pynvme:
test NVMe devices in Python

https://github.com/cranechu/pynvme

pynvme

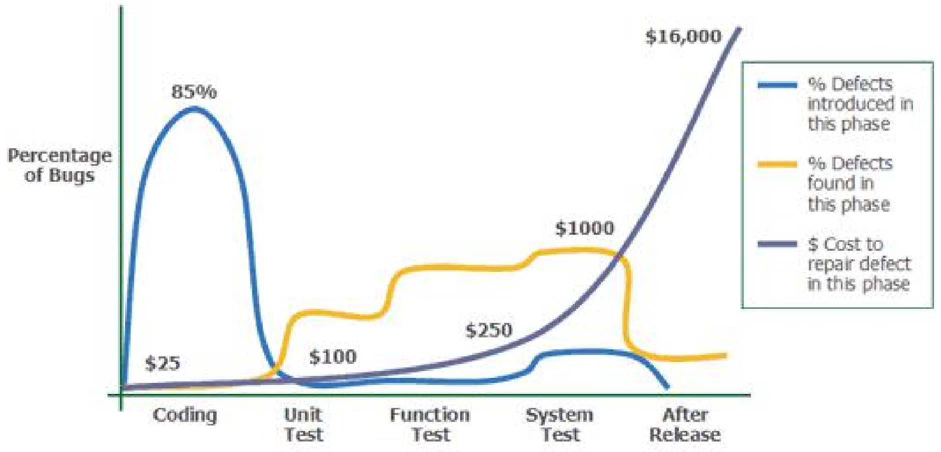
The pynvme is a python extension module. Users can operate NVMe SSD intuitively in Python scripts. It is designed for NVMe SSD testing with performance considered. Integrated with third-party tools, vscode and pytest, pynvme provides a convenient and professional solution to test NVMe devices.

Why pynvme?

- Embedded system provides limited resources;
- It is not flexible to rely only on existed testing software;
- Developers need the infrastructure to implement test programs or scripts rapidly;

- Function test
- Regress test
- Continuous Integration

- Cost $$$
- Fail early! Fail fast!

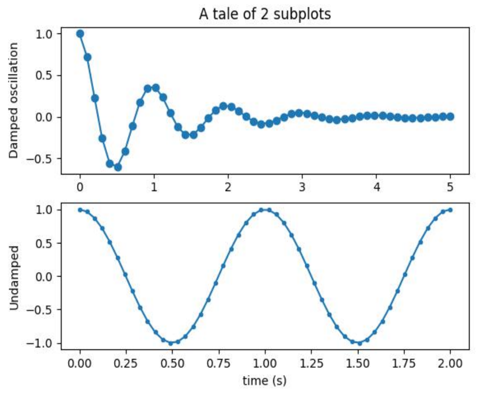


Why Python?

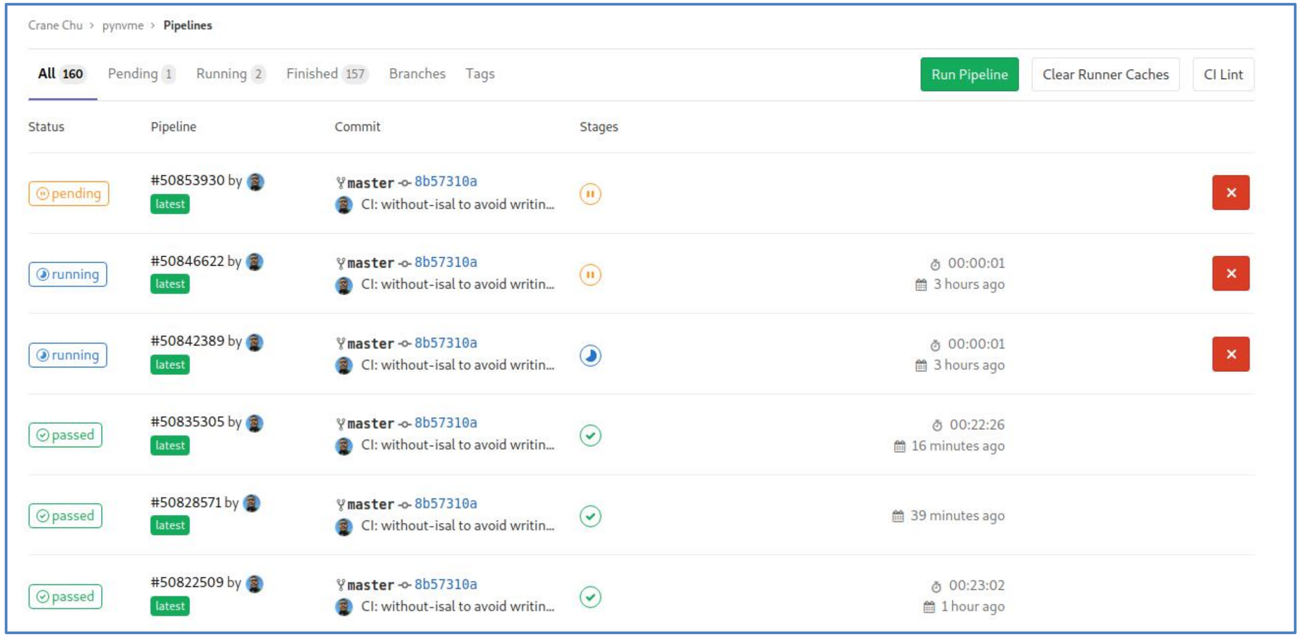
√ Many beautiful mature libraries
- pytest
- logging
- multiprocessing
- numpy
- matplotlib
- pydoc
- os, io, time, pytemperature, statistics, yaml, json, struct, …

