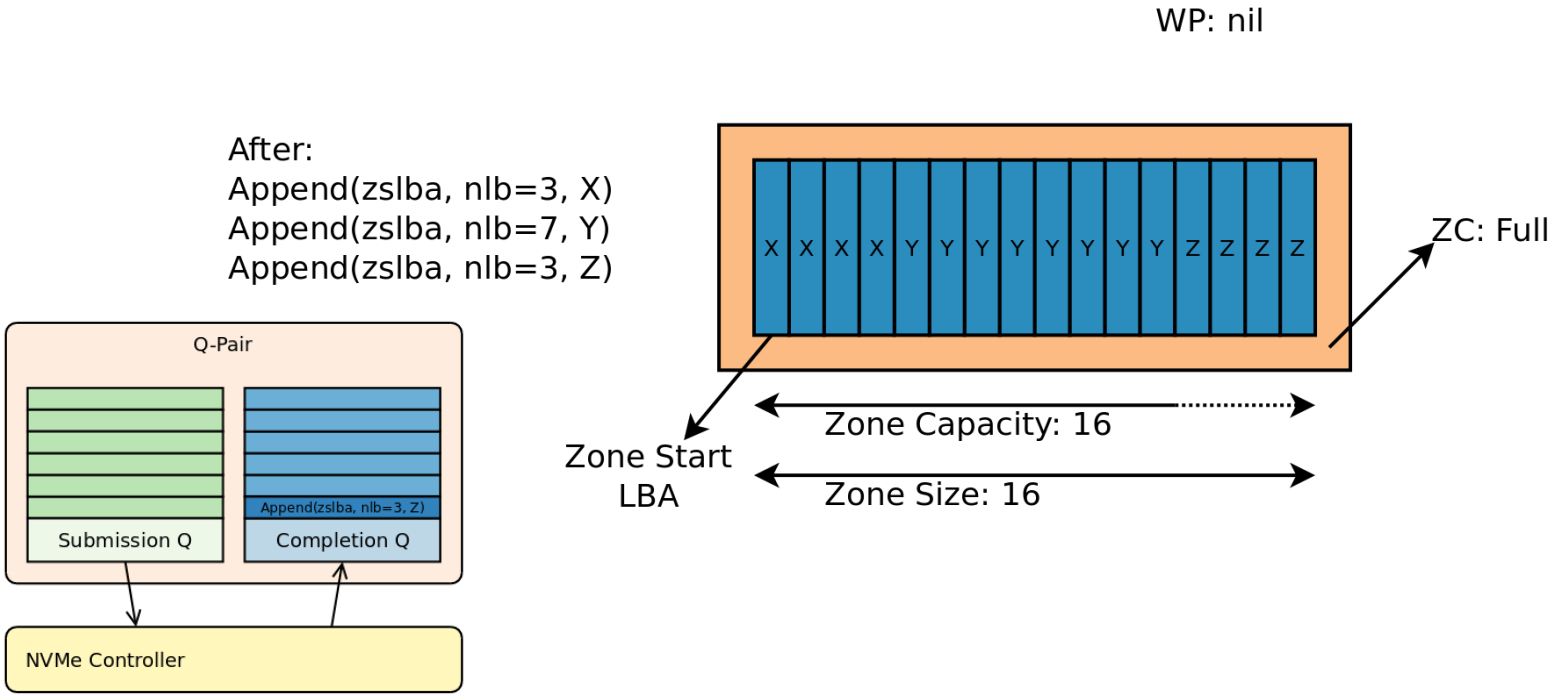
Host Responsibilities: Zone Append

After:
Append(zslba, nlb=3, X)
Append(zslba, nlb=7, Y)

