

TEST

PYNVME QPAIRS

0000:3d:00.0 Q00:

0000:3d:00.0 Q01: >>> CAZ-82256-Q1 NVMe LITEON 256GB

PYTHON

- scripts
- conformance
- 01_admin_cmd
- 02_nvme_cmd
- 03_features
- 04_registers
- 05_controller
- arbitration_test.py
- interrupt_test.py
- prp_test.py
- sq_cq_test.py
- sqe_cqe_test.py
- 06_tcg
- ftl
- performance
- stress
- dirty_power_cycle_test.py
- endurance_test.py
- test_ioworker_jedec_e...
- test_ioworker_jedec_e...
- C test_replay_jedec_clien...
- marathon_test.py
- trace
- test_examples.py

CMDLOG 0000:3d:00.0 Q00 X

1 2020-06-22 08:24:29.897073 [cmd001: Identify]
 2 0x007d0006, 0x00000001, 0x00000000, 0x00000000
 3 0x00000000, 0x00000000, 0x4ac0f000, 0x00000001
 4 0x00000000, 0x00000000, 0x00000000, 0x00000000
 5 0x00000000, 0x00000000, 0x00000000, 0x00000000
 6 2020-06-22 08:24:29.897102: [cpl: SUCCESS]
 7 0x00000000, 0x00000000, 0x0000000c, 0x0001007d
 8
 9 2020-06-22 08:24:29.896836 [cmd002: Identify]
 10 0x007d0006, 0x00000001, 0x00000000, 0x00000000
 11 0x00000000, 0x00000000, 0x4ac0f000, 0x00000001
 12 0x00000000, 0x00000000, 0x00000000, 0x00000000
 13 0x00000000, 0x00000000, 0x00000000, 0x00000000
 14 2020-06-22 08:24:29.897059: [cpl: SUCCESS]
 15 0x00000000, 0x00000000, 0x0000000b, 0x0001007d
 16
 17 2020-06-22 08:24:28.452258 [cmd003: Format NVM]
 18 0x007d0080, 0x00000001, 0x00000000, 0x00000000
 19 0x00000000, 0x00000000, 0x00000000, 0x00000000
 20 0x00000000, 0x00000000, 0x00000000, 0x00000000
 21 0x00000000, 0x00000000, 0x00000000, 0x00000000
 22 2020-06-22 08:24:29.573384: [cpl: SUCCESS]
 23 0x00000000, 0x00000000, 0x0000000a, 0x0001007d
 24

Performance Gauge X

...
 pynvme MB/s 104.96
 IOPS K/s 009.72

PROBLEMS OUTPUT ... Python Test Log

root@...: /home/craneclay/pynvme, python -m pytest -v

plugins: cov-2.10.0

collected 1 item

scripts/stress/endurance_test.
 py::test_replay_jedec_client_trace
 ----- live log setup

 [2020-06-22 08:24:27.666] INFO script(60): setup random seed:
 0x4400ee0c
 ----- live log call

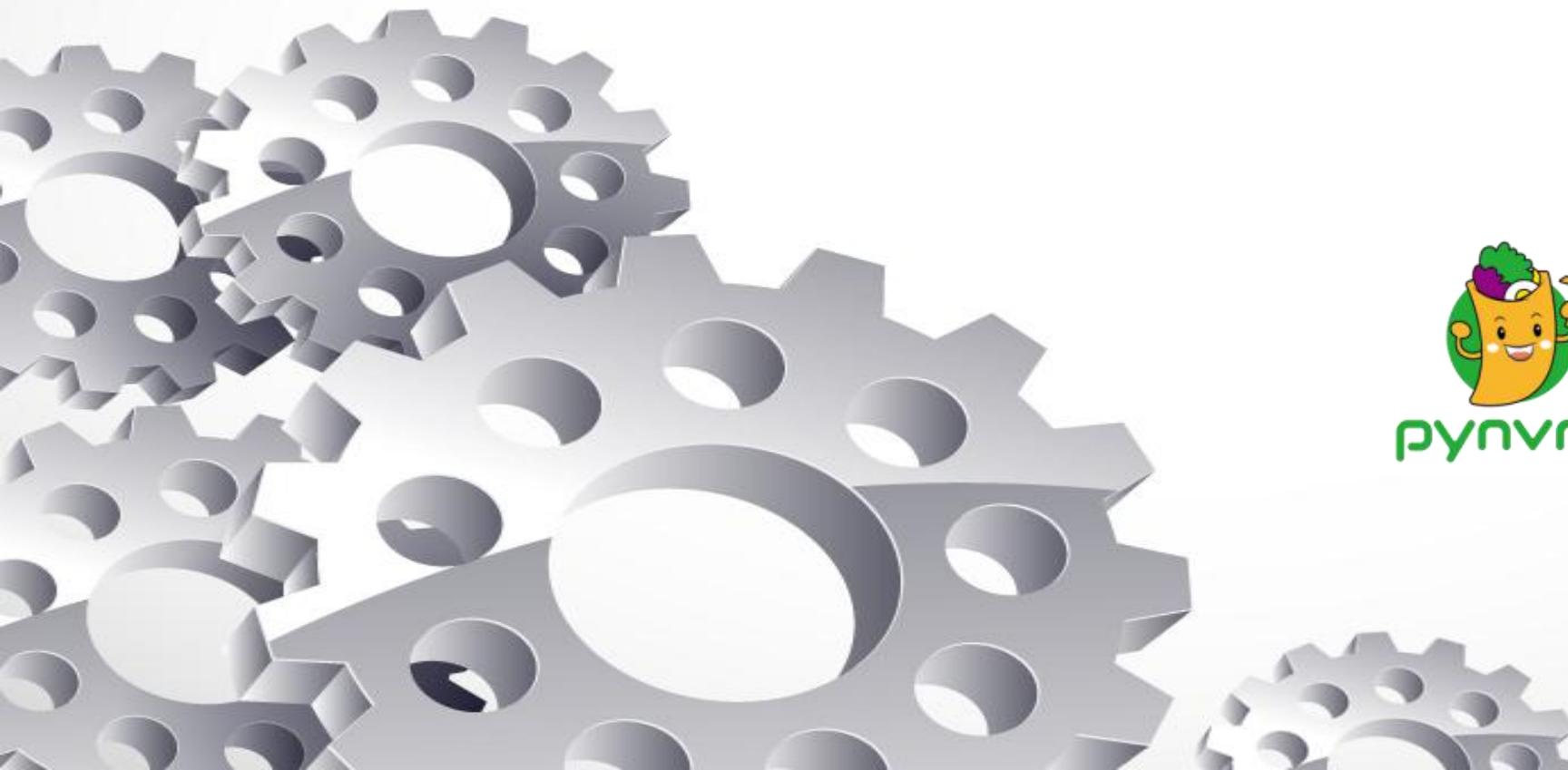
 [2020-06-22 08:24:32.194] INFO test_replay_jedec_client_trace
 (95): replay batch 0
 [2020-06-22 08:24:41.628] INFO test_replay_jedec_client_trace
 (95): replay batch 1
 [2020-06-22 08:24:45.792] INFO test_replay_jedec_client_trace
 (95): replay batch 2
 [2020-06-22 08:25:12.507] INFO test_replay_jedec_client_trace
 (95): replay batch 3
 [2020-06-22 08:25:31.836] INFO test_replay_jedec_client_trace
 (95): replay batch 4
 [2020-06-22 08:25:41.889] INFO test_replay_jedec_client_trace
 (95): replay batch 5
 [2020-06-22 08:25:45.449] INFO test_replay_jedec_client_trace
 (95): replay batch 6
 [2020-06-22 08:25:55.715] INFO test_replay_jedec_client_trace
 (95): replay batch 7
 [2020-06-22 08:26:09.297] INFO test_replay_jedec_client_trace



pynvme builds your own tests.

master* Python 3.8.3 64-bit 0 △ 0 Running Tests / Ln 1, Col 1 Spaces: 4 Plain Text

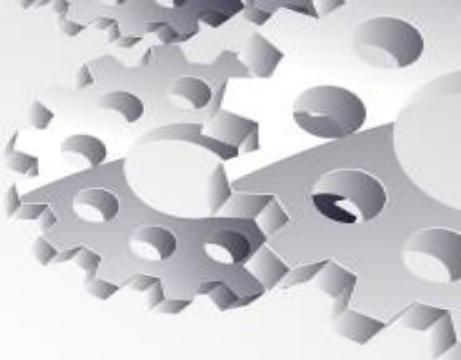
Requirement



pynvme builds your own tests.

Changes in SSD

- SSD has been changing for the decade:
 - media:
 - SLC, MLC, TLC, QLC
 - 2D => 3D
 - PCM, 3D-Xpoint...
 - host:
 - PATA, SATA, PCIe/NVMe
 - open-channel
 - up coming: ZNS, KV, ... ?
 - DRAM
 - form factor
- Agile: good for the constant change and uncertainty

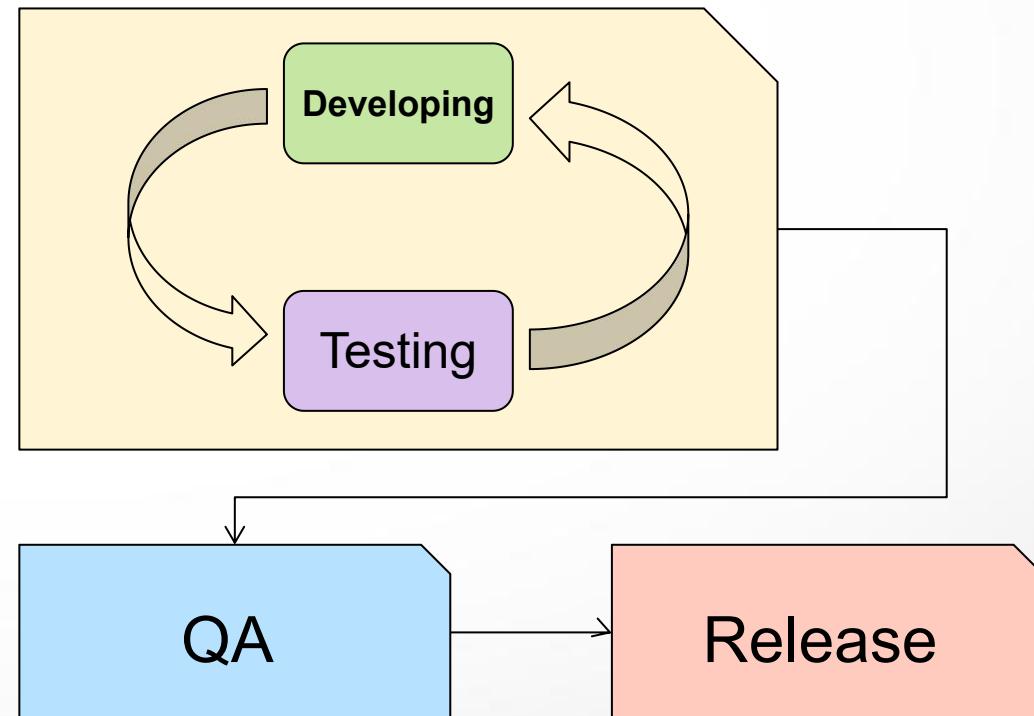


Agile Testing



- Developing and Testing are done interactively and iteratively.
- QA verifies the product of Dev/Test for customers.
- Testing and QA are different. Testing tools and QA tools are also different.
- Most available tools in the market are QA tools.

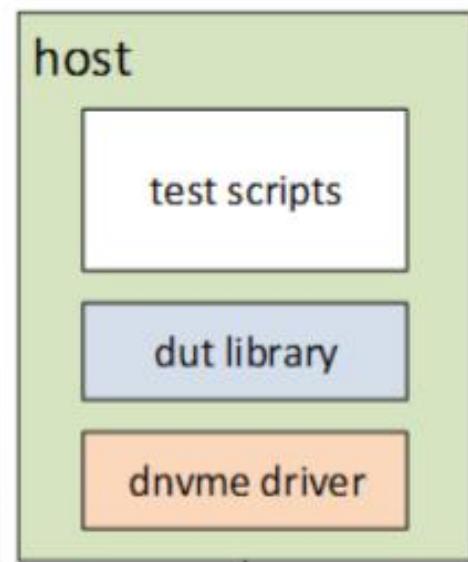
test	QA
for developer	for customer
before checkin	before release
automatic	manual
white-box	black-box
short	long
changing	stable



Experience in a Startup: dnvme



- dnvme: @2015
 - wrap with python in userspace
 - functional tests
 - integrated with Jenkins
 - firmware engineers develop scripts
 - PASS IOL test on the first try
- challenges:
 - low performance:
 - IOPS, latency, consistency
 - test efficiency
 - stress tests
 - maintainness: kernel module
 - function coverage: PRP, ...
 - GPL License
- dnvme is good at NVMe test, but in-efficient on SSD test.



Born for NVMe: SPDK



- SPDK is open from 2016
 - super high performance: [10M IOPS](#)
 - user space application
 - based on DPDK environment, which abstracts low-level resources
 - PCIe
 - memory
- meet challenges:
 - low performance:
 - IOPS, latency, consistency
 - test efficiency
 - stress tests
 - maintainness: kernel module
 - function coverage: PRP, ...
 - BSD License



SDC2020



A screenshot of a Google Chrome browser window showing the SDC 2020 website. The title bar shows multiple tabs including "SDC 2020 |". The address bar shows the URL "storagedeveloper2020.org/nvme". The page header includes the SDC 20 logo and navigation links for LOBBY, AGENDA, SPONSORS, SPEAKERS, BOFS, SMB3 IO LAB, PMEM BOOTCAMP, and CONNECT AT SDC.