√ Friendly IDEs for developing, debugging, and testing
- VSCode, emacs, Pycharm

√ CI: develop firmware softly pipeline passed



CI Status of pynvme



Crane Chu › pynvme › **Pipelines**

All 160 Pending 1 Running 2 Finished 157 Branches Tags

Run Pipeline | Clear Runner Caches | CI Lint

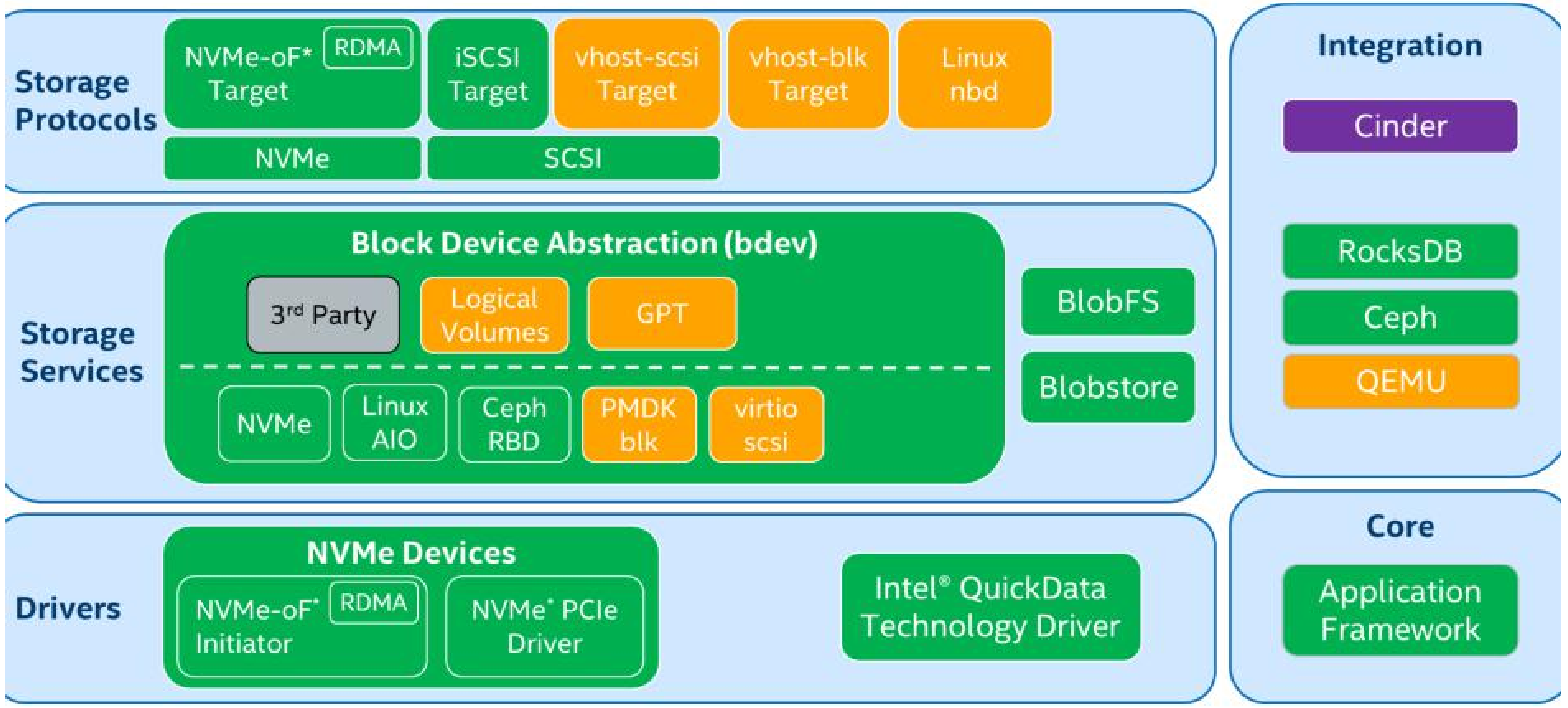
Status	Pipeline	Commit	Stages		
pending	#50853930 by latest	master 8b57310a CI: without-isal to avoid writin...	⏸		×
running	#50846622 by latest	master 8b57310a CI: without-isal to avoid writin...	⏸	00:00:01 3 hours ago	×
running	#50842389 by latest	master 8b57310a CI: without-isal to avoid writin...	◔	00:00:01 3 hours ago	×
passed	#50835305 by latest	master 8b57310a CI: without-isal to avoid writin...	✓	00:22:26 16 minutes ago	
passed	#50828571 by latest	master 8b57310a CI: without-isal to avoid writin...	✓	39 minutes ago	
passed	#50822509 by latest	master 8b57310a CI: without-isal to avoid writin...	✓	00:23:02 1 hour ago	

Introduce software methodologies, processes and tools to SSD firmware development!