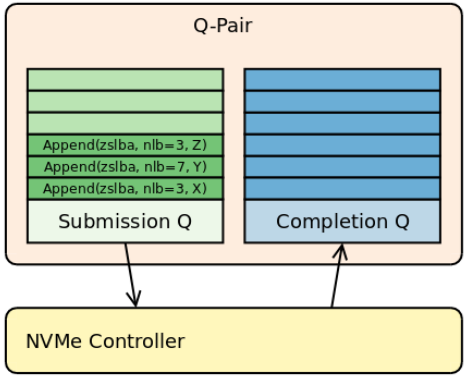


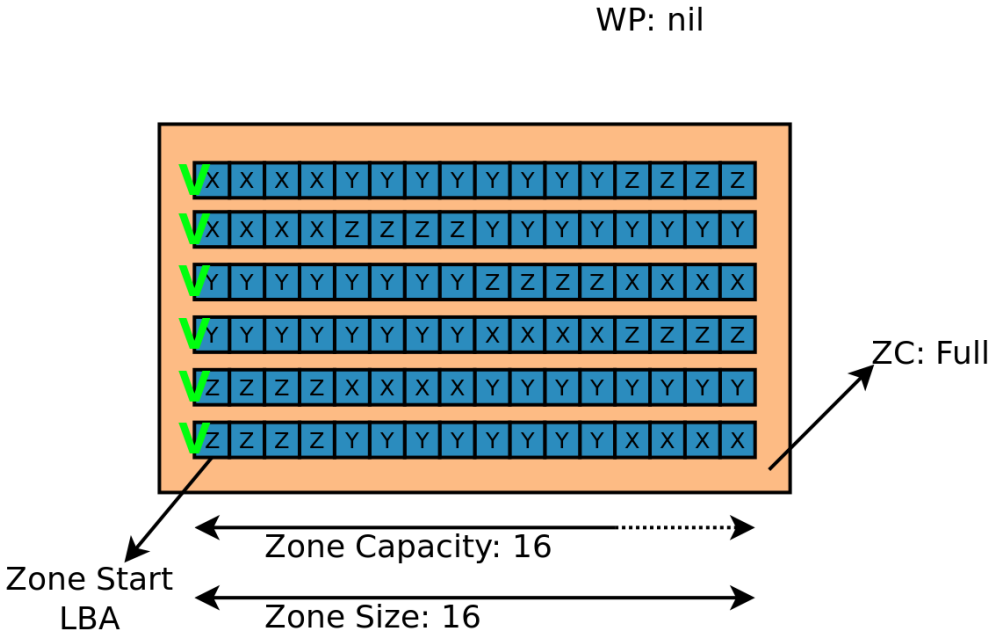


Host Responsibilities: Zone Append



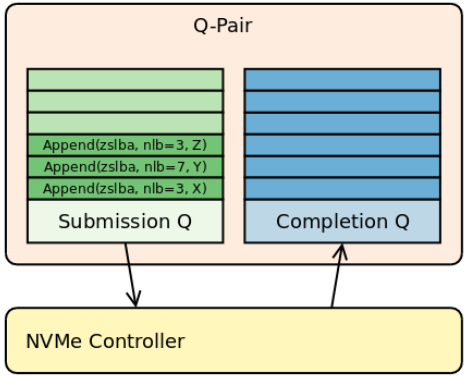
Host Responsibilities: Append QD > 1

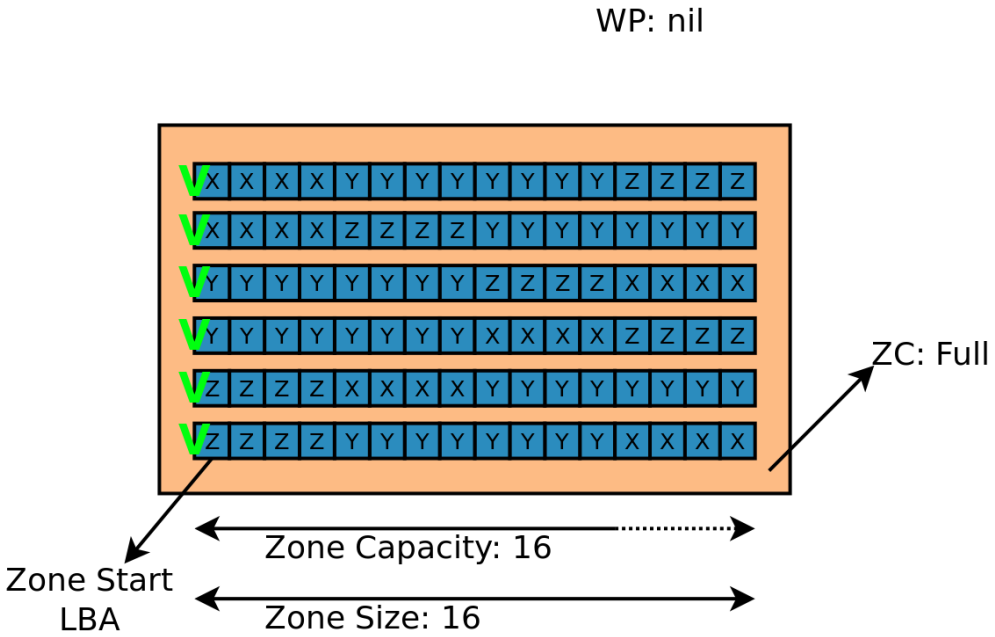




Host Responsibilities: Append QD > 1

Where is my data?



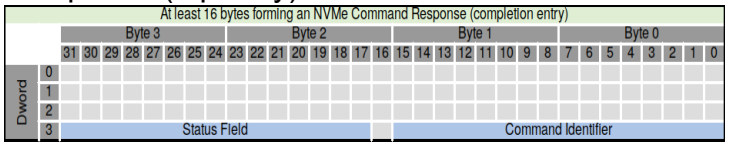


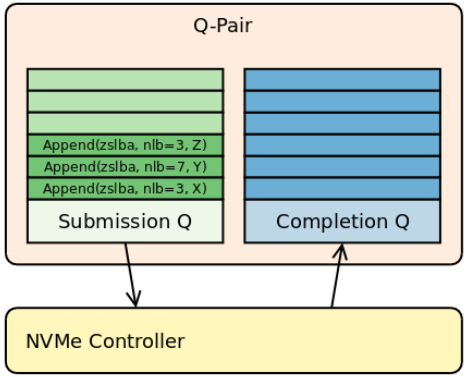
Host Responsibilities: Append QD > 1

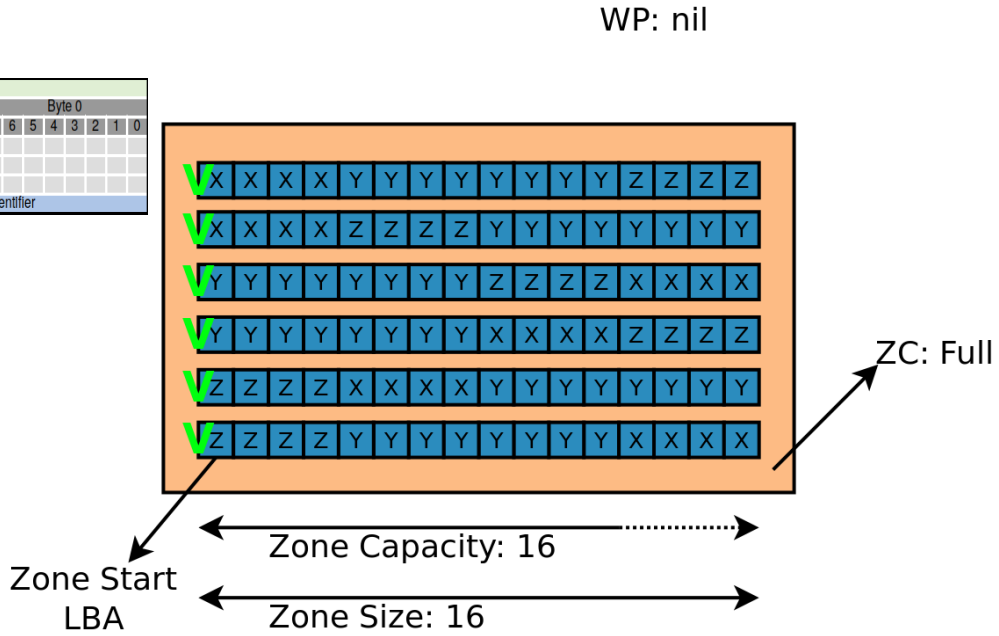
Where is my data?

Read the completion entry for location

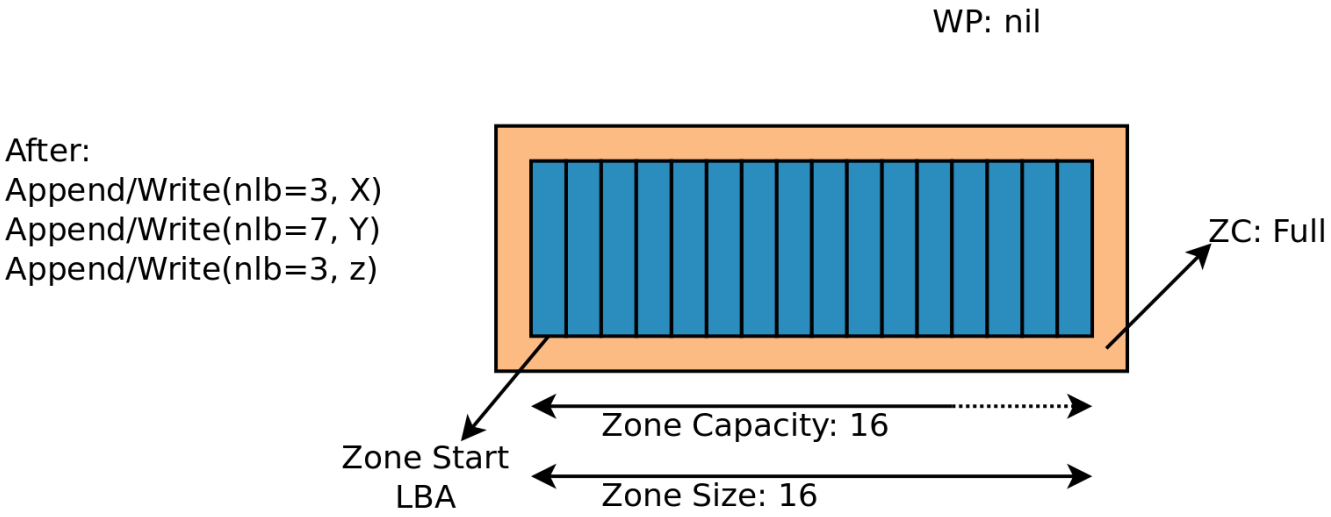
Response (cq-entry)