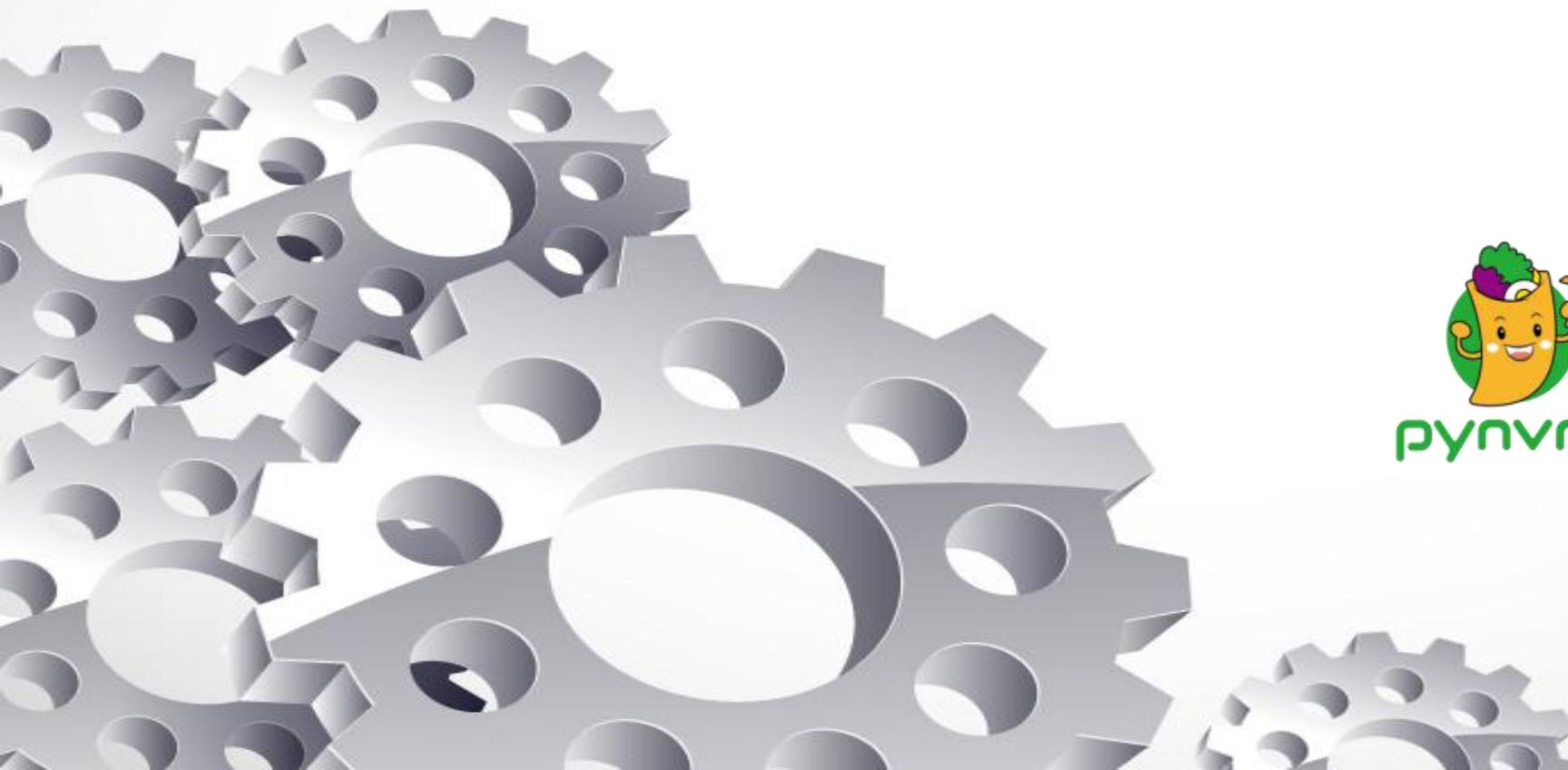
pynvme: an open, fast and extensible NVMe SSD test tool

Crane Chu
GENG YUN Technology Pte Ltd

- Python tool for testing your NVMe design

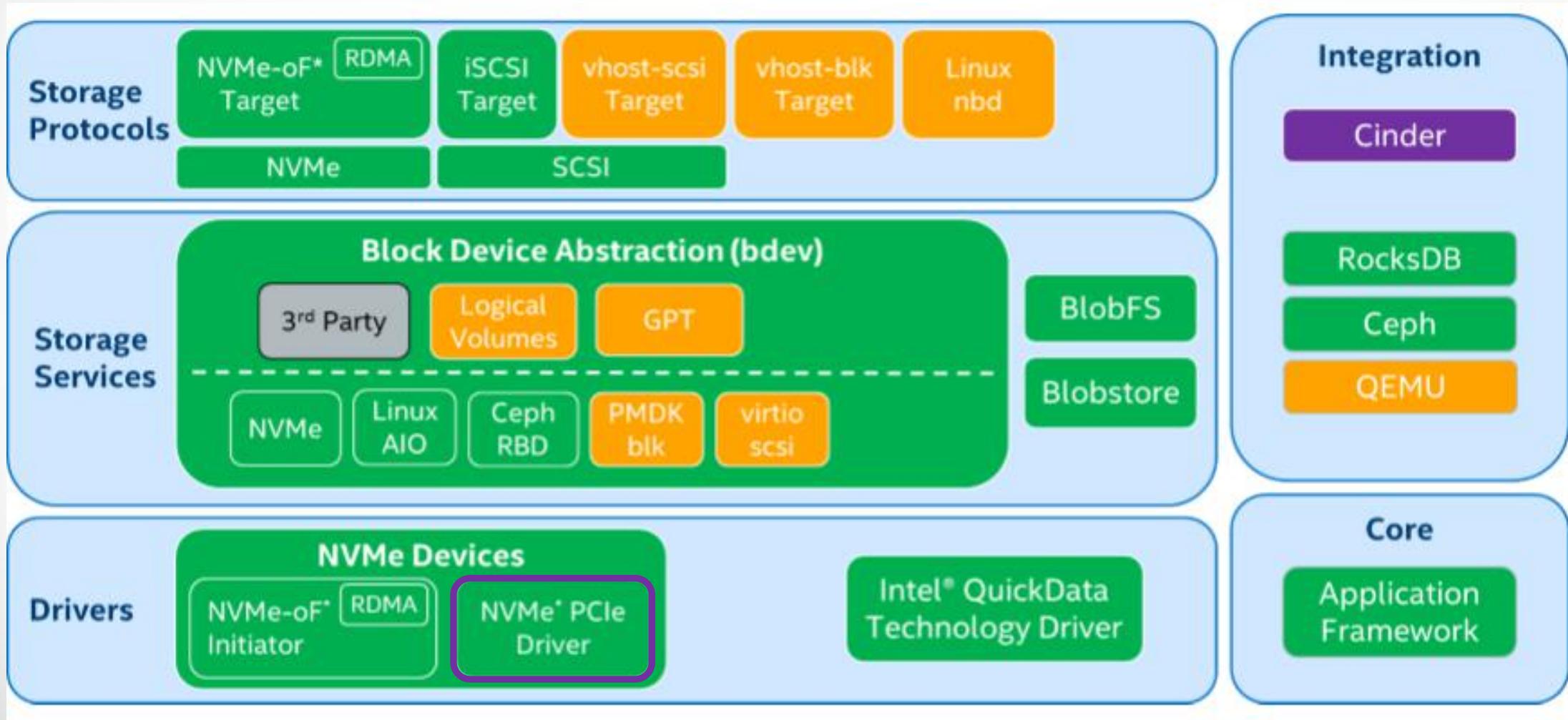
<https://www.youtube.com/watch?v=You7vzVyl8>

Design



pynvme builds your own tests.

SPDK



SPDK/DPDK



- Moving all of the necessary drivers into userspace, which avoids syscalls and enables zero-copy access from the application.
- Polling hardware for completions instead of relying on interrupts, which lowers both total latency and latency variance.
- Avoiding all locks in the I/O path, instead relying on message passing.

Performance



fio (unit: K IOPS)

Q count	1	2	4
test 1	200	332	353
test 2	211	319	340
test 3	211	248	354

pynvme (unit: K IOPS)

Q count	1	2	4
test 1	358	359	359
test 2	358	358	359
test 3	358	356	359



Performance: latency

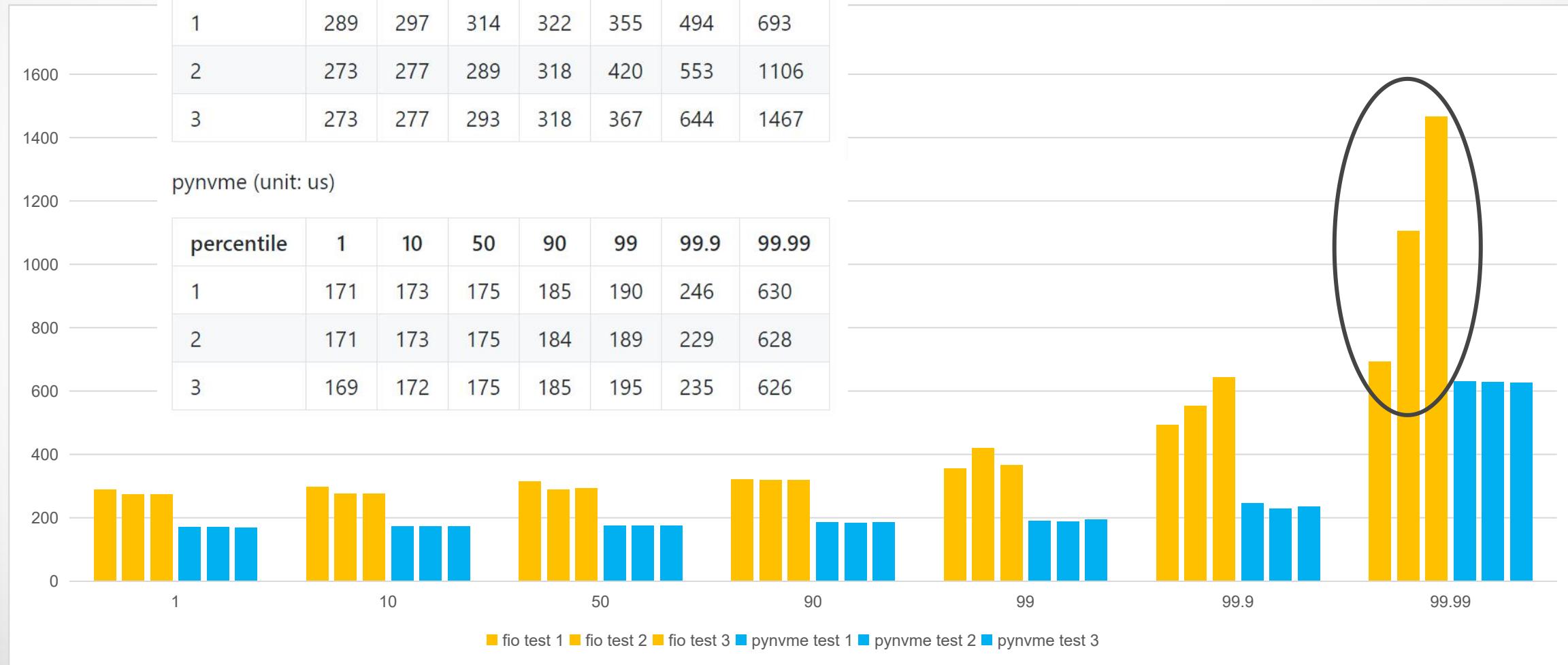


fio (unit: us)

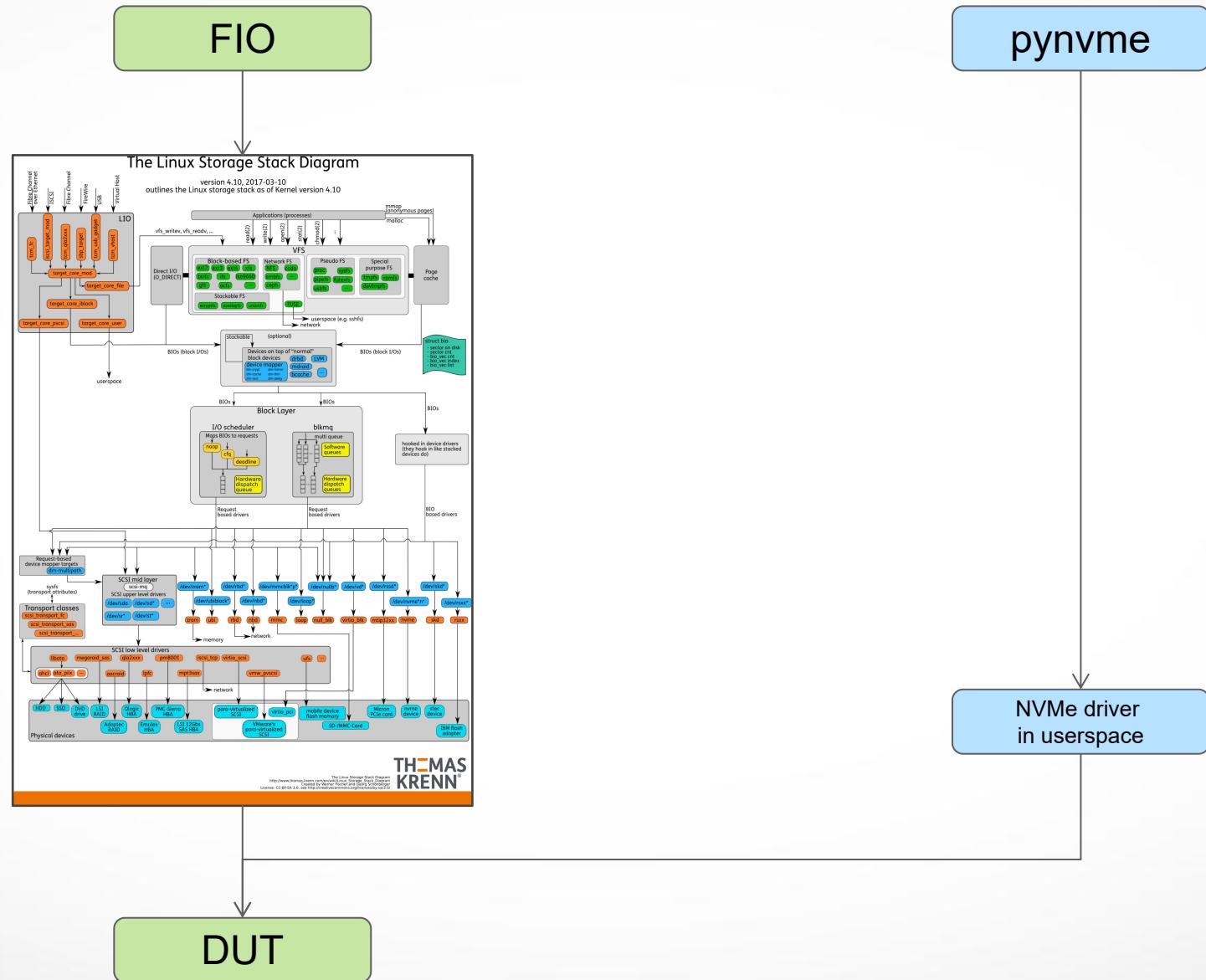
percentile	1	10	50	90	99	99.9	99.99
1	289	297	314	322	355	494	693
2	273	277	289	318	420	553	1106
3	273	277	293	318	367	644	1467

pynvme (unit: us)