Gap is the Driver.

- A light-weighted NVMe driver;
  - export features to test scripts
  - export flaws to test scripts
- Reliable;
- Performance;
- test dedicated;
- Develop test scripts in Python.

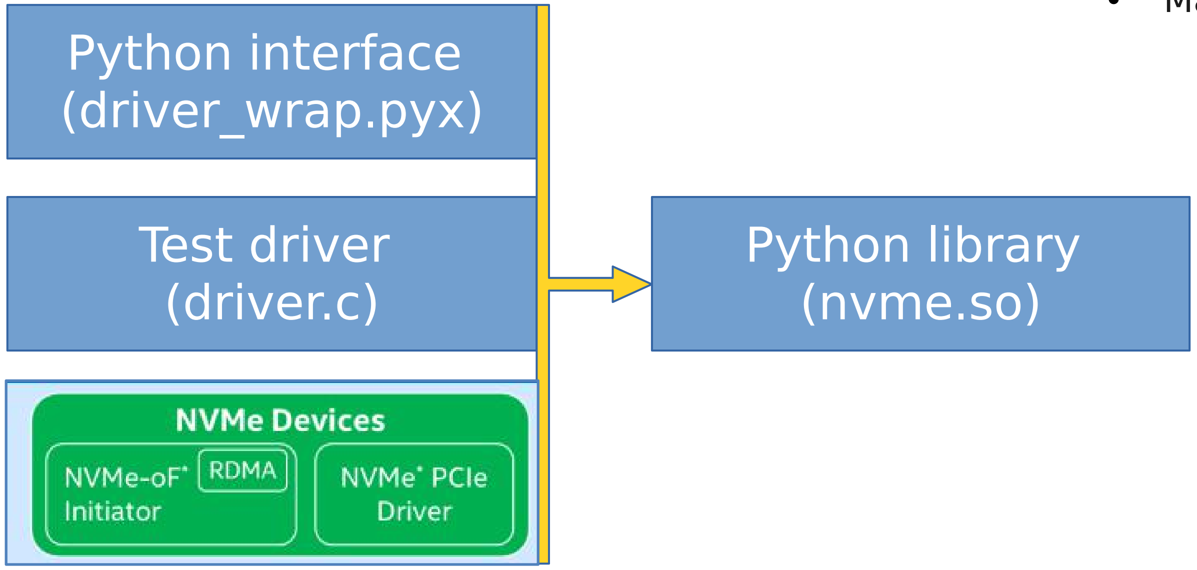
Pynvme is based on SPDK



Pynvme Architecture

Build python library with Cython:

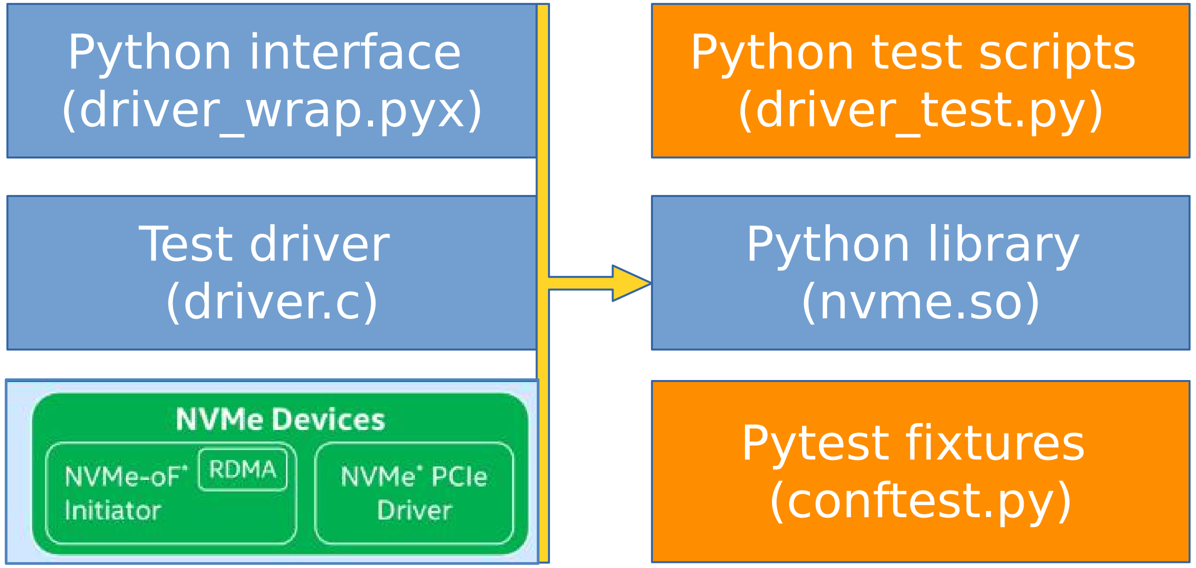
- setup.py
- driver.c
- driver.h
- cdriver.pxd
- driver_wrap.pyx
- Makefile