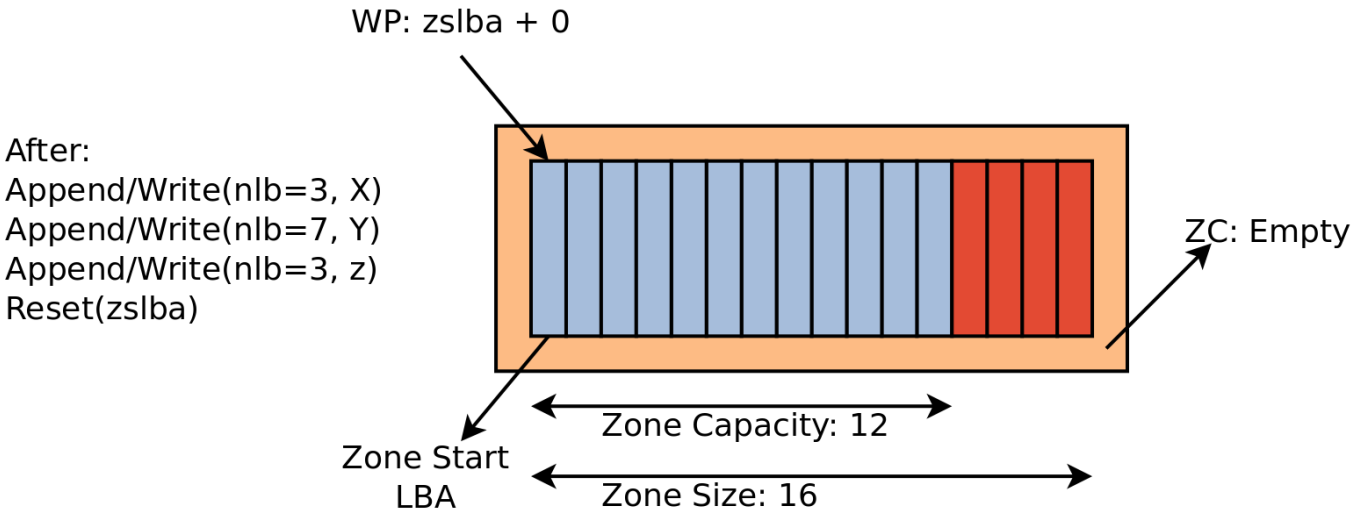




Host Responsibilities: Zone Reset

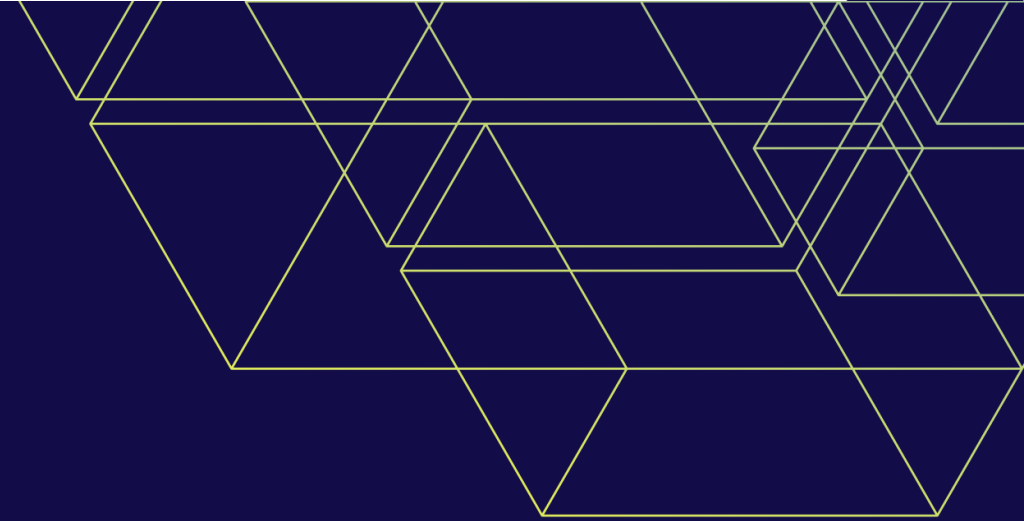


Host Responsibilities: Zone Reset



Host Responsibilities

- How to manage this as storage developer?
- You need to get retrieve information on
  - Zone Layout
  - Zone Attributes and Condition
- Read, Write, Append, and Reset commands



User Space tools and libraries

Open-Source Ecosystem: OS Support

- UNIX-like OS: everything is a file

Open-Source Ecosystem: OS Support

- UNIX-like OS: everything is a file
- System Calls
  - **ioctl()**, read(), write(), pread(), pwrite(), etc.
  - aio_read(), aio_write()
  - io_uring_prep_readv / io_uring_submit

Open-Source Ecosystem: OS Support

- UNIX-like OS: everything is a file
- System Calls
  - **ioctl()**, read(), write(), pread(), pwrite(), etc.
  - aio_read(), aio_write()
  - io_uring_prep_readv / io_uring_submit
- Wrapped in libraries libc, libaio, liburing

Open-Source Ecosystem: OS Support

- Pros:
  - General block storage infrastructure
  - Efficient async R/W with **io_uring** / **liburing**
- Cons:
  - Syncronous **ioctl()** interface
  - Limited control over command construction

Open-Source Ecosystem: OS Bypass

- API: Everything is a function call to opaque*

Open-Source Ecosystem: OS Bypass

- API: Everything is a function call to opaque*
- Driver **in** User Space
  - Intel SPDK
  - libnvme (SPDK without DPDK)

Open-Source Ecosystem: OS Bypass

- API: Everything is a function call to opaque*
- Driver **in** User Space
  - Intel SPDK
  - libnvme (SPDK without DPDK)
- Driver **in** Kernel access **from** User Space
  - NVMe-Direct

Open-Source Ecosystem: OS Bypass

- Pros:
  - Full control over command construction
  - Efficient async interface for ANY command
- Cons:
  - Controller detachment from kernel
  - Non-trivial controller sharing

Demo detach

Open-Source Ecosystem: tools

- nvme-cli
  - Built on Linux ioctl()
  - Limited port for FreeBSD ioctl()
  - Port built on SPDK
- nvmecontrol
  - FreeBSD base system, built on ioctl()

Virtual NVMe Devices

Setup, usage, and modification with

QEMU: The Quick Emulator

- A generic machine emulator and virtualizer
  - ia32, x86_64, mips, sparc, arm, risc-v
  - KVM-client e.g. using Intel VT-x
- Includes a huge collection of emulated devices

QEMU: The Quick Emulator

- A generic machine emulator and virtualizer
  - ia32, x86_64, mips, sparc, arm, risc-v
  - KVM-client e.g. using Intel VT-x
- Includes a huge collection of emulated devices
- Active community
  - ~130 subsys maintainers
  - ~1500 individual contributors)