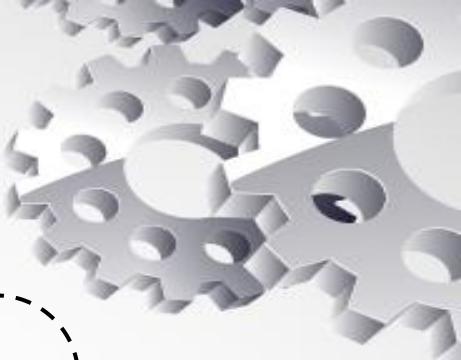
percentile	1	10	50	90	99	99.9	99.99
1	171	173	175	185	190	246	630
2	171	173	175	184	189	229	628
3	169	172	175	185	195	235	626



Performance: design



Architecture



test suite:

...

conformance

performance

scripts

library:

power

ZNS

TCG

psd

API:

controller

namespace

qpair

pcie

buffer

driver

SPDK: nvme driver

cmdlog

checksum

ioworker

psd: Python Space Driver



NVMe SSD

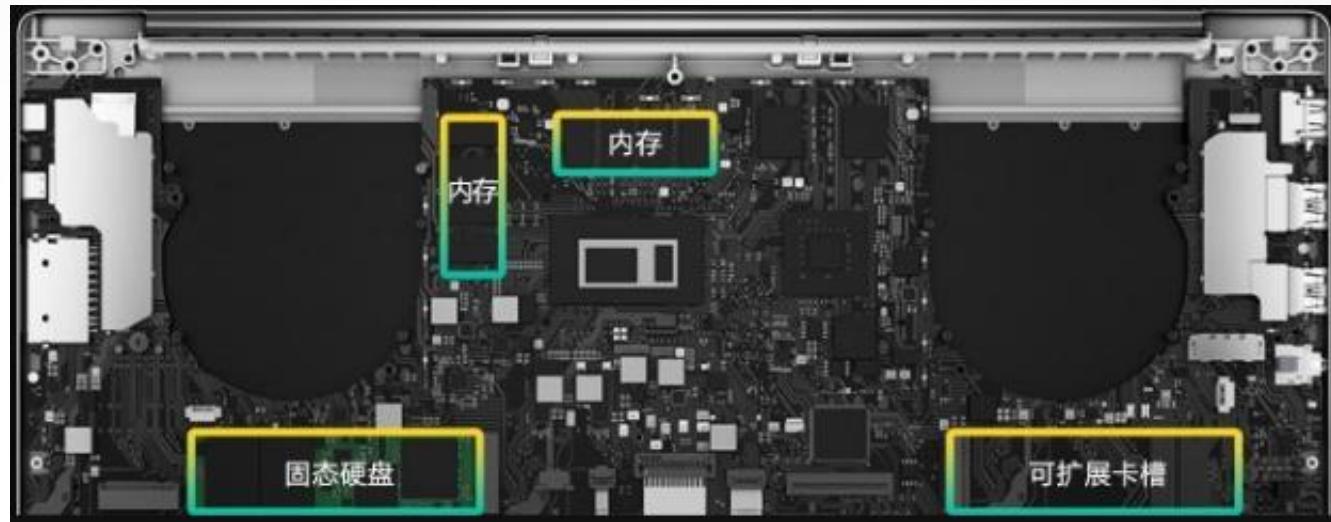
Open Ecosystem



Flexible Hardware Configuration



- Single Node
 - laptop
 - workstation
- Mass Deploy
 - server



Install and Test

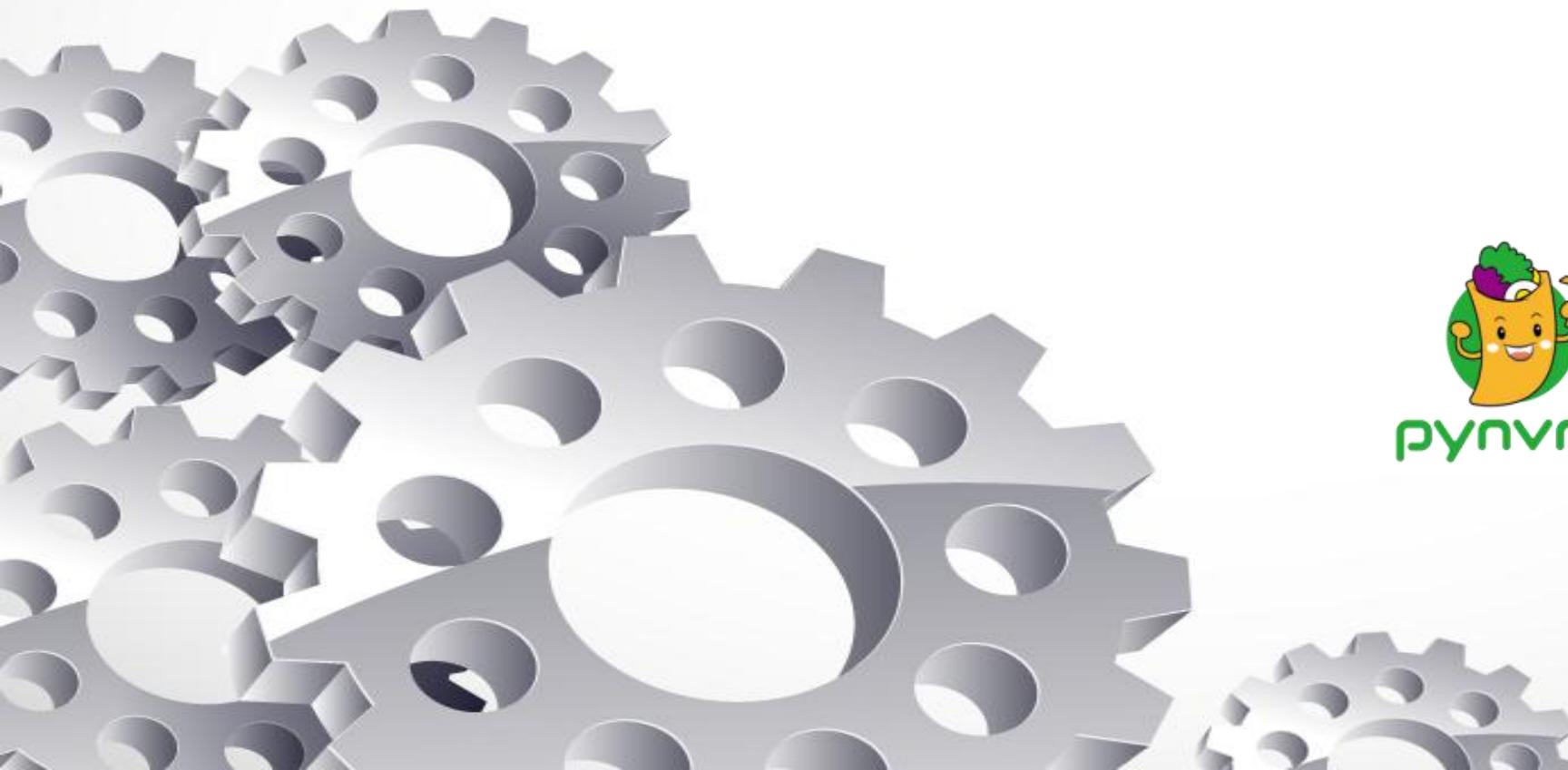


- git clone https://github.com/pynvme/pynvme
- cd pynvme
- ./install.sh

- make setup
- make test TESTS="driver_test.py::test_ioworker_iops_multiple_queue[1]"

- make test TESTS=scripts/stress/endurance_test.py::test_replay_jedec_client_trace
pciaddr=02:00.0
- make test TESTS=scripts/stress/endurance_test.py::test_replay_jedec_client_trace
pciaddr=172.168.5.44

Scripts



pynvme builds your own tests.

Test Scripts

```
1 import time
2 import pytest
3 import logging
4
5 import nvme as d
6
7
8 # intuitive, spec, qpair, vscode, debug, cmdlog, assert
9 def test_hello_world(nvme0, nvme0n1, qpair):
10     # prepare data buffer and IO queue
11     read_buf = d.Buffer(512)
12     write_buf = d.Buffer(512)
13     write_buf[10:21] = b'hello world'
14
15     # send write and read command
16     def write_cb(cdw0, status1): # command callback function
17         nvme0n1.read(qpair, read_buf, 0, 1)
18         nvme0n1.write(qpair, write_buf, 0, 1, cb=write_cb)
19
20     # wait commands complete and verify data
21     assert read_buf[10:21] != b'hello world'
22     qpair.waitdone(2)
23     assert read_buf[10:21] == b'hello world'
```

```
8     def test_quarch_dirty_power_cycle_single(nvme0, nvme0n1, subsystem, buf, verify):
9         # get the unsafe shutdown count before test
10        nvme0.getlogpage(2, buf, 512).waitdone()
11        orig_unsafe_count = buf.data(159, 144)
12        logging.info("unsafe shutdowns: %d" % orig_unsafe_count)
13        assert verify == True
14
15        # 128K random write
16        cmdlog_list = [None]*1000
17        with nvme0n1.ioworker(io_size=256,
18                               lba_random=True,
19                               read_percentage=30,
20                               region_end=256*1000*1000,
21                               time=30,
22                               qdepth=1024,
23                               output_cmdlog_list=cmdlog_list):
24            # sudden power loss before the ioworker end
25            time.sleep(10)
26            subsystem.poweroff()
27
28            # power on and reset controller
29            time.sleep(5)
30            subsystem.poweron()
31            time.sleep(0)
32            nvme0.reset()
```

Test Scripts: dirty power cycle

- Quarch
 - PCIe Card Module
 - Torridon Interface Kit
 - PAM
- 3-rd party fixtures supported
- poweroff process
 - poweroff when ioworker is alive
 - remove device from system
- poweron process
 - poweron
 - remove kernel driver
 - rescan device
 - nvme initialization



Features

- access PCI configuration space
 - access NVMe registers in BAR space
 - send any NVMe admin/IO commands
 - support callback functions for NVMe commands
 - support MSI/MSIx interrupts
 - transparent checksum verification on every LBA
 - generates IO workload of high performance and low latency
 - support multiple namespaces
 - support multiple tests on different controllers
 - integrate with the test framework pytest
 - integrate with VSCode to display cmdlog in GUI
 - support NVMe over TCP targets
-
- doc: <https://pynvme.readthedocs.io/>



Test Scripts: 3 ways of sending IO



```
8 # intuitive, spec, qpair, vscode, debug, cmdlog, assert
9 def test_hello_world(nvme0, nvme0n1, qpair):
10     # prepare data buffer and IO queue
11     read_buf = d.Buffer(512)
12     write_buf = d.Buffer(512)
13     write_buf[10:21] = b'hello world'
14
15     # send write and read command
16     def write_cb(cdw0, status1): # command callback function
17         nvme0n1.read(qpair, read_buf, 0, 1)
18         nvme0n1.write(qpair, write_buf, 0, 1, cb=write_cb)
```

```
def test_ioworker_simplified(nvme0n1):
    nvme0n1.ioworker(io_size=2, time=2).start().close()
```