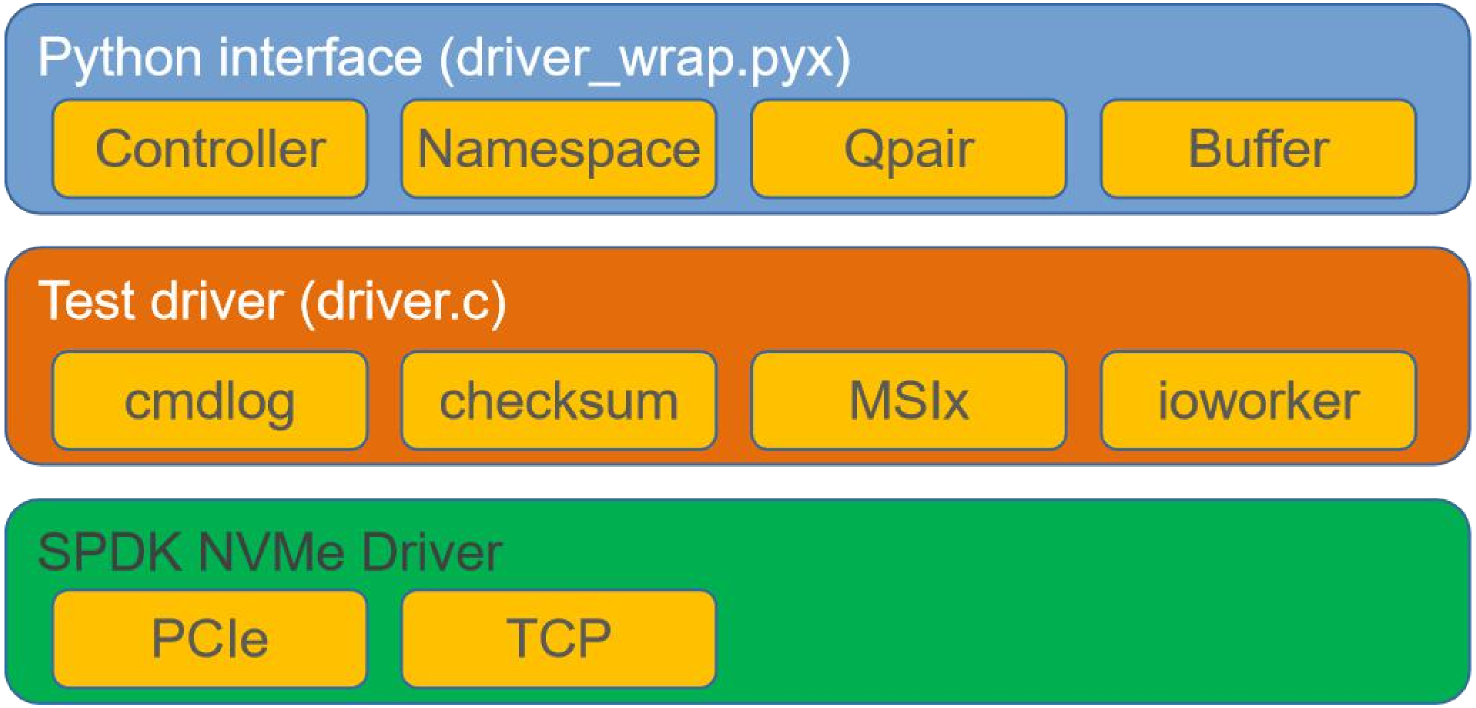
Pynvme Architecture

Organize test cases in pytest:

- mvme.so
- pytest.ini
- conftest.py
- driver_test.py



Pynvme Details

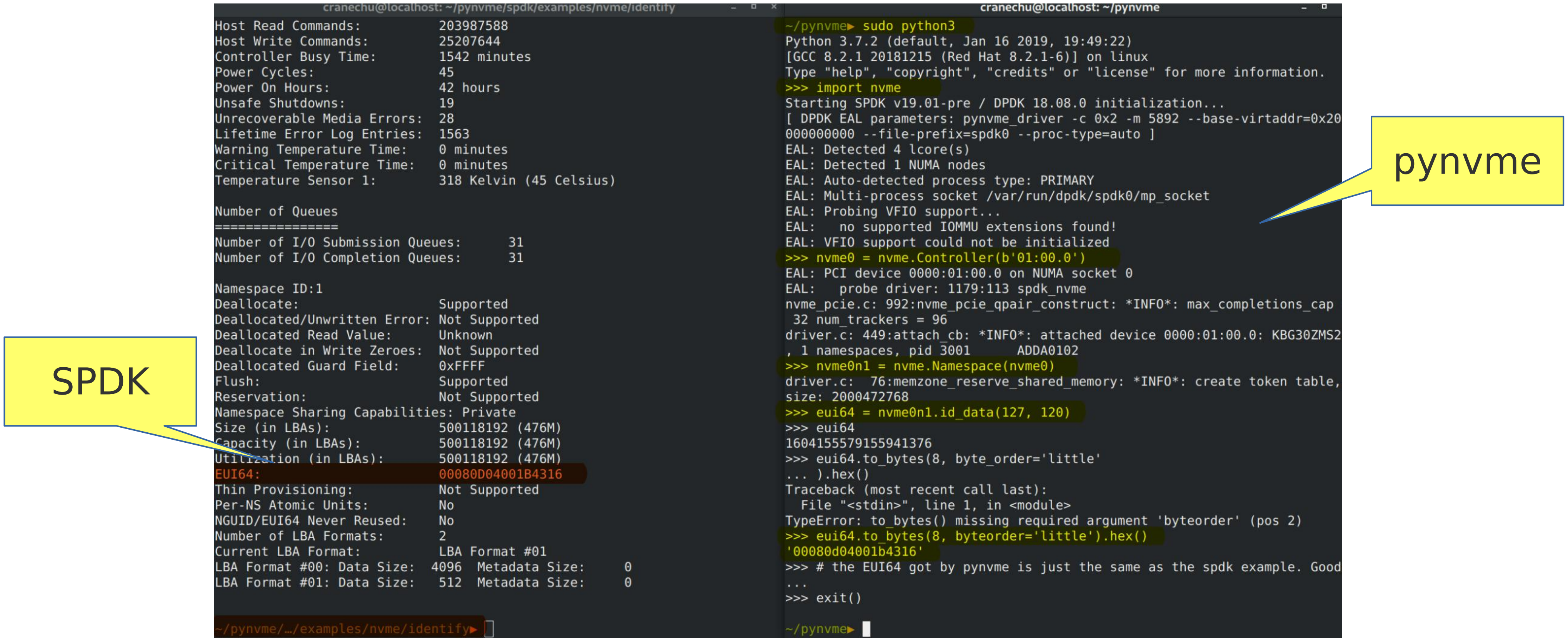


Config and Compile

1. git clone https://github.com/cranechu/pynvme
2. cd pynvme
3. ./install.sh
4. now, ready to run test scripts with pytest

- Fedora29, or CentOS8, is recommended.
- find test script examples in driver_test.py.
- **find more =>** https://github.com/cranechu/pynvme

First Example in Python IDLE



```
cranechu@localhost: ~/pynvme/spdk/examples/nvme/identify

Host Read Commands:             203987588
Host Write Commands:            25207644
Controller Busy Time:           1542 minutes
Power Cycles:                   45
Power On Hours:                 42 hours
Unsafe Shutdowns:               19
Unrecoverable Media Errors:     28
Lifetime Error Log Entries:     1563
Warning Temperature Time:       0 minutes
Critical Temperature Time:      0 minutes
Temperature Sensor 1:           318 Kelvin (45 Celsius)

Number of Queues
================
Number of I/O Submission Queues:      31
Number of I/O Completion Queues:      31

Namespace ID:1
Deallocate:                     Supported
Deallocated/Unwritten Error:    Not Supported
Deallocated Read Value:         Unknown
Deallocate in Write Zeroes:     Not Supported
Deallocated Guard Field:        0xFFFF
Flush:                          Supported
Reservation:                    Not Supported
Namespace Sharing Capabilities: Private
Size (in LBAs):                 500118192 (476M)
Capacity (in LBAs):             500118192 (476M)
Utilization (in LBAs):          500118192 (476M)
EUI64:                          00080D04001B4316
Thin Provisioning:              Not Supported
Per-NS Atomic Units:            No
NGUID/EUI64 Never Reused:       No
Number of LBA Formats:          2
Current LBA Format:             LBA Format #01
LBA Format #00: Data Size:  4096  Metadata Size:     0
LBA Format #01: Data Size:   512  Metadata Size:     0

~/pynvme/…/examples/nvme/identify▸
```

```
cranechu@localhost: ~/pynvme

~/pynvme▸ sudo python3
Python 3.7.2 (default, Jan 16 2019, 19:49:22)
[GCC 8.2.1 20181215 (Red Hat 8.2.1-6)] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>> import nvme
Starting SPDK v19.01-pre / DPDK 18.08.0 initialization...
[ DPDK EAL parameters: pynvme_driver -c 0x2 -m 5892 --base-virtaddr=0x20
000000000 --file-prefix=spdk0 --proc-type=auto ]
EAL: Detected 4 lcore(s)
EAL: Detected 1 NUMA nodes
EAL: Auto-detected process type: PRIMARY
EAL: Multi-process socket /var/run/dpdk/spdk0/mp_socket
EAL: Probing VFIO support...
EAL:   no supported IOMMU extensions found!
EAL: VFIO support could not be initialized
>>> nvme0 = nvme.Controller(b'01:00.0')
EAL: PCI device 0000:01:00.0 on NUMA socket 0
EAL:   probe driver: 1179:113 spdk_nvme
nvme_pcie.c: 992:nvme_pcie_qpair_construct: *INFO*: max_completions_cap
 32 num_trackers = 96
driver.c: 449:attach_cb: *INFO*: attached device 0000:01:00.0: KBG30ZMS2
, 1 namespaces, pid 3001       ADDA0102
>>> nvme0n1 = nvme.Namespace(nvme0)
driver.c:  76:memzone_reserve_shared_memory: *INFO*: create token table,
size: 2000472768
>>> eui64 = nvme0n1.id_data(127, 120)
>>> eui64
1604155579155941376
>>> eui64.to_bytes(8, byte_order='little'
... ).hex()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: to_bytes() missing required argument 'byteorder' (pos 2)
>>> eui64.to_bytes(8, byteorder='little').hex()
'00080d04001b4316'
>>> # the EUI64 got by pynvme is just the same as the spdk example. Good
...
>>> exit()

~/pynvme▸
```