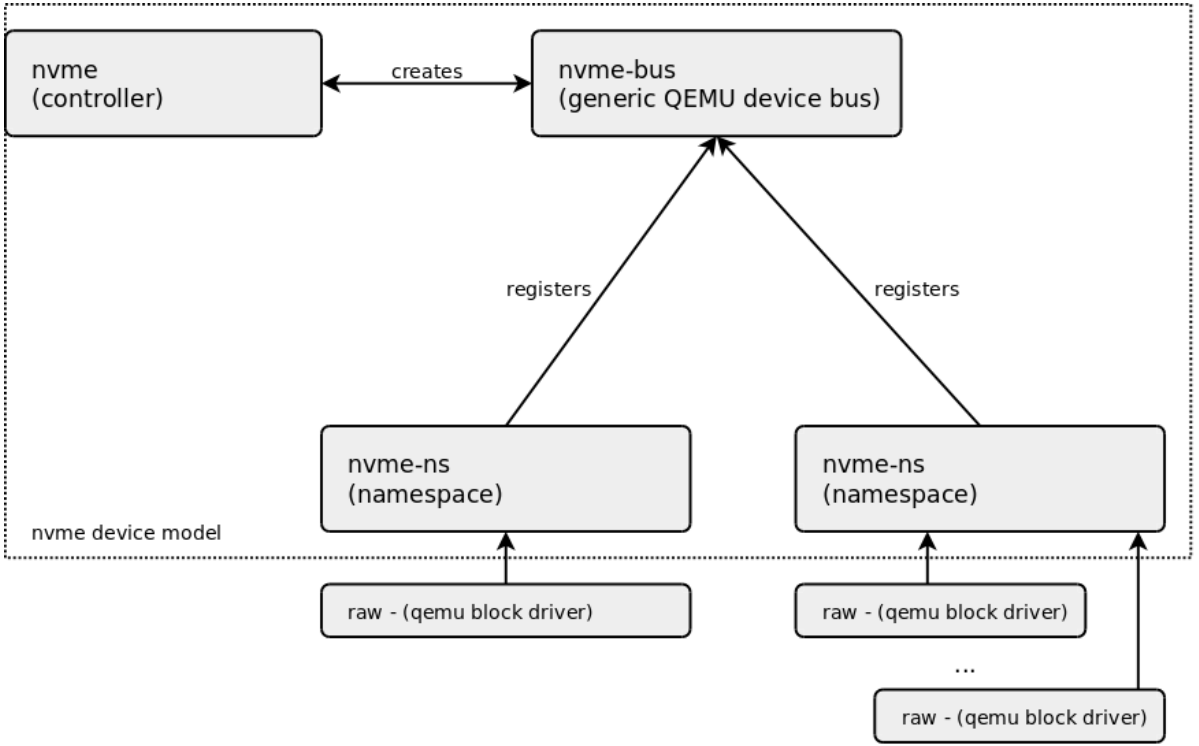
QEMU: Contributions

- Upstream contributions (Klaus A. B. Jensen)
  - Full NVMe 1.3 support
  - Ongoing NVMe 1.4 support
  - Full ZNS support
  - Upcoming TPs

QEMU: Contributions

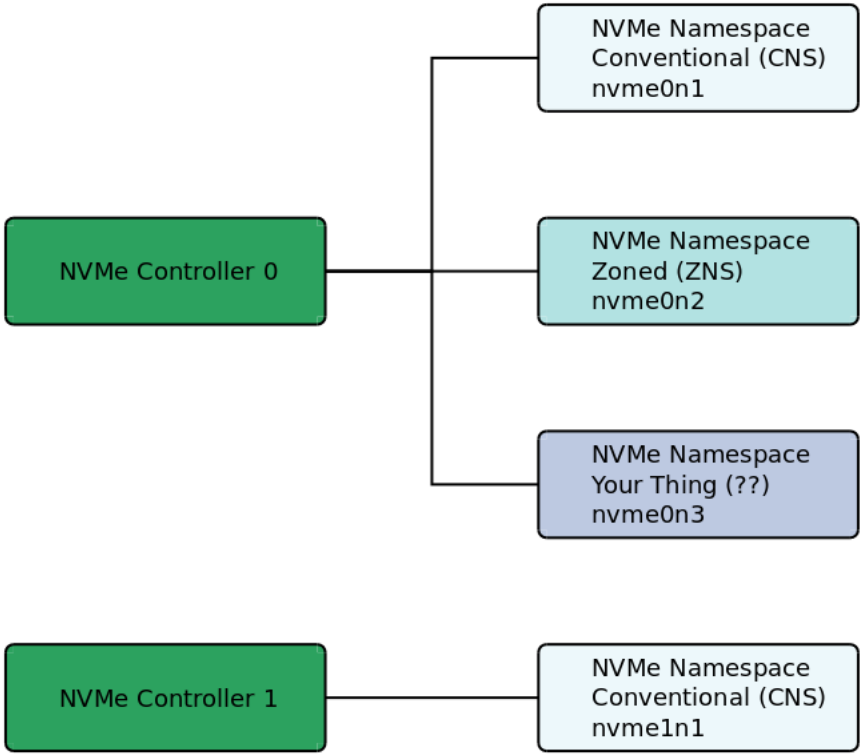
- Upstream contributions (Klaus A. B. Jensen)
  - Full NVMe 1.3 support
  - Ongoing NVMe 1.4 support
  - Full ZNS support
  - Upcoming TPs
- Extending the QEMU NVMe drive model

QEMU: NVMe Device Model



- QEMU/hw/block/nvme.c

QEMU: NVMe Device Model Usage



QEMU: NVMe Usage Hands On!

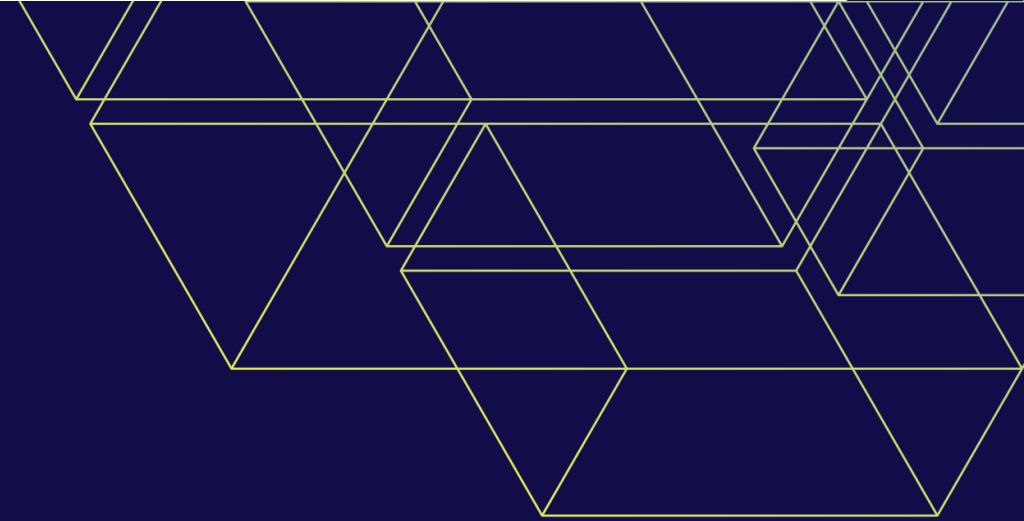
- QEMU configure and build:

QEMU build demo link

```
mkdir build
cd build
../configure
 --target-list=x86_64-softmmu
make -j $(nproc)
```