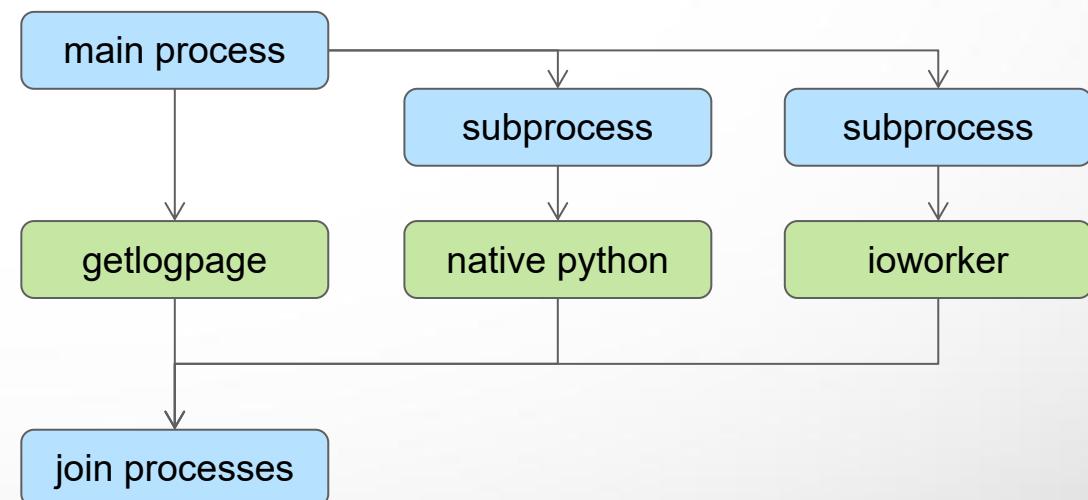
```
698 def test_write_before_power_cycle(nvme0, subsystem):
699     cq = IOCQ(nvme0, 1, 128, PRP(2*1024))
700     sq = IOSQ(nvme0, 1, 128, PRP(8*1024), cqid=1)
701
702     #burst write
703     for i in range(127):
704         cmd = SQE(1, 1)
705         buf = PRP(512, ptype=32, pvalue=i)
706         cmd.prp1 = buf
707         cmd[10] = i
708         sq[i] = cmd
709
710     # write 127 512byte at one shot
711     sq.tail = 127
```

Test Scripts: multiprocessing



```
72 def test_ioworker_with_temperature_and_trim(nvme0, nvme0n1):
73     # start trim process
74     import multiprocessing
75     mp = multiprocessing.get_context("spawn")
76     p = mp.Process(target = subprocess Trim,
77                     args = (nvme0.addr.encode('utf-8'),
78                             300000))
79     p.start()
80
81     # start read/write ioworker and admin commands
82     smart_log = d.Buffer(512, "smart log")
83     with nvme0n1.ioworker(io_size=8, lba_align=16,
84                           lba_random=True, qdepth=16,
85                           read_percentage=67, iops=10000, time=10):
86         for i in range(15):
87             nvme0.getlogpage(0x02, smart_log, 512).waitdone()
88             ktemp = smart_log.data(2, 1)
89
90             from pytemperature import k2c
91             logging.info("temperature: %0.2f degreeC" % k2c(ktemp))
92             time.sleep(1)
93
94     # wait trim process complete
95     p.join()
96
```

```
60     # ioworker with admin commands, multiprocessing, log, cmdlog, pythonic
61     def subprocess Trim(pciaddr, loops):
62         nvme0 = d.Controller(pciaddr)
63         nvme0n1 = d.Namespace(nvme0)
64         q = d.Qpair(nvme0, 8)
65         buf = d.Buffer(4096)
66         buf.set_dsm_range(0, 8, 8)
67
68         # send trim commands
69         for i in range(loops):
70             nvme0n1.dsm(q, buf, 1).waitdone()
71
```



Test Scripts: power related

```
188 # PCIe, different of power states and resets
189 def test_power_and_reset(pcie, nvme0, subsystem):
190     pcie.aspm = 2                      # ASPM L1
191     pcie.power_state = 3                # PCI PM D3hot
192     pcie.aspm = 0
193     pcie.power_state = 0
194
195     nvme0.reset()                     # controller reset: CC.EN
196     nvme0.getfeatures(7).waitdone()
197
198     pcie.reset()                      # PCIe reset: hot reset, TS1, TS2
199     nvme0.reset()                     # reset controller after pcie reset
200     nvme0.getfeatures(7).waitdone()
201
202     pcie.flr()                        # PCIe function level reset
203     nvme0.reset()                     # reset controller after pcie reset
204     nvme0.getfeatures(7).waitdone()
205
206     subsystem.reset()                 # NVMe subsystem reset: NSSR
207     nvme0.reset()                     # controller reset: CC.EN
208     nvme0.getfeatures(7).waitdone()
209
210     subsystem.power_cycle(10)        # power cycle NVMe device: cold reset
211     nvme0.reset()                     # controller reset: CC.EN
212     nvme0.getfeatures(7).waitdone()
```

```
42 @pytest.mark.parametrize("ps", [4, 3, 2, 1, 0])
43 def test_format_at_power_state(nvme0, nvme0n1, ps):
44     nvme0.setfeatures(0x2, cdw11=ps).waitdone()
45     assert nvme0n1.format(ses=0) == 0
46     assert nvme0n1.format(ses=1) == 0
47     p = nvme0.getfeatures(0x2).waitdone()
48     assert p == ps
```

```
191 @pytest.mark.parametrize("aspm", [0, 2])
192 @pytest.mark.parametrize("gen", [1, 2, 3, 2, 1, 1, 2, 3])
193 def test_PCIE_link_speed(pcie, nvme0, nvme0n1, gen, aspm):
194     linkctr2_addr = pcie.cap_offset(0x10)+0x30
195     linkctr2 = pcie.register(linkctr2_addr, 4)
196     logging.info(linkctr2)
197
198     pcie[linkctr2_addr] = (linkctr2 & 0xf0) | gen
199     logging.info(pcie.register(linkctr2_addr, 4))
200     pcie.reset()
201     nvme0.reset()
202     test_PCIE_read_bandwidth(nvme0n1)
203     test_PCIE_link_control_aspm(nvme0, pcie, aspm)
```

Test Scripts: NVMe initialization for WRR

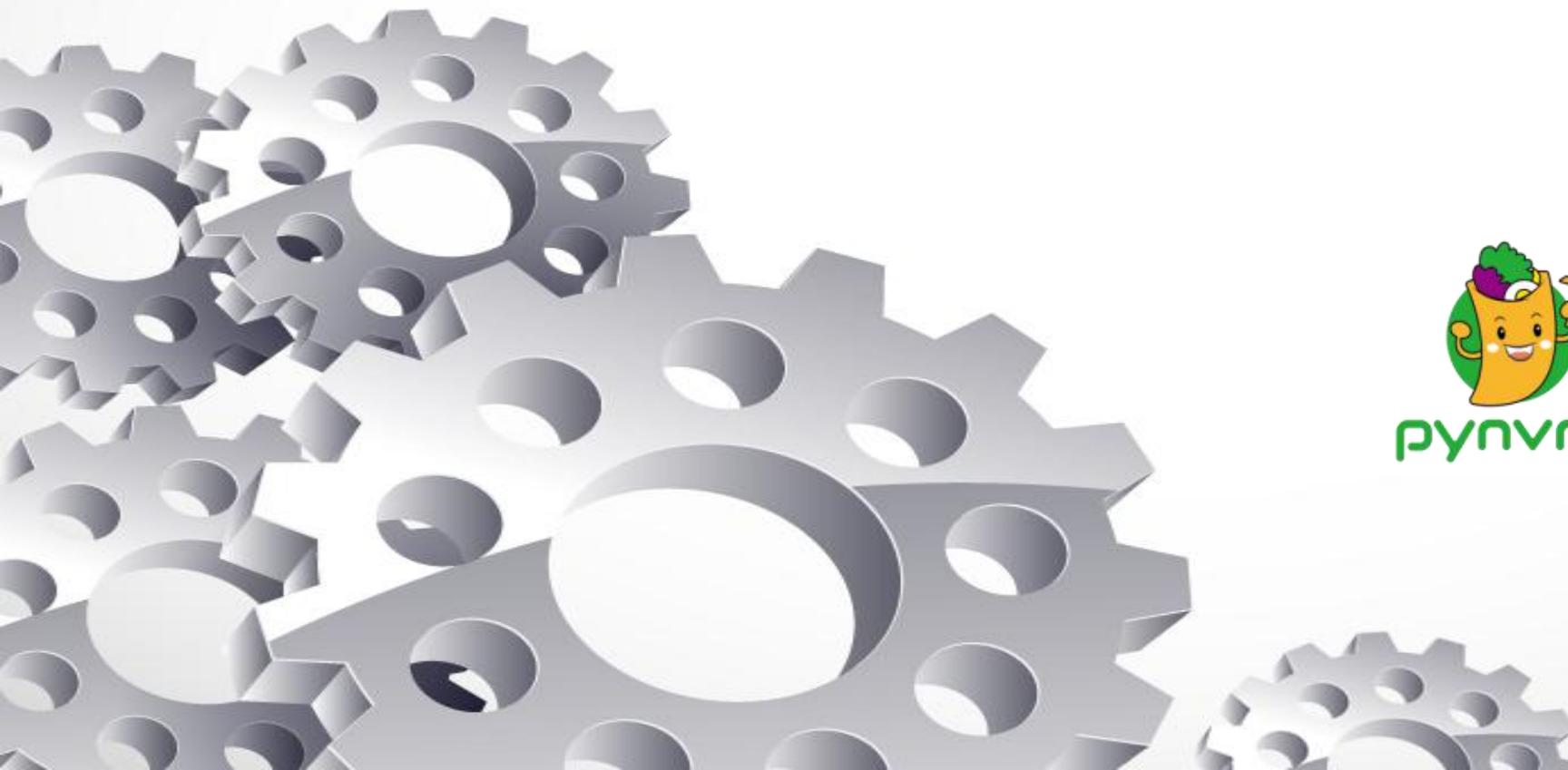
```
9  def nvme_init_wrr(nvme0):
10     logging.info("user defined nvme init")
11
12     nvme0[0x14] = 0
13     while not (nvme0[0x1c]&0x1) == 0: pass
14
15     # 3. set admin queue registers
16     nvme0.init_adminq()
17
18     # 4. set register cc
19     if (nvme0.cap>>17) & 0x1:
20         logging.info("set WRR arbitration")
21         nvme0[0x14] = 0x00460800
22     else:
23         nvme0[0x14] = 0x00460000
24
25     # 5. enable cc.en
26     nvme0[0x14] = nvme0[0x14] | 1
27
28     # 6. wait csts.rdy to 1
29     while not (nvme0[0x1c]&0x1) == 1: pass
30
31     # 7. identify controller
32     nvme0.identify(Buffer(4096)).waitdone()
33
34     # 8. create and identify all namespace
35     nvme0.init_ns()
36
37     # 9. set/get num of queues
38     nvme0.setfeatures(0x7, cdw11=0x00ff00ff).waitdone()
39     nvme0.getfeatures(0x7).waitdone()
```

Test Scripts: error code

```
93 def test_write_in_sanitize_operations(nvme0, nvme0n1, buf, qpairs):
94     if nvme0.id_data(331, 328) == 0: #L9
95         pytest.skip("sanitize operation is not supported") #L10
96
97     logging.info("supported sanitize operation: %d" % nvme0.id_data(331, 328))
98     nvme0.sanitize().waitdone() #L13
99
100    with pytest.warns(UserWarning, match="ERROR status: 00/1d"):
101        nvme0n1.write(qpair, buf, 0).waitdone()
102
103    # check sanitize status in log page
104    with pytest.warns(UserWarning, match="AER notification is triggered"):
105        nvme0.getlogpage(0x81, buf, 20).waitdone() #L17
106        while buf.data(3, 2) & 0x7 != 1: #L18
107            time.sleep(1)
108            nvme0.getlogpage(0x81, buf, 20).waitdone() #L20
109            progress = buf.data(1, 0)*100//0xffff
110            logging.info("%d%%" % progress)
111
112    # check sanitize status
113    nvme0.getlogpage(0x81, buf, 20).waitdone()
114    assert buf.data(3, 2) & 0x7 == 1
115
```



ioworker



pynvme builds your own tests.

ioworker: Parameters



Input Parameters:

- lba_start, lba_step, lba_align
- lba_random
- region_start, region_end
- distribution
- io_size (int, range, list, dict)
- read_percentage, **op_percentage**
- time, io_count
- qdepth, qprio
- pvalue, ptype
- **iops**
- ...

Output Parameters:

- io_count_read
- io_count_write, io_count_nonread
- mseconds
- latency_max_us
- latency_average_us
- error
- cpu_usage
- output_io_per_second (optional)
- output_percentile_latency (optional)
- output_cmdlog_list (optional)
- ...