Pytest Execution

- '''The pytest framework makes it easy to write small tests, yet scales to support complex functional testing for applications and libraries.'''

- '''pytest fixtures offer dramatic improvements over the classic xUnit style of setup/teardown functions'''

- use “make test” to start pytest sessions
  - make test
  - make test TESTS=scripts
  - make test TESTS=scripts/demo_test.py
  - make test TESTS=scripts/utility_test.py::test_download_firmware
- find test logs in test.log

Test Script Files

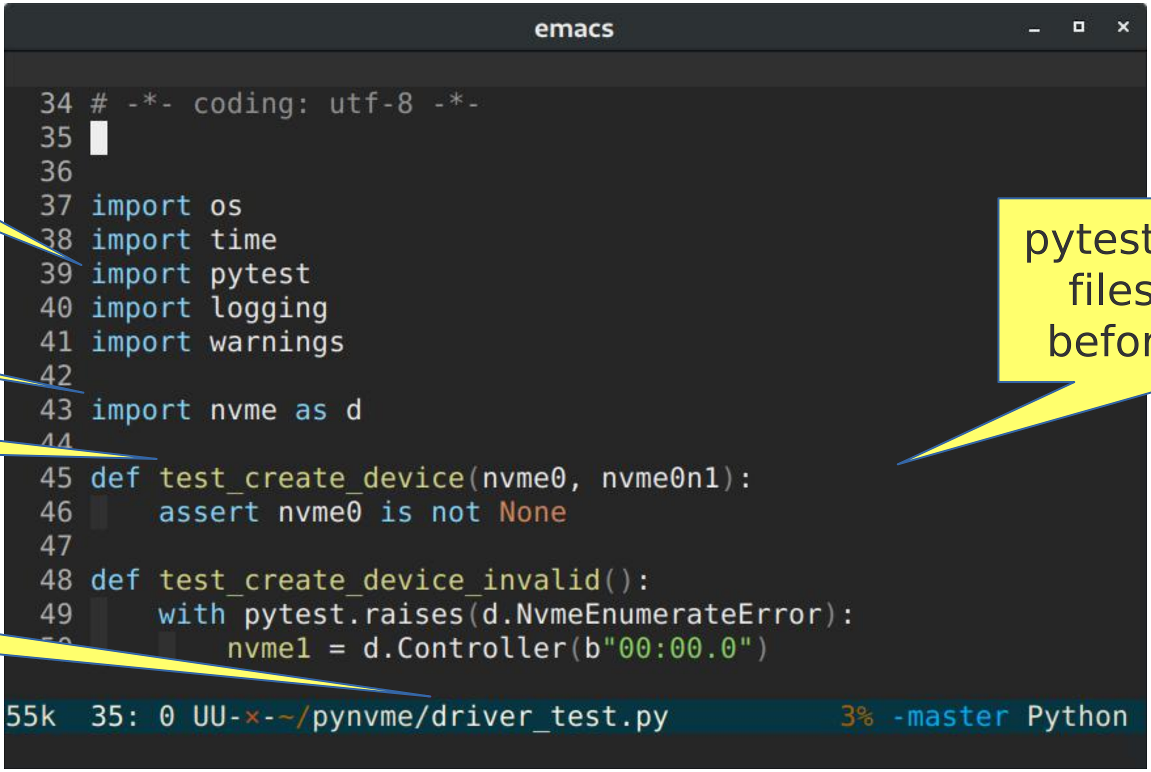
import pytest

import nvme

test functions

test file name

pytest collects test files and cases before execution



```
# -*- coding: utf-8 -*-


import os
import time
import pytest
import logging
import warnings

import nvme as d

def test_create_device(nvme0, nvme0n1):
    assert nvme0 is not None

def test_create_device_invalid():
    with pytest.raises(d.NvmeEnumerateError):
        nvme1 = d.Controller(b"00:00.0")
```