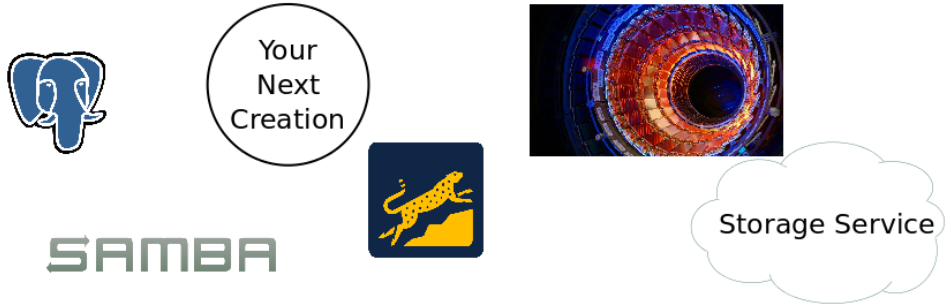
- QENV setup
  - environment config
  - machine config
  - device config
  - run and access

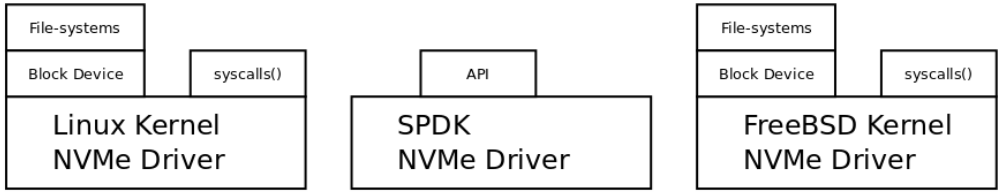
QENV setup demo link



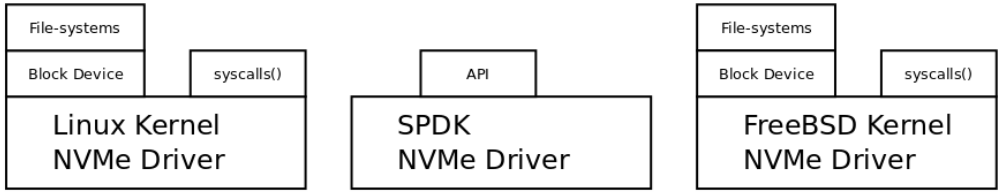
User Space tools and libraries

Open-Source Ecosystem: an overview

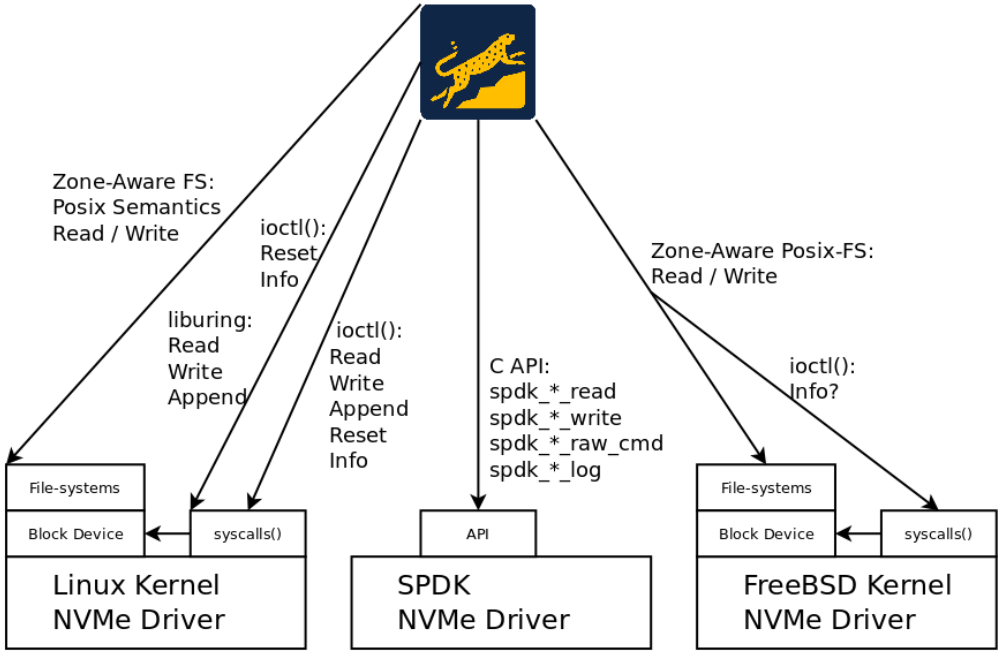




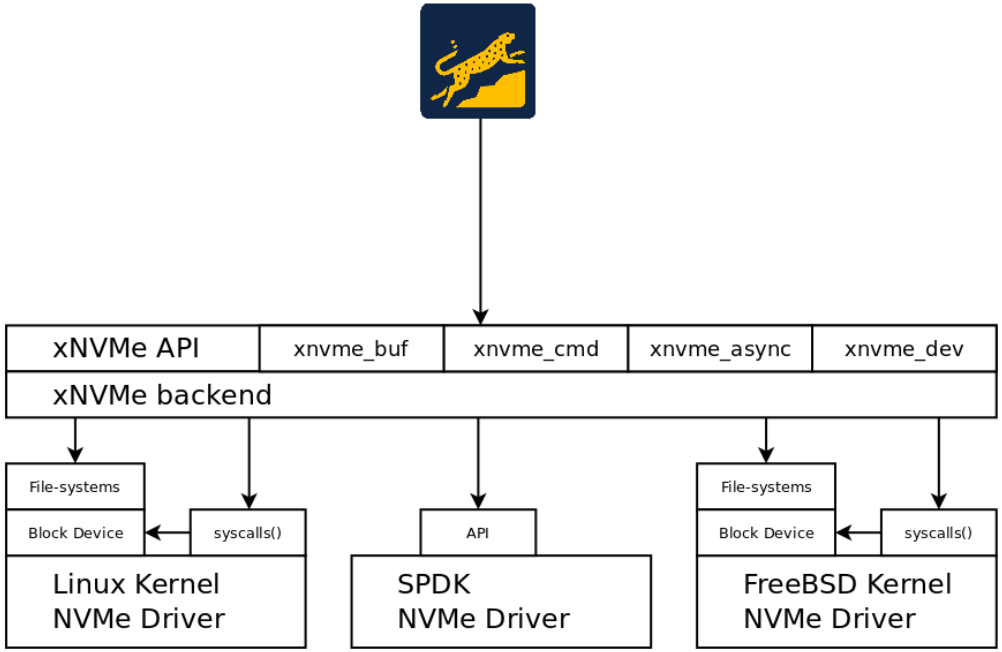
Open-Source Ecosystem: an overview



Open-Source Ecosystem: an overview



Open-Source Ecosystem: a contribution



xNVMe

Cross-platform libraries and tools for NVMe devices

xNVMe: API: xnvme_dev

Abstract handle to your controller / namespace

- Linux Backend
  - Open FDs for NVMe controller and namespace
  - io_uring_register(.., IORING_REGISTER_FILES,)
  - Reduce overhead of kernel retrieving handles for each IO
- SPDK Backend
  - Initialize and attach to controller
  - spdk_env_opts_init() / spdk_env_init() / spdk_nvme_probe()