API document: <https://pynvme.readthedocs.io/api.html>

ioworker: Python API

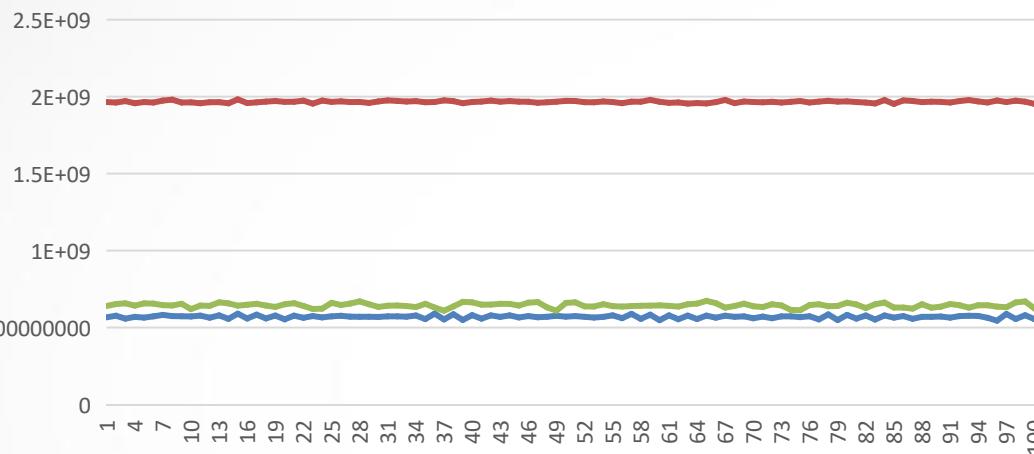


```
774 def test_ioworker_with_temperature(nvme0, nvme0n1, buf):
775     with nvme0n1.ioworker(io_size=256,
776                           time=30,
777                           op_percentage={0:10, # flush
778                                         2:60, # read
779                                         9:30}), \
780         nvme0n1.ioworker(io_size=8,
781                           time=30,
782                           op_percentage={0:10, # flush
783                                         9:10, # trim
784                                         1:80}):# write
785     for i in range(40):
786         time.sleep(1)
787         nvme0.getlogpage(0x02, buf, 512).waitdone()
788         ktemp = buf.data(2, 1)
789         from pytemperature import k2c
790         logging.info("temperature: %0.2f degreec" %
791                      k2c(ktemp))
792
```

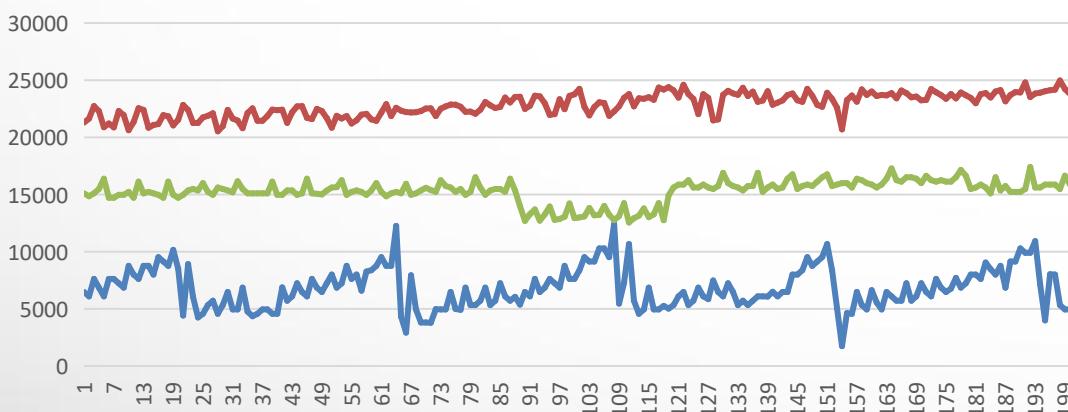
ioworker: Gallery



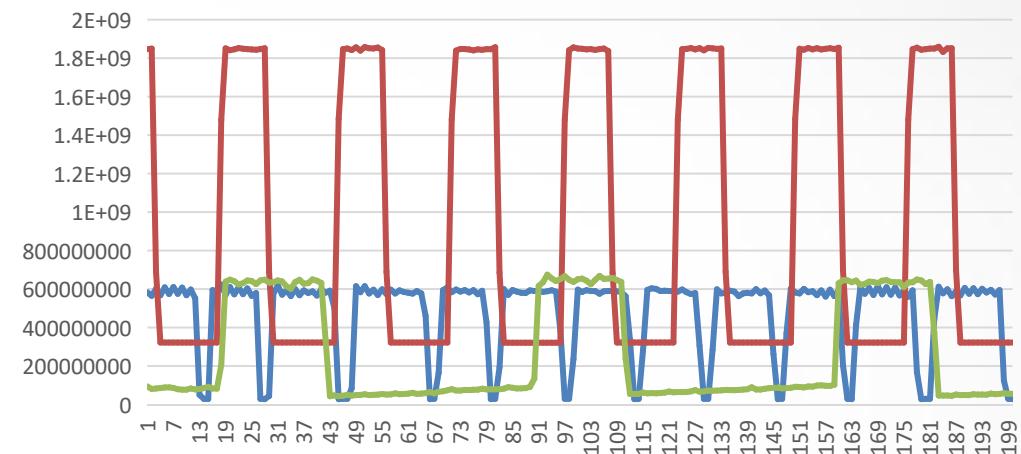
sequential write 1st pass (x: second, y: B/s)



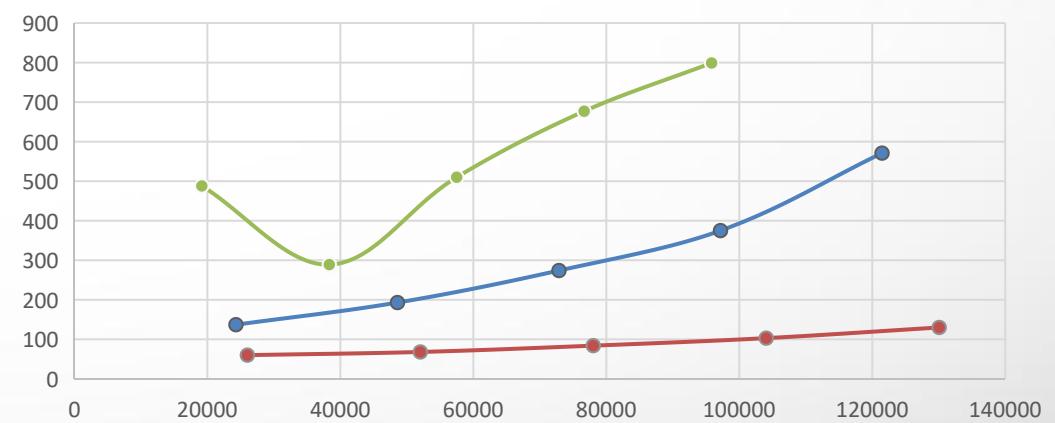
4K random write (x: second, y: IOPS)



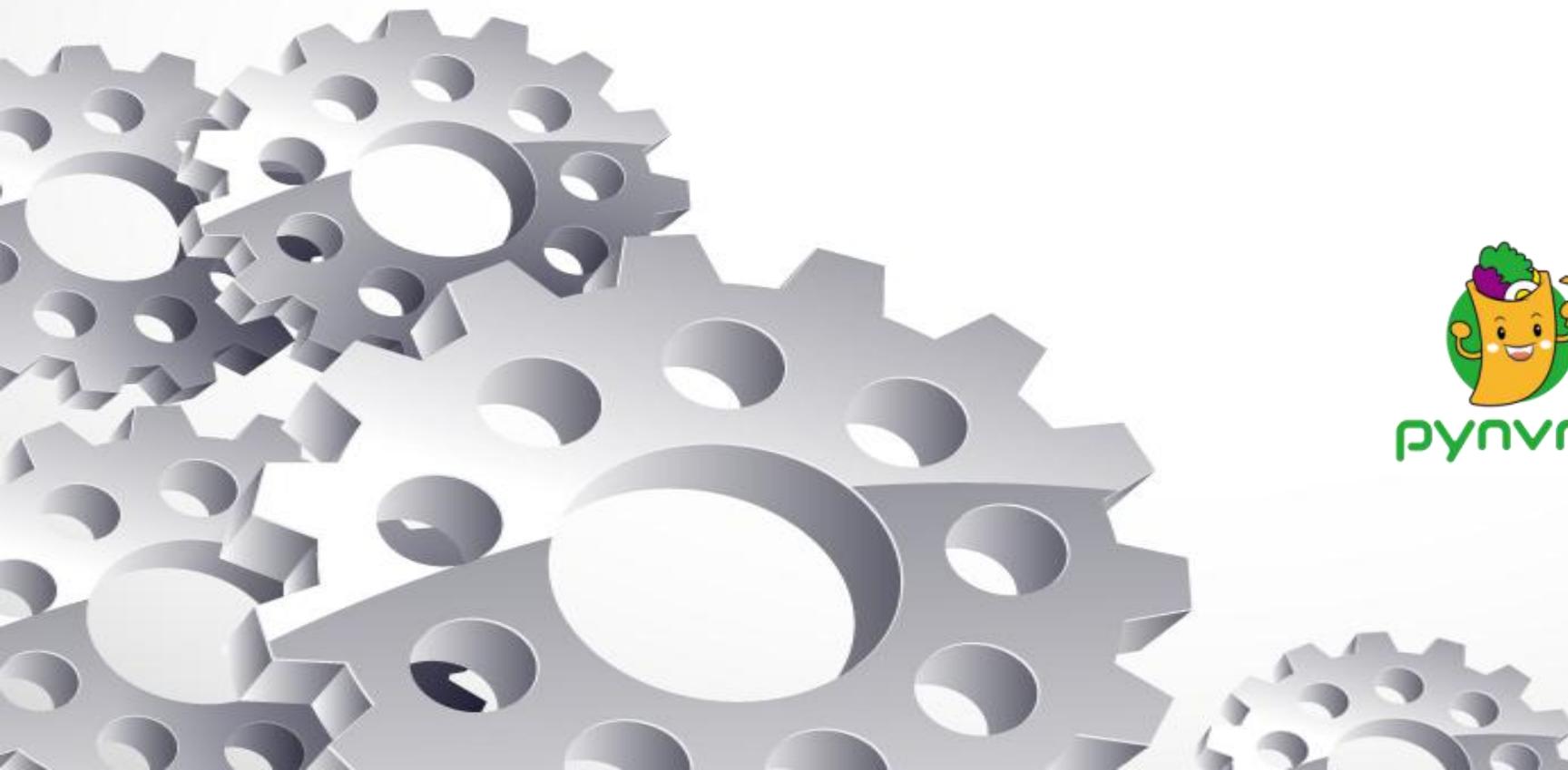
sequential write 3rd pass (x: second, y: B/s)



latency against IOPS, 2R1W (x: IOPS, y: us)



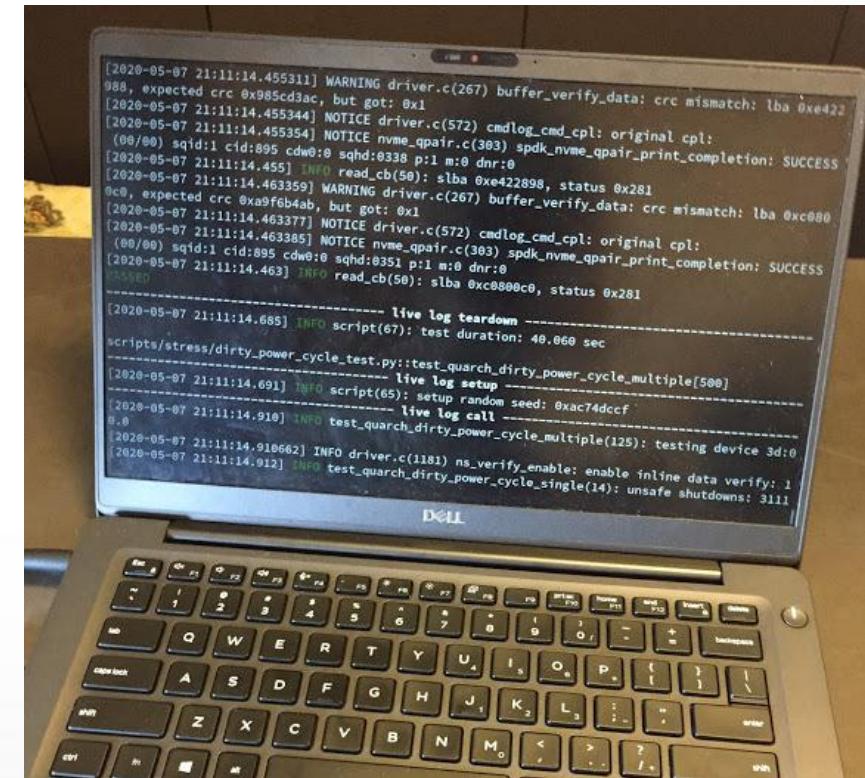
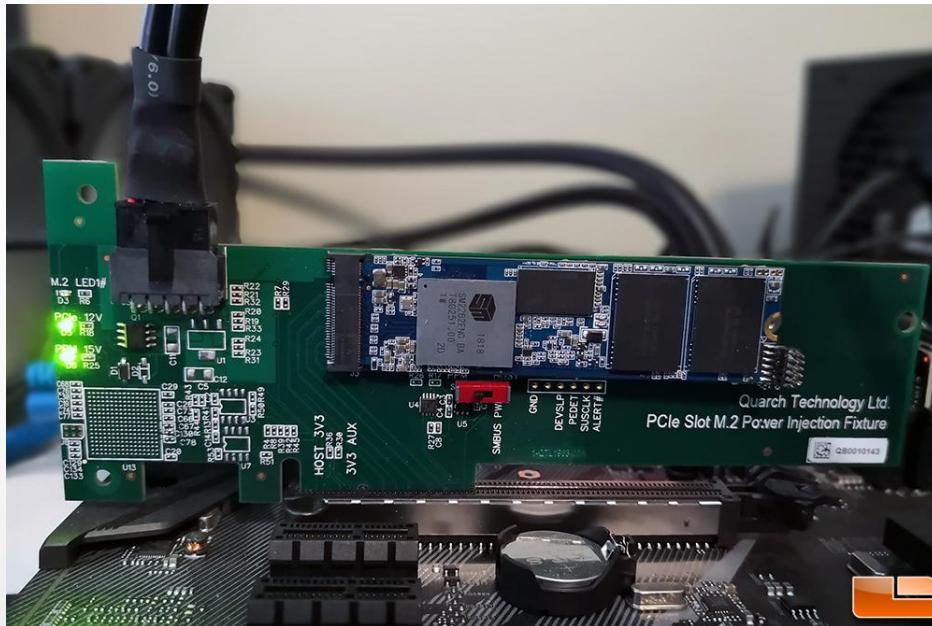
Features



pynvme builds your own tests.

vPower to ON and OFF

- Usually we need a special hardware box to control the power of SSD
- vPower controls the power of SSD:
 - power off: enter S3/sleep mode
 - power on: wake up by RTC



vAnalyzer



TEST

PYNVME QPAIRS

0000:3d:00.0 Q00: >>

0000:3d:00.0 Q01: >>

0000:3d:00.0 Q02: >>

0000:3d:00.0 Q03: >>

0000:3d:00.0 Q04: >>

0000:3d:00.0 Q05: >>

0000:3d:00.0 Q06: >>

0000:3d:00.0 Q07: >>

0000:3d:00.0 Q08: >>

0000:3d:00.0 Q09: >> **selected**

0000:3d:00.0 Q10: >>

0000:3d:00.0 Q11: >>

0000:3d:00.0 Q12: >>

0000:3d:00.0 Q13: >>

0000:3d:00.0 Q14: >>

0000:3d:00.0 Q15: >>

0000:3d:00.0 Q16: >>

PYTHON

scripts

conformance

ftl

performance

snia

stress

tcg

trace

test_examples.py

test_utilities.py

LOG 0000:3d:00.0 Q02

CMDLOG 0000:3d:00.0 Q05

G 0000:3d:00.0 Q02

CMDLOG 0000:3d:00.0 Q13

CMDLOG 0000:3d:00.0 Q00

Performance Gauge

1353.80 MB/s

330.52 K/s

1 2020-04-15 13:33:21.463617 [cmd001: Read]

2 0x00050002, 0x00000001, 0x00000000, 0x00000000

3 0x00000000, 0x00000000, 0x0c7d3000, 0x00000000

4 0x00000000, 0x00000000, 0x213d9b90, 0x00000000

5 0x00000007, 0x00000000, 0x00000000, 0x00000000

6 not completed

7 ...