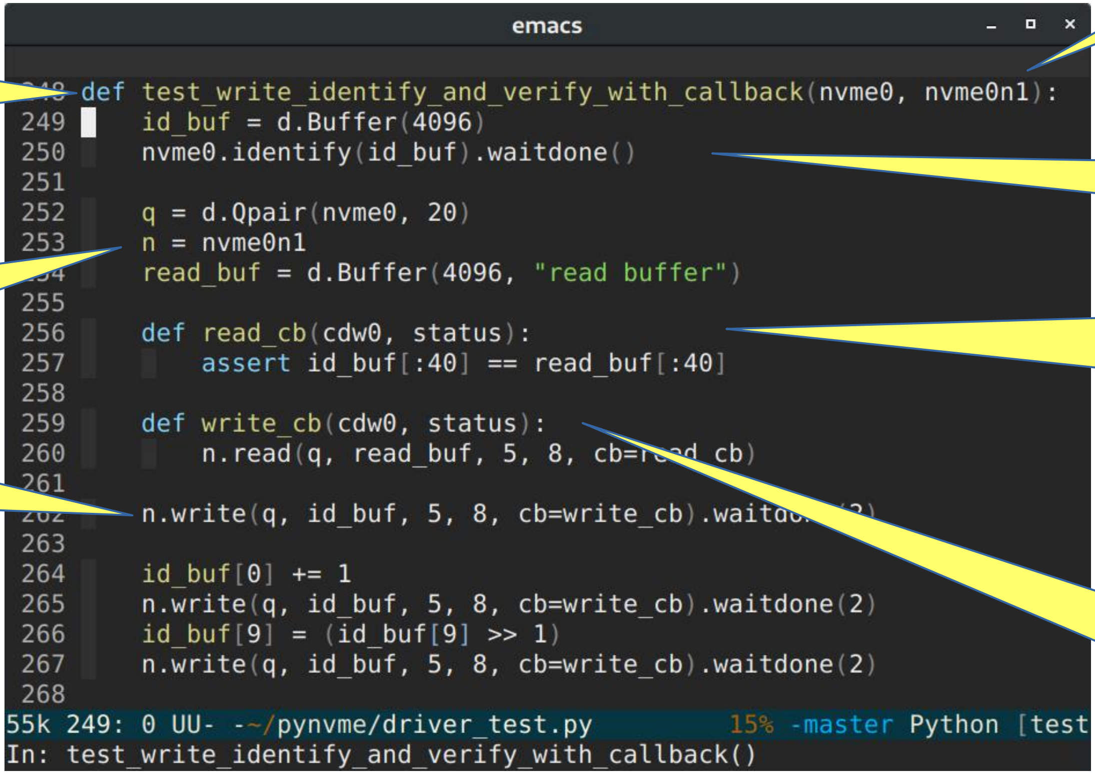
```
55k  35: 0 UU-x-~/pynvme/driver_test.py          3% -master Python
```

An Example

pytest cases are started with test_

create qpair and buffer for write commands

write data, and then read in the callback



```
def test_write_identify_and_verify_with_callback(nvme0, nvme0n1):
    id_buf = d.Buffer(4096)
    nvme0.identify(id_buf).waitdone()

    q = d.Qpair(nvme0, 20)
    n = nvme0n1
    read_buf = d.Buffer(4096, "read buffer")

    def read_cb(cdw0, status):
        assert id_buf[:40] == read_buf[:40]

    def write_cb(cdw0, status):
        n.read(q, read_buf, 5, 8, cb=read_cb)

    n.write(q, id_buf, 5, 8, cb=write_cb).waitdone(2)

    id_buf[0] += 1
    n.write(q, id_buf, 5, 8, cb=write_cb).waitdone(2)
    id_buf[9] = (id_buf[9] >> 1)
    n.write(q, id_buf, 5, 8, cb=write_cb).waitdone(2)

55k 249: 0 UU- -~/pynvme/driver_test.py        15% -master Python [test
In: test_write_identify_and_verify_with_callback()
```