xNVMe: API: xnvme_buf

Allocate and free memory for use by the **xnvme_cmd** interface

- Linux Backend
  - Pagesize aligned for **ioctl()**
  - posix_memalign() / free()
  - io_uring_register(IORING_REGISTER_BUFFERS, ...)
- SPDK Backend
  - Allocate physical memory / DMA transferable
  - spdk_dma_{malloc,realloc,free}()

xNVMe: API: xnvme_async

Context for asynchronous / non-blocking **xnvme_cmd** interface

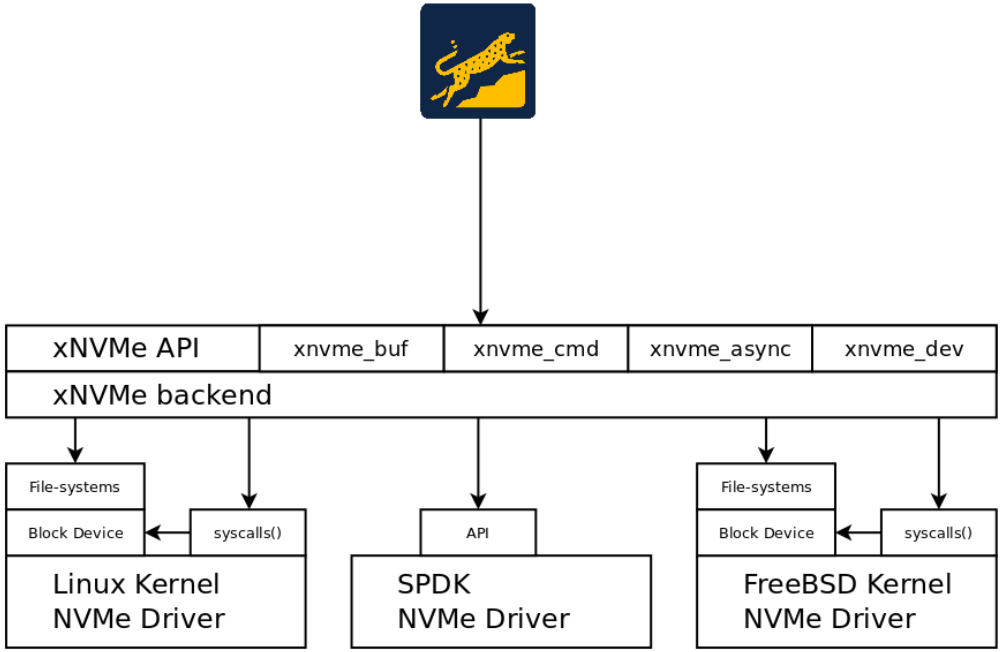
- Linux Backend
  - Threadpool allocation for pseudo-async behavior via **ioctl()**
  - SQ / CQ setup for **io_uring**
- SPDK Backend
  - NVMe QP setup
  - spdk_nvme_ctrlr_{alloc,free}_io_qpair()

xNVMe: API: xnvme_cmd

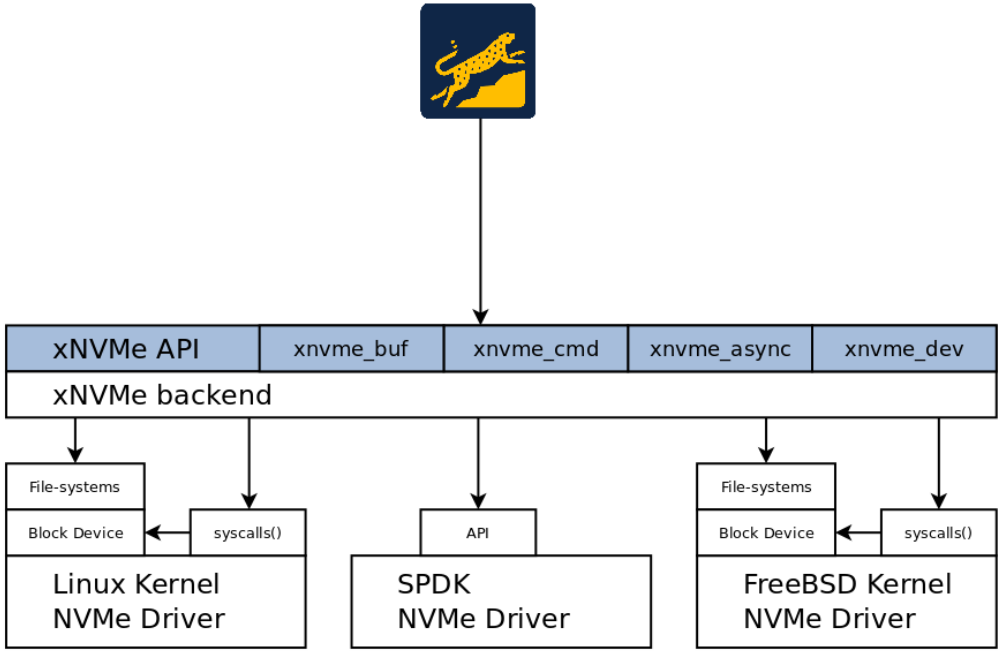
Synchronous and asynchronous command interface

- Linux Backend
  - io_uring_{submit, peek , wait}
  - Jobs to **ioctl()** threadpool
- SPDK Backend
  - spdk_nvme_ctrlr_cmd_{admin_raw, io_raw_with_md}()
  - spdk_nvme_qpair_process_completions()