9 2020-04-15 13:33:21.463613 [cmd002: Read]

10 0x00010002, 0x00000001, 0x00000000, 0x00000000

11 0x00000000, 0x00000000, 0x0c7d7000, 0x00000000

12 0x00000000, 0x00000000, 0x16b26aa0, 0x00000000

13 0x00000007, 0x00000000, 0x00000000, 0x00000000

14 not completed

15 ...

17 2020-04-15 13:33:21.463607 [cmd003: Read]

18 0x00030002, 0x00000001, 0x00000000, 0x00000000

19 0x00000000, 0x00000000, 0x0c7db000, 0x00000000

20 0x00000000, 0x00000000, 0x151c50c0, 0x00000000

21 0x00000007, 0x00000000, 0x00000000, 0x00000000

22 not completed

1 2020-04-15 13:32:39.104405 [cmd001: Create I/O Submission Queue]

2 0x005a0001, 0x00000000, 0x00000000, 0x00000000

3 0x00000000, 0x00000000, 0x0ea0000, 0x00000001

4 0x00000000, 0x00000000, 0x00070010, 0x00100001

5 0x00000000, 0x00000000, 0x00000000, 0x00000000

6 2020-04-15 13:32:39.104519: [cpl: SUCCESS]

7 0x00000000, 0x00000000, 0x00000056, 0x0000005a

8 ...

9 2020-04-15 13:32:39.103458 [cmd002: Create I/O Completion Queue]

10 0x005a0005, 0x00000000, 0x00000000, 0x00000000

11 0x00000000, 0x00000000, 0x0e800000, 0x00000001

12 0x00000000, 0x00000000, 0x00070010, 0x00100003

13 0x00000000, 0x00000000, 0x00000000, 0x00000000

14 2020-04-15 13:32:39.104403: [cpl: SUCCESS]

15 0x00000000, 0x00000000, 0x00000055, 0x0000005a

16 ...

17 2020-04-15 13:32:38.533985 [cmd003: Create I/O Submission Queue]

18 0x005a0001, 0x00000000, 0x00000000, 0x00000000

19 0x00000000, 0x00000000, 0x0e600000, 0x00000001

20 0x00000000, 0x00000000, 0x0007000f, 0x000f0001

21 0x00000000, 0x00000000, 0x00000000, 0x00000000

22 2020-04-15 13:32:38.534648: [cpl: SUCCESS]

23 0x00000000, 0x00000000, 0x00000054, 0x0000005a

24 ...

25 2020-04-15 13:32:38.533838 [cmd004: Create I/O Completion Queue]

26 0x005a0005, 0x00000000, 0x00000000, 0x00000000

27 0x00000000, 0x00000000, 0x0e400000, 0x00000001

28 0x00000000, 0x00000000, 0x0007000f, 0x000f0003

29 0x00000000, 0x00000000, 0x00000000, 0x00000000

30 2020-04-15 13:32:38.533979: [cpl: SUCCESS]

31 0x00000000, 0x00000000, 0x00000053, 0x0000005a

32 ...

33 2020-04-15 13:32:38.313247 [cmd005: Create I/O Submission Queue]

34 0x005a0001, 0x00000000, 0x00000000, 0x00000000

35 0x00000000, 0x00000000, 0x0e200000, 0x00000001

36 0x00000000, 0x00000000, 0x0007000e, 0x000e0001

37 0x00000000, 0x00000000, 0x00000000, 0x00000000

Ln 1, Col 1 Spaces: 4 Plain Text

vTracer: IO Recorder and Replayer



Windows 10 Virtual Machine

QEMU with pynvme vSSD

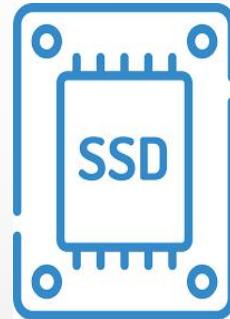
Linux

record



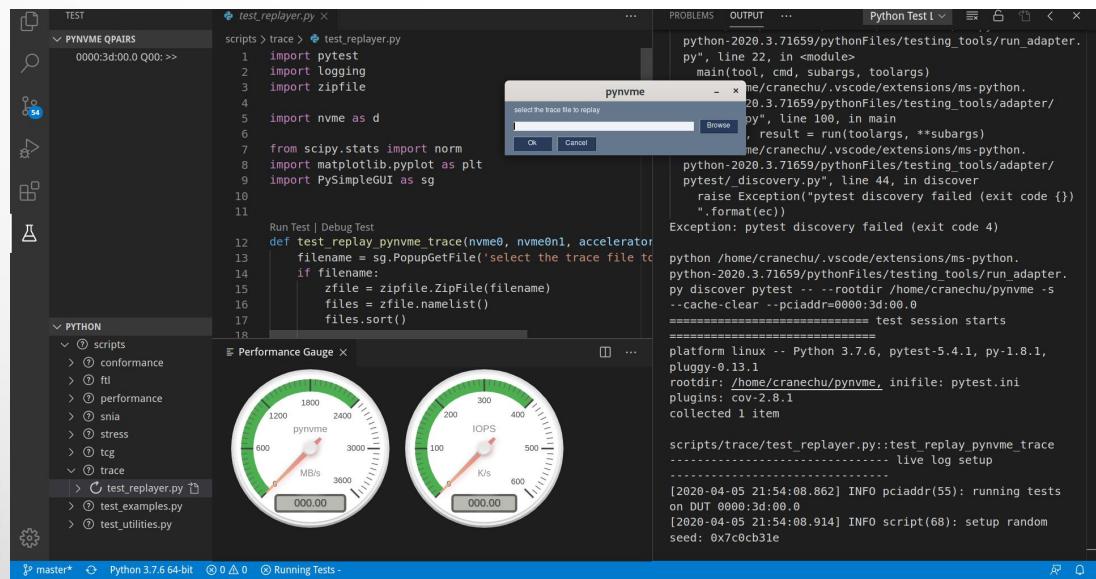
replay

pynvme ioworker



vTracer: Demo

```
Laptop:/pynvme/scripts/trace> ./home/cranechu/gemu/build/x86_64-softmmu/qemu-system-x86_64 -m 4096 -drive file=/home/cranechu/vm/win10_100g.qcow2,lf=none,id=drv0,discard=on -device nvme,drive=drv0,serial=foo -device usb-ehci,id=ehci -device usb-tablet,bus=ehci.0 -enable-kvm -cpu host -smp 4,sockets=1,cores=4,threads=1 | ./recorder.py  
VNC server running on ::1:5900  
trace time base 0  
create minute trace file /tmp/pynvme_trace/0/1  
create minute trace file /tmp/pynvme_trace/0/2  
create minute trace file /tmp/pynvme_trace/0/3  
create minute trace file /tmp/pynvme_trace/0/4  
  
  
gemu-system-x86_64: warning: guest updated active QH  
  
gemu-system-x86_64: warning: guest updated active QH
```

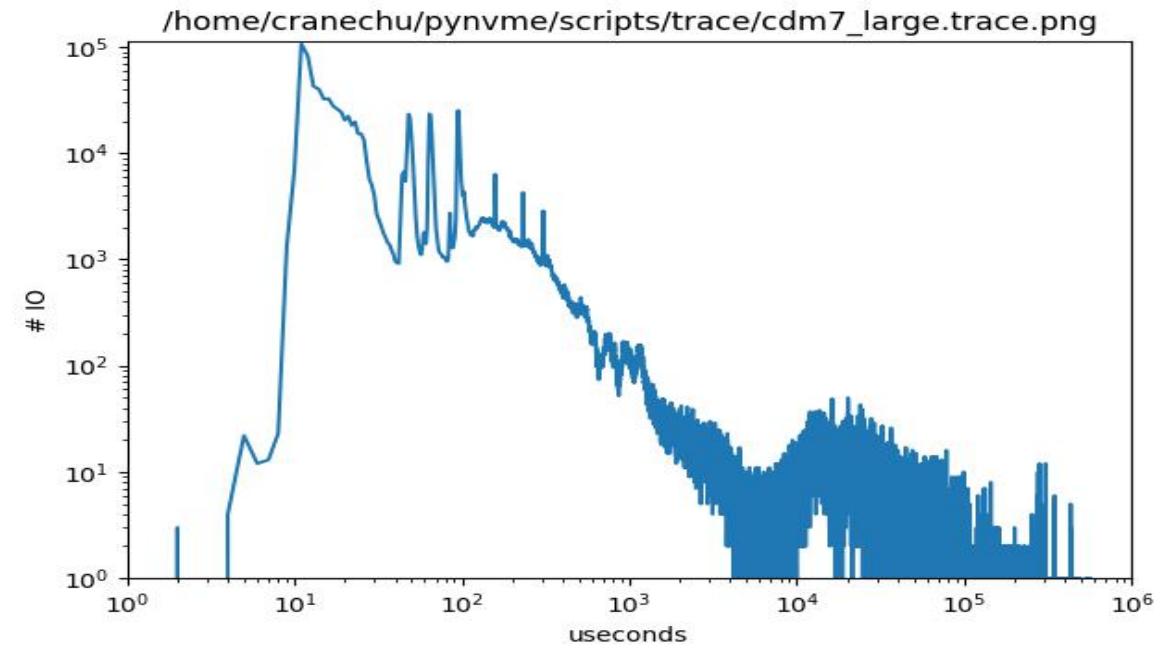
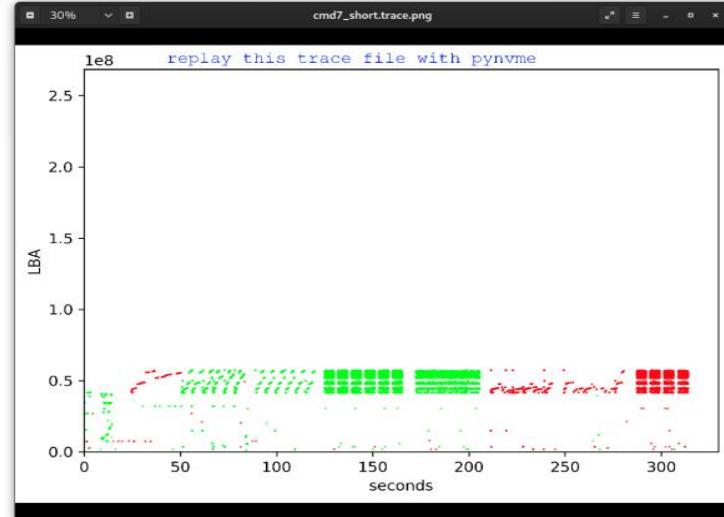


TEST PYNVME QPAIRS 0000:3d:00.0 Q0:00: > test_replayer.py
scripts > trace > test_replayer.py
0000:3d:00.0 Q0:00: >
1 import pytest
2 import logging
3 import zipfile
4
5 import nvme as d
6
7 from scipy.stats import norm
8 import matplotlib.pyplot as plt
9 import PysimpleGUI as sg
10
11 Run Test | Debug Test
12 def test_replay_pynvme_trace(nvme0, nvme0n1, accelerator
13 filename = sg.PopupGetFile('select the trace file to
14 if filename:
15 zfile = zipfile.ZipFile(filename)
16 files = zfile.namelist()
17 files.sort()
18
19
PROBLEMS OUTPUT Python Testl
python-2020.3.71659/pythonFiles/testing_tools/run_adapter.py", line 22, in <module>
main(tool, cmd, subargs, toolargs)
- x me/cranechu/.vscode/extensions/ms-python.
20.3.71659/pythonFiles/testing_tools/adapter/
py", line 100, in main
, result = run(toolargs, **subargs)
me/cranechu/.vscode/extensions/ms-python.
python-2020.3.71659/pythonFiles/testing_tools/adapter/
pytest/discovery.py", line 44, in discover
raise Exception("pytest discovery failed (exit code {}")
".format(ec))
Exception: pytest discovery failed (exit code 4)
python /home/cranechu/.vscode/extensions/ms-python.
python-2020.3.71659/pythonFiles/testing_tools/run_adapter.
py discover pytest --rootdir /home/cranechu/pynvme -s
--cache-clear --pciaid=0000:3d:00.0
===== test session starts
platform linux -- Python 3.7.6, pytest-5.4.1, py-1.8.1,
pluggy-0.13.1
rootdir: /home/cranechu/pynvme, inifile: pytest.ini
plugins: cov-2.8.1
collected 1 item

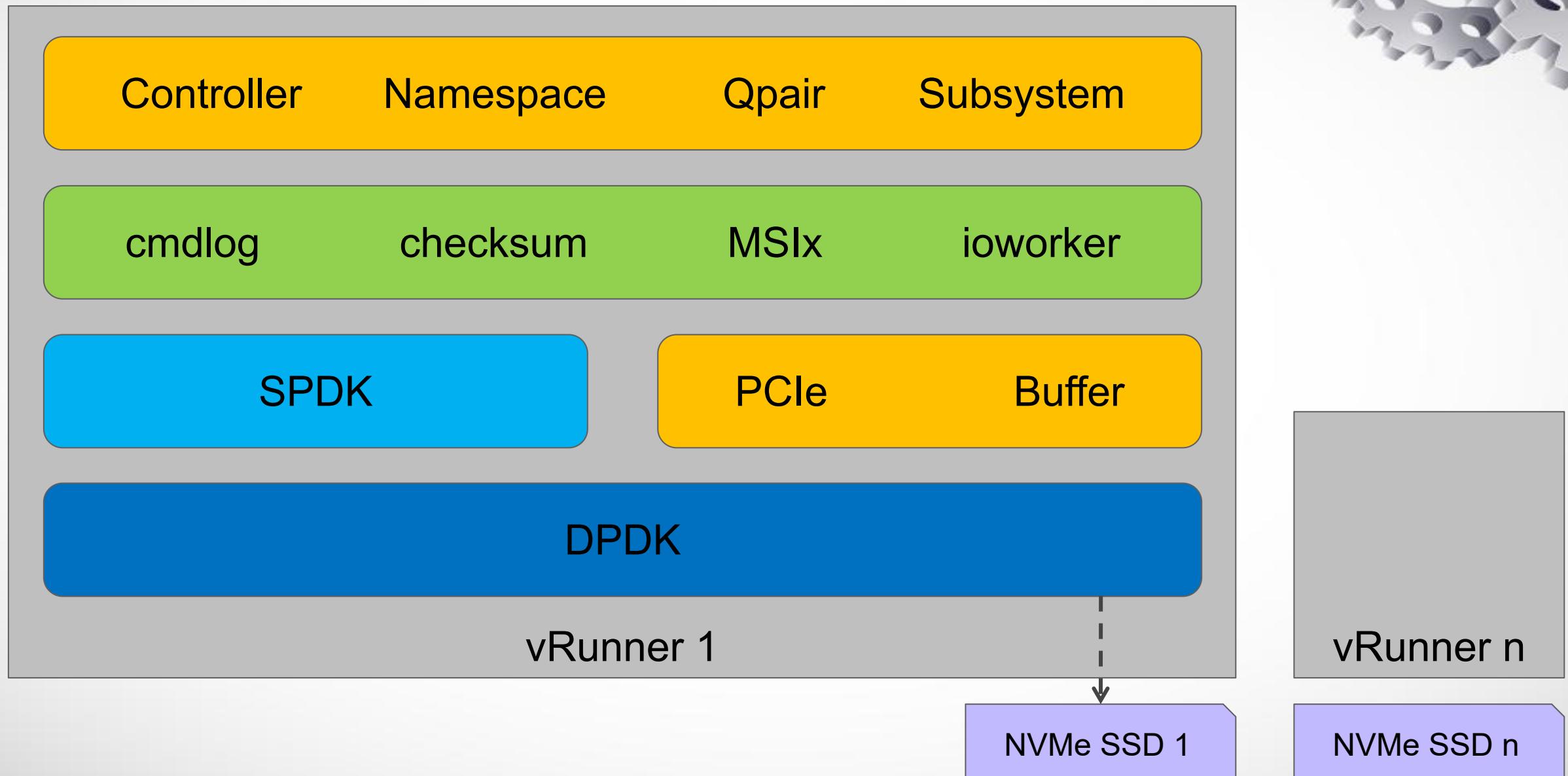
scripts/trace/test_replayer.py::test_replay_pynvme_trace
----- live log setup
[2020-04-05 21:54:08.862] INFO pciaddr(55): running tests
on DUT 0000:3d:00.0
[2020-04-05 21:54:08.914] INFO script(68): setup random
seed: 0x7c0cb31e

Performance Gauge X
pynvme MB/s 000.00 3600
IOPS K/s 000.00 600

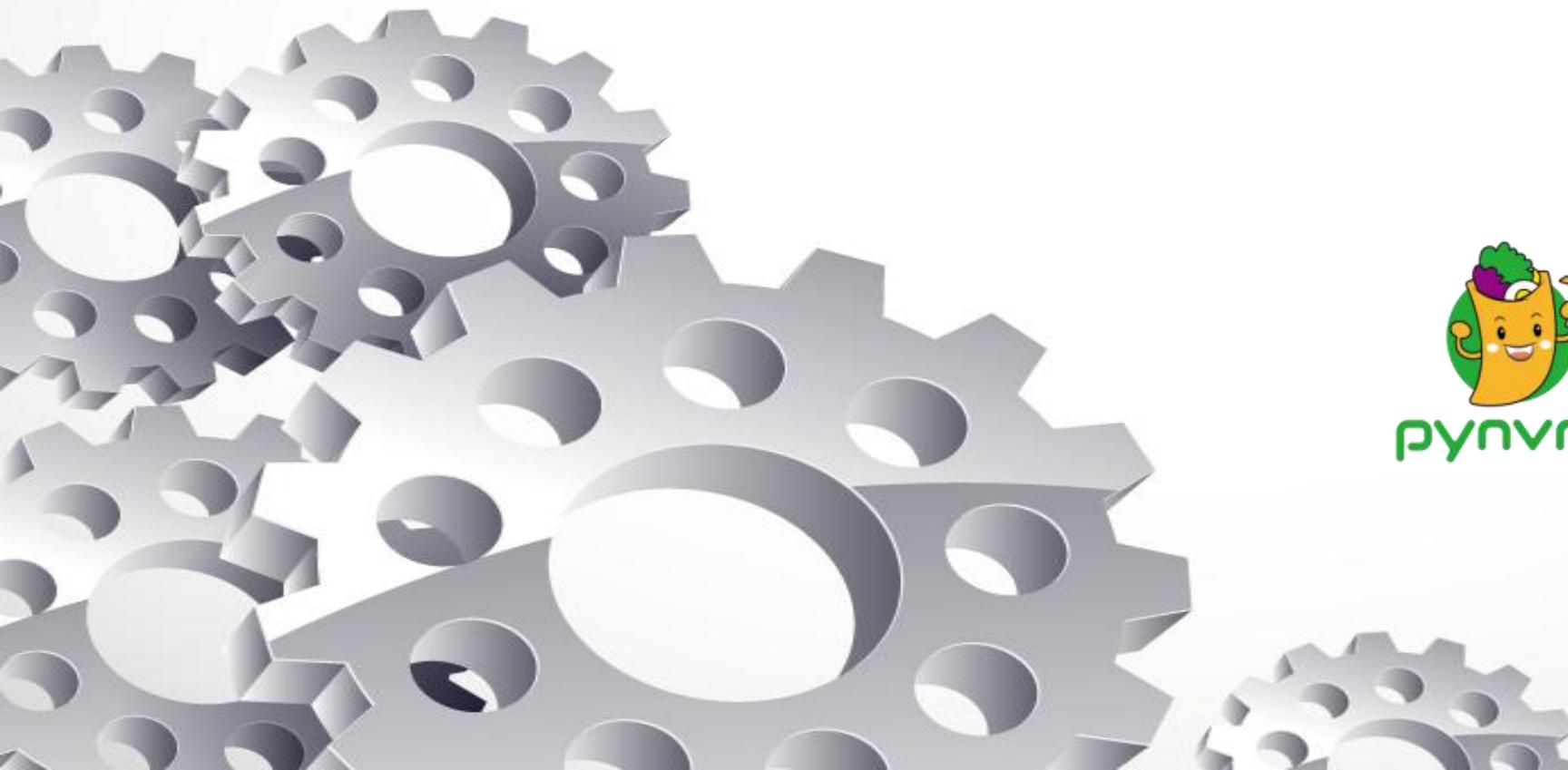
master* Python 3.7.6 64-bit 0 0 0 Running Tests -



vRunner: Mass Deploy



Services



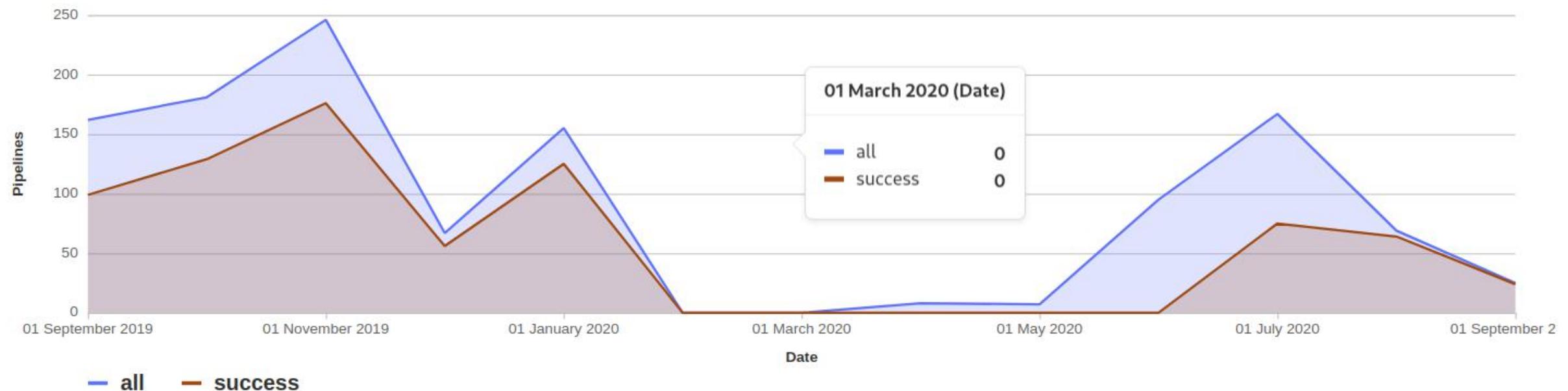
pynvme builds your own tests.