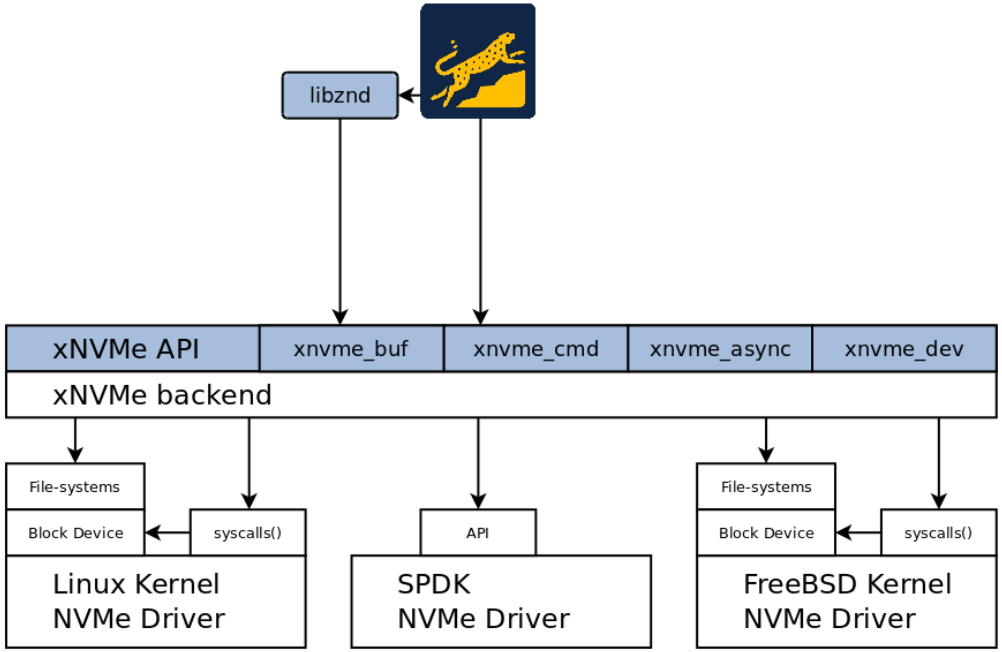
Open-Source Ecosystem: a contribution



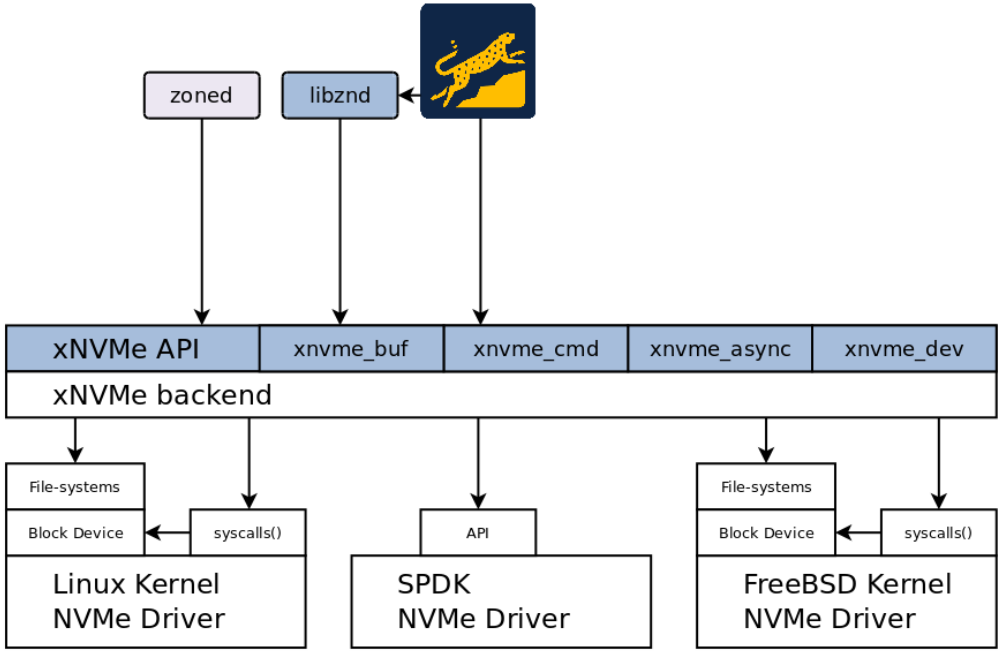
Open-Source Ecosystem: a contribution



Open-Source Ecosystem: a contribution



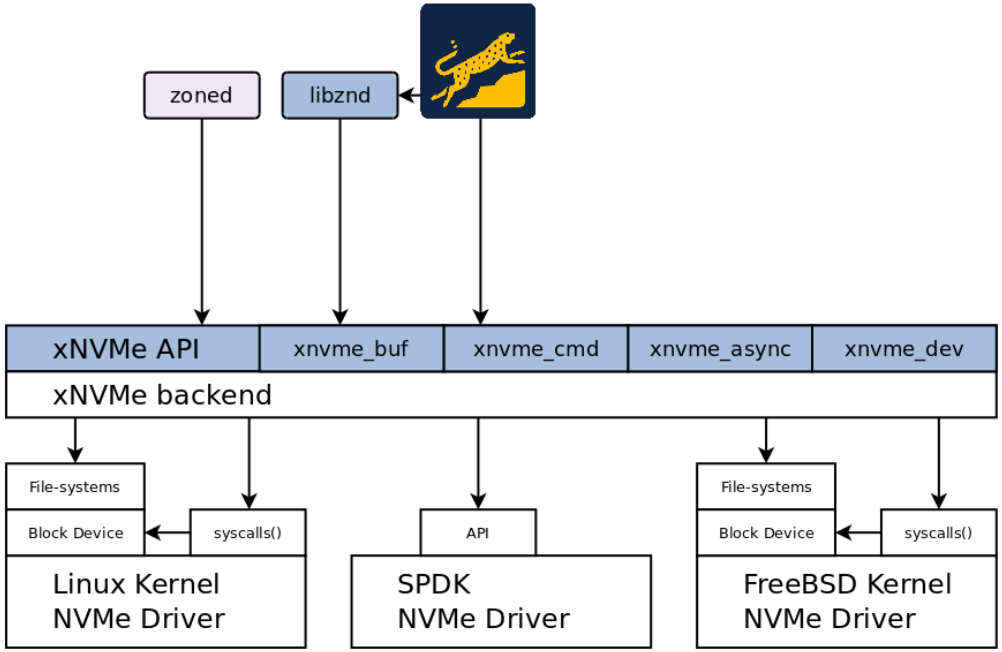
Open-Source Ecosystem: a contribution



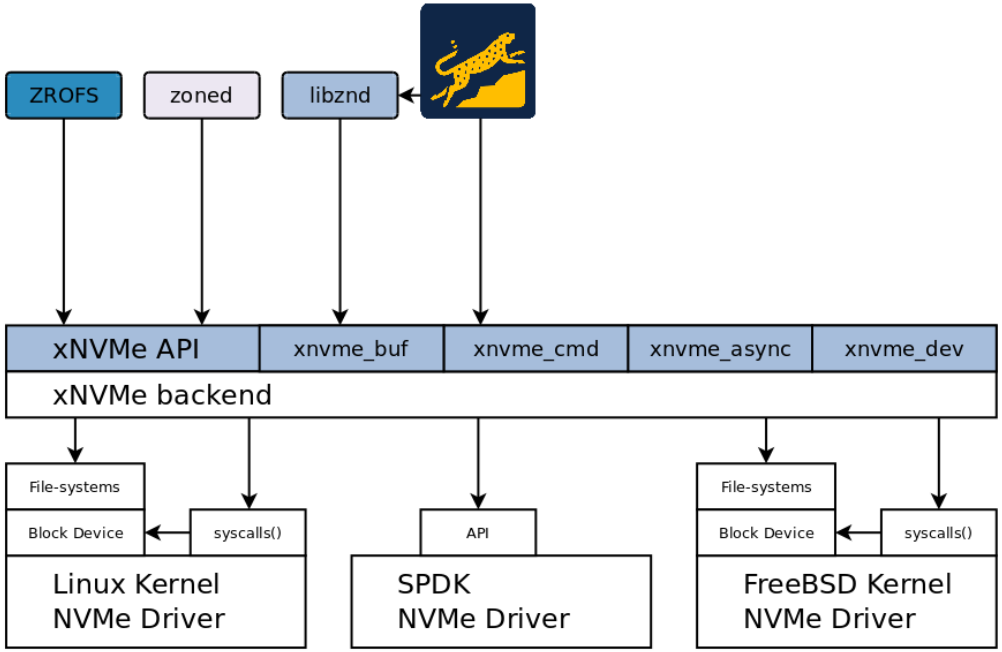
Usage of `zoned`

Demo link

Open-Source Ecosystem: a contribution



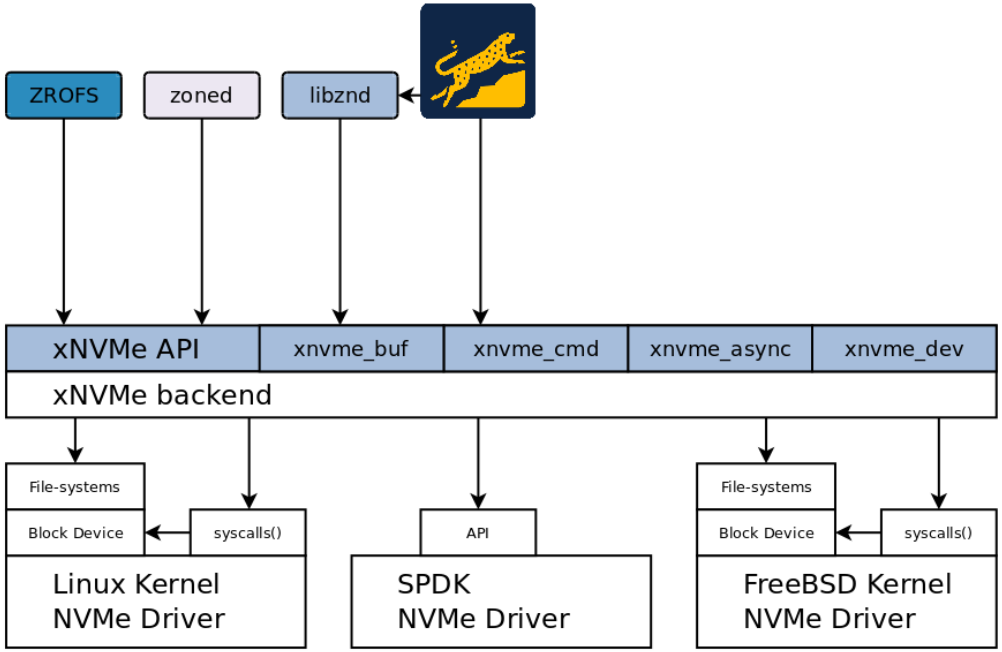
Open-Source Ecosystem: a contribution



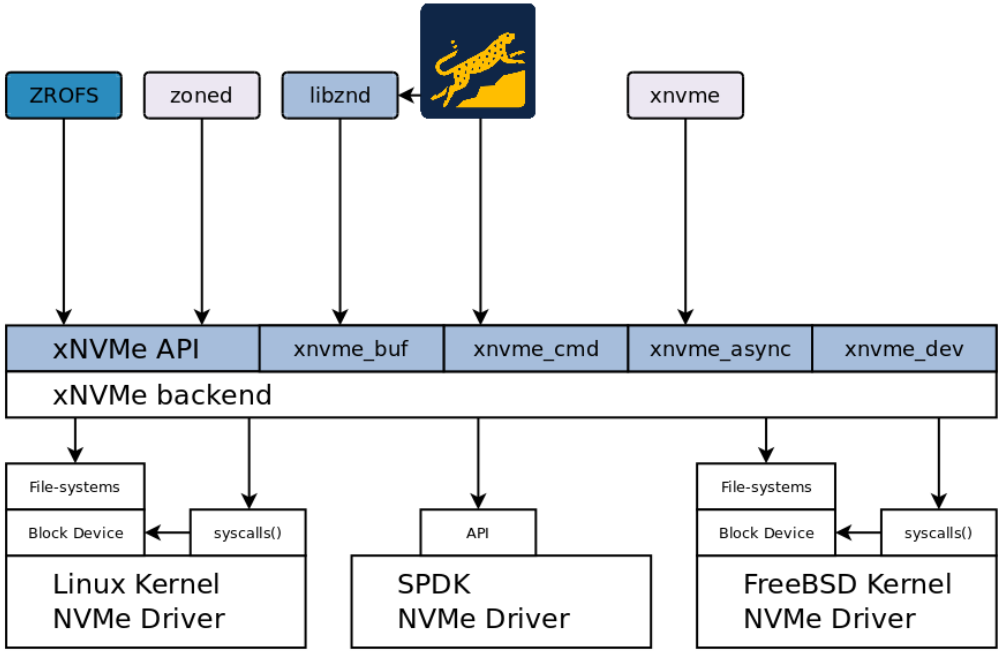
Usage of `ZROFS`

Demo link

Open-Source Ecosystem: a contribution



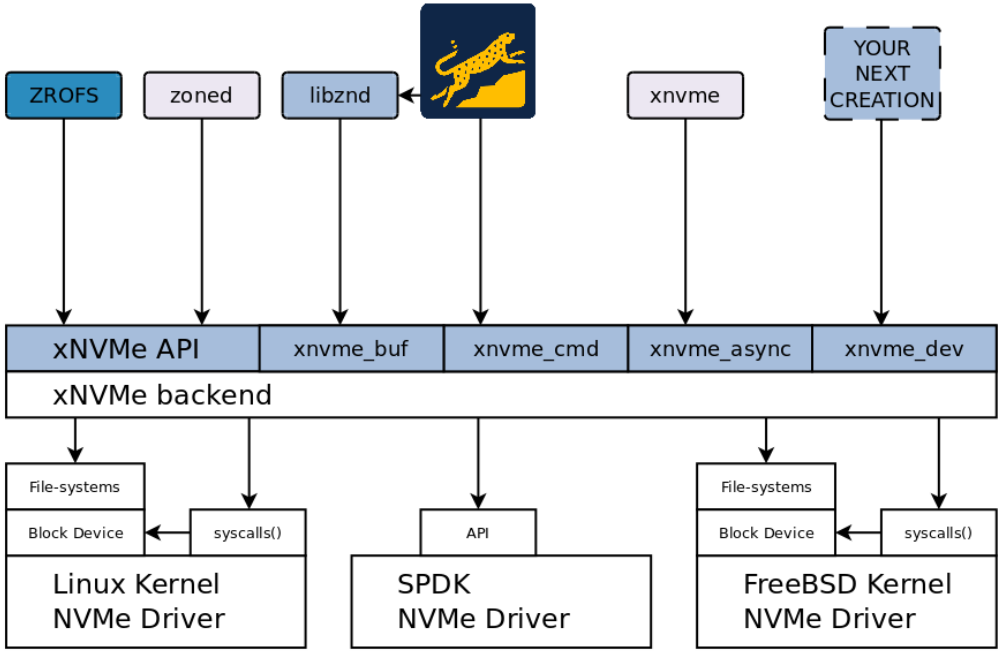
Open-Source Ecosystem: a contribution



Usage of `xnvme`

Demo link

Open-Source Ecosystem: a contribution



- Building Open-Source ecosystem

xNVMe

- Building Open-Source ecosystem
- Cross-platform for existing and emerging storage interfaces

xNVMe

- Building Open-Source ecosystem
- Cross-platform for existing and emerging storage interfaces
- Tools

xNVMe

- Building Open-Source ecosystem
- Cross-platform for existing and emerging storage interfaces
- Tools
- Libraries

xNVMe

- Building Open-Source ecosystem
- Cross-platform for existing and emerging storage interfaces
- Tools
- Libraries
- VALUE

Thanks

WWW https://xnvme.io

MAIL simon.lund@samsung.com

www.linkedin.com/in/simonlund