Quality: test of the test infrastructure



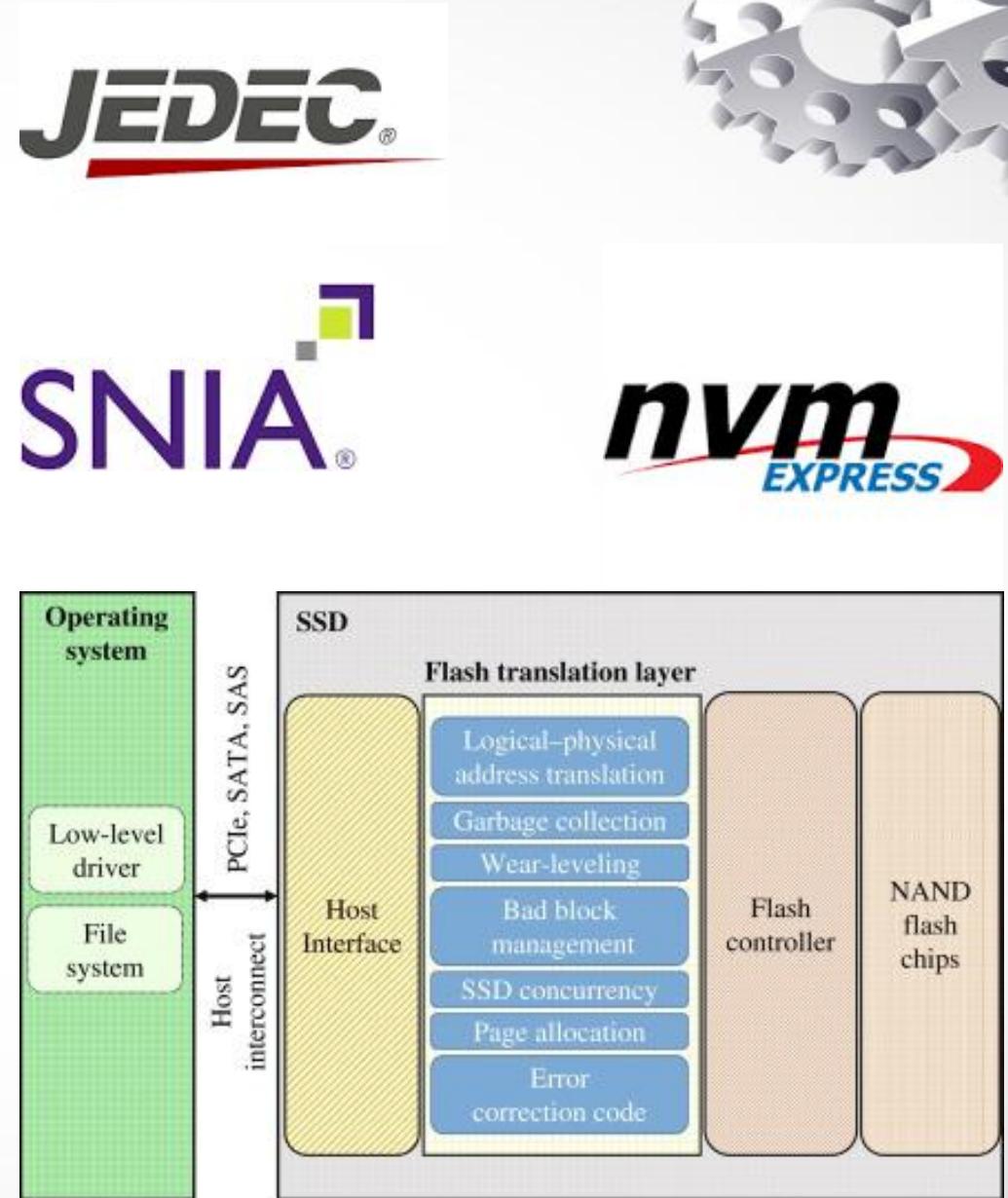
- CI in gitlab.com
- ~600 test items

Pipelines for last year



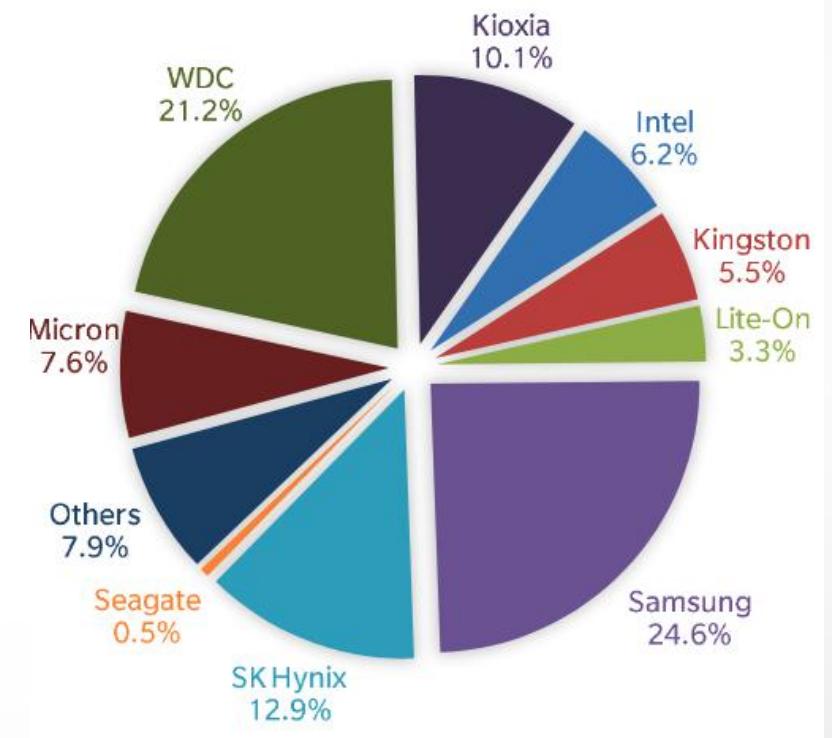
Services

```
5 def test_ioworker_jedec_workload(nvme0n1):
6     distribution = [1000]*5 + [200]*15 + [25]*80
7     iosz_distribution = {1: 4,
8                           2: 1,
9                           3: 1,
10                          4: 1,
11                          5: 1,
12                          6: 1,
13                          7: 1,
14                          8: 67,
15                          16: 10,
16                          32: 7,
17                          64: 3,
18                          128: 3}
19
20 nvme0n1.ioworker(io_size=iosz_distribution,
21                   lba_random=True,
22                   qdepth=128,
23                   distribution = distribution,
24                   read_percentage=0,
25                   ptype=0xbeef, pvalue=100,
26                   time=12*3600).start().close()
```

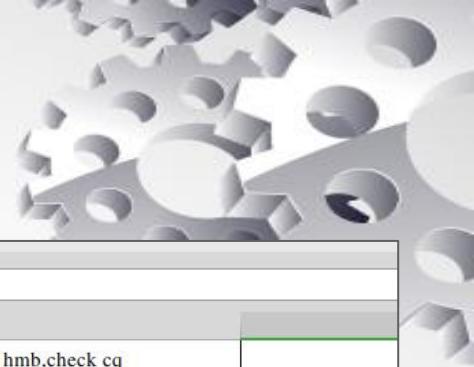




- PyNvMe3 is derived from pynvme with more functions and better commercial services. <http://pynv.me/3/>
- the gap between SSD development and test
 - many SSD controller and product vendors
 - SSD fast growing
- the gap between SSD vendors and customers
 - 3rd party test suites and technology supplier



HMB example



Test 3.4 – Host Memory Buffer (M).....				
Case 1: Proper Structure (M).....				
Case 2: Configuration (FYI).....				
Case 3: Reset Persistent (FYI).....				
Case 4: Enable HMB when Already Enabled (FYI)				
Case 5: Disable HMB when Already Disabled (FYI)				

5

V.S.

32

A	B	C	D	
41	Test_HMB_028	test_HMB_sanitize_format	verify sanitize and user data erase command can be passed when enabling hmb	1. Host send "set feature command"to enable hmb,check cq 2. start ioworker without error 3. host send "sanitize command" 4. run ioworker without error 5. host send " user data erase command " 6. start ioworker, there is no error 7. host send "TCG operation ",there is no error HMB_042 HMB_043 HMB_044
42	Test_HMB_029	test_HMB_stress	enable and disable hmb stress	1. Host send "set feature command"to enable hmb,check cq 2. start ioworker 3. Host send "set feature command"to disable hmb,check cq 4. run ioworker 5. repeat step1-4 many times 6. open the thread to do ioworker 7. Host send "set feature command"to enable hmb,check cq 8. Host send "set feature command"to disable hmb,check cq 9. repeat step7-8 many times HMB_045 HMB_046
43	Test_HMB_030	test_HMB_out_of_bounds	verify memory access out of bounds	1. get three Buffers 2. The middle of buffer is used to hmb 3. Host send "set feature command"to enable hmb,check cq 4. run ioworker 5. check the pattern in the first and end buffer has not changed HMB_047
44	Test_HMB_031	test_HMB_data_consistency	verify data consistency	1. Host send "set feature command"to enable hmb,check cq 2. write data 3. Host send "set feature command"to disable hmb,check cq 4. verify data at step 2 5. write data 6. Host send "set feature command"to enable hmb,check cq 7. verify data at step 5 HMB_048 HMB_049
45	Test_HMB_032	test_HMB_with_command	verify admin command and nvm command without error when	1. Host send "set feature command"to enable hmb,check cq 2. Host send admin command(like: AER/set feature..) and nvm command HMB_050
46				

Conformance Test Scripts



- <https://github.com/pynvme/conformance>
 - GPL-3.0
 - suites
 - registers
 - admin
 - nvm
 - features
 - controller
 - TCG
 - ZNS

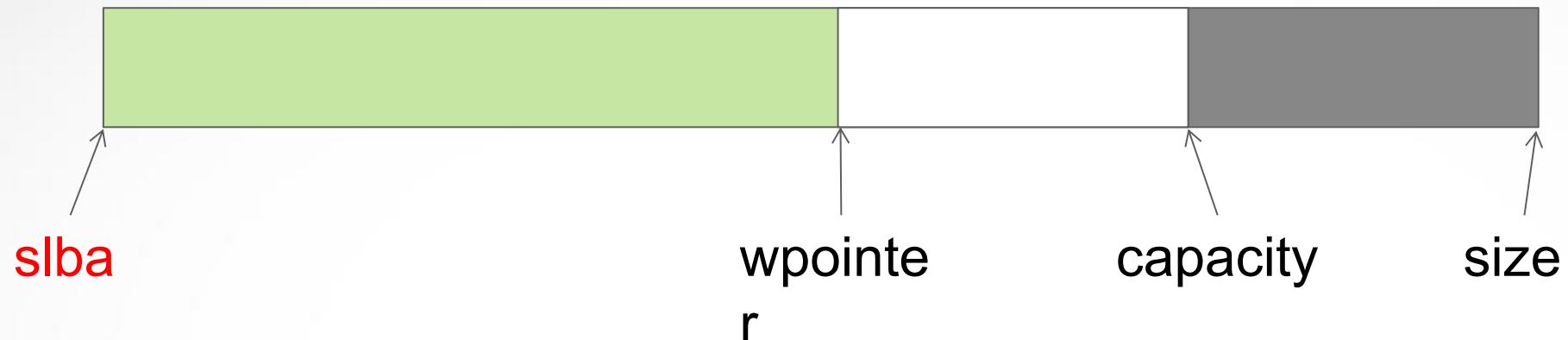
Enterprise SSD (April 2021)



- commercial tools and services

	pynvme supported	SPDK supported	to be developed
multiple controllers	✓		
multiple namespaces	✓		
zoned namespace	✓		
namespace mgmt	✓		
reservation command			✓
SGL	✓	✓	
metadata	✓		
E2E data protection			✓
CMB		✓	✓
SRIOV	✓		
latency histogram	✓		

Zone Class



Zone.state

- Empty
- Implicitly Opened
- Explicitly Opened
- Closed
- Read Only
- Full
- Offline

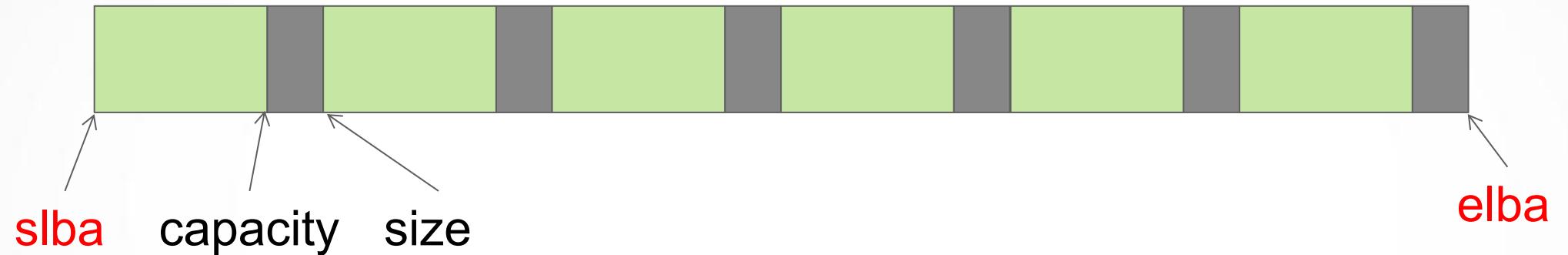
Zone actions: applied to all physical zones in a super zone

- `close()`
- `finish()`
- `open()`
- `reset()`
- `offline()`
- `set_descriptor_extension()`

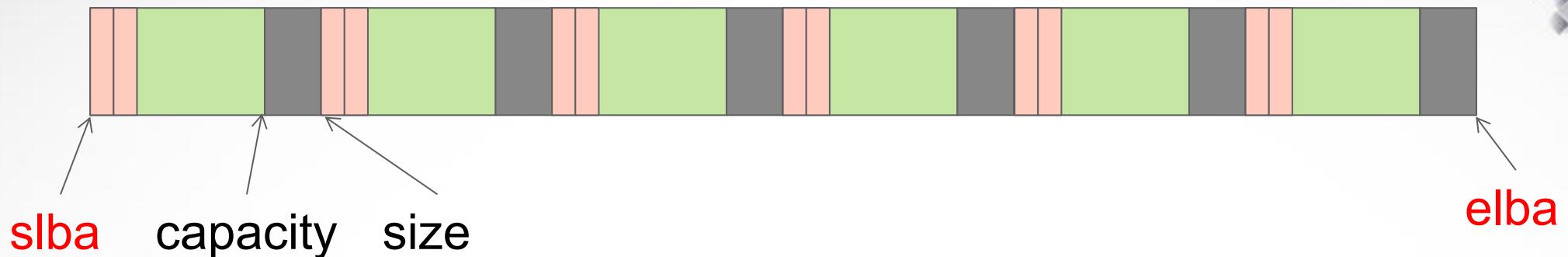
IO:

- `read(offset)`
- `write(offset)`
- `ioworker()`

Super Zone



ioworker: fill super zone



- ✓ maximize opened zone count
- ✓ increase write bandwidth
- ✓ avoid the LBA holes between capacity and size
- ✓ leverage the step parameter of ioworker

notes:

1. enough qdepth: $8 * (\text{physical zone count})$
2. 100% write in one ioworker. Mixed read in another ioworker.

```
def test_zns_write_super_zone_basic(nvme0n1, buf, qpair, nzones=1):  
    Zone(qpair, nvme0n1, 0, 0x4000*nzones).reset().\n        ioworker(io_size=32, io_count=384*nzones, qdepth=8*nzones).start().close()
```

Editions



PyNVMe3 Edition	community	Ecosystem	Individual	Teamwork	Cooperate
Driver	open source	Proprietary	Proprietary	Proprietary	Proprietary
Scripts	-	Yes	Yes	Yes	Yes
Updates	-	Quarterly	Quarterly	Quarterly	Quarterly
Reports	-	1	unlimited	unlimited	unlimited
Nodes	unlimited	3	10	30	unlimited
Enterprise Features	-	-	-	Yes	Yes
Basic Services	-	Yes	-	Yes	Yes
Enhanced Services	-	-	-	-	Yes
Annual Subscription	free	3,000	10,000	30,000	100,000

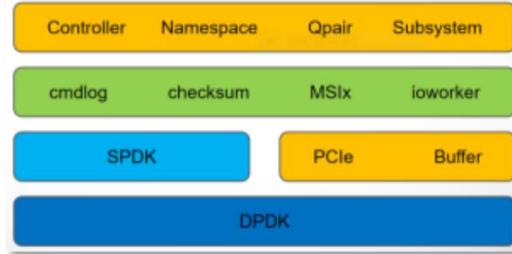
Values



Ecosystem



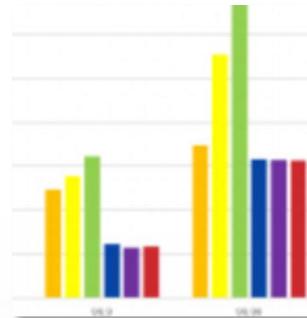
Scripts



Expendability



Hardware



Performance



Service





pynvme builds your own tests.

<http://pynv.me/3/>

Thanks!