pytest fixtures

fill buffer with identify data

callback functions are called when cmds are completed

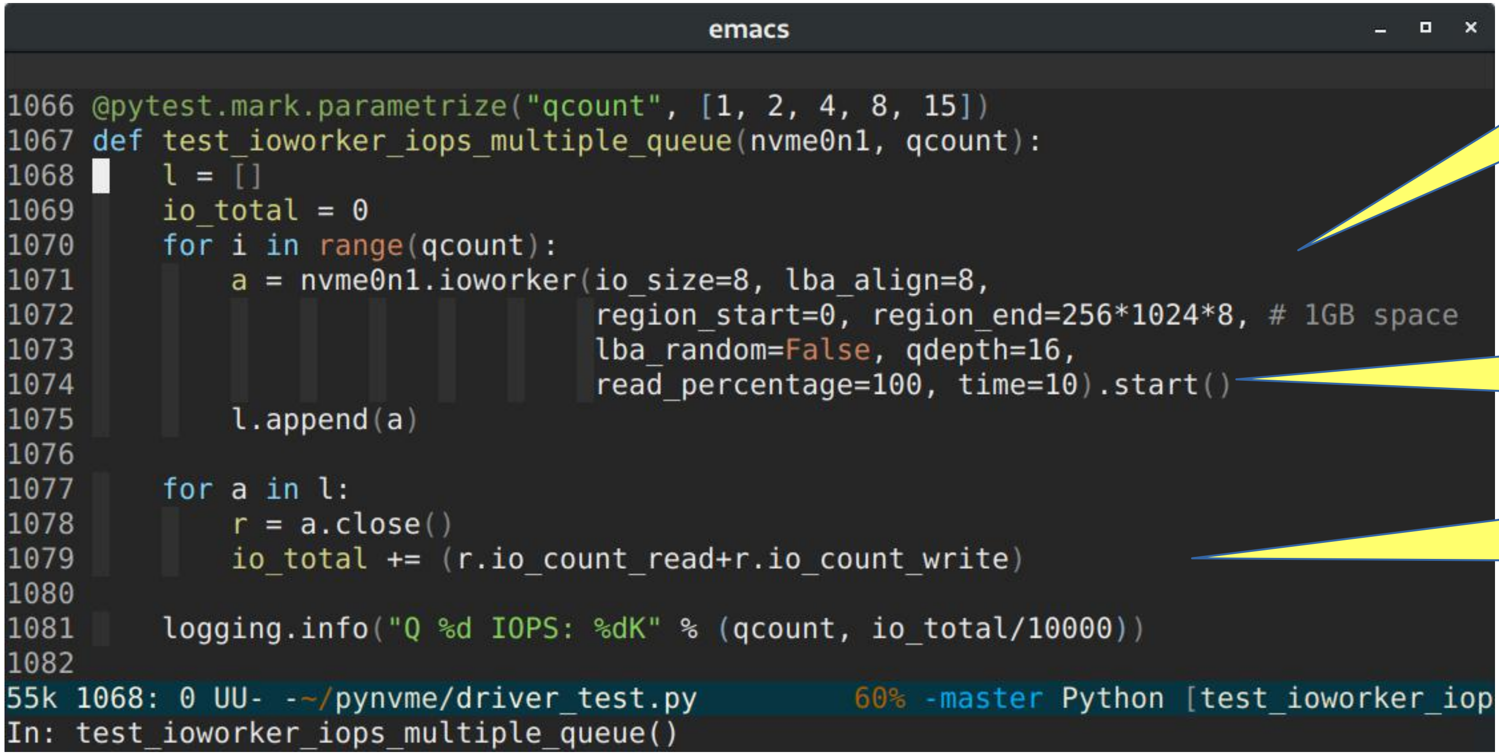
the status of the callback function also includes the **Phase Tag** bit

Fixtures of Pynvme

- create/delete test objects. in conftest.py:
  - nvme0
  - nvme0n1
  - pcie
  - ...
- parametrize of tests
  - @pytest.mark.parametrize("qcount", [1, 2, 4, 8, 15])
  - @pytest.mark.parametrize("repeat", range(10))
- test control
  - @pytest.mark.skip("nvme over tcp")

- doc: https://docs.pytest.org/en/latest/fixture.html

IOWorker


emacs

```
@pytest.mark.parametrize("qcount", [1, 2, 4, 8, 15])
def test_ioworker_iops_multiple_queue(nvme0n1, qcount):
    l = []
    io_total = 0
    for i in range(qcount):
        a = nvme0n1.ioworker(io_size=8, lba_align=8,
                             region_start=0, region_end=256*1024*8, # 1GB space
                             lba_random=False, qdepth=16,
                             read_percentage=100, time=10).start()
        l.append(a)

    for a in l:
        r = a.close()
        io_total += (r.io_count_read+r.io_count_write)

    logging.info("Q %d IOPS: %dK" % (qcount, io_total/10000))

55k 1068: 0 UU- -~/pynvme/driver_test.py        60% -master Python [test_ioworker_iop
In: test_ioworker_iops_multiple_queue()
```

define IO patterns in ioworker's parameter list

send IO in a separated process

wait ioworkers till finish, and collect result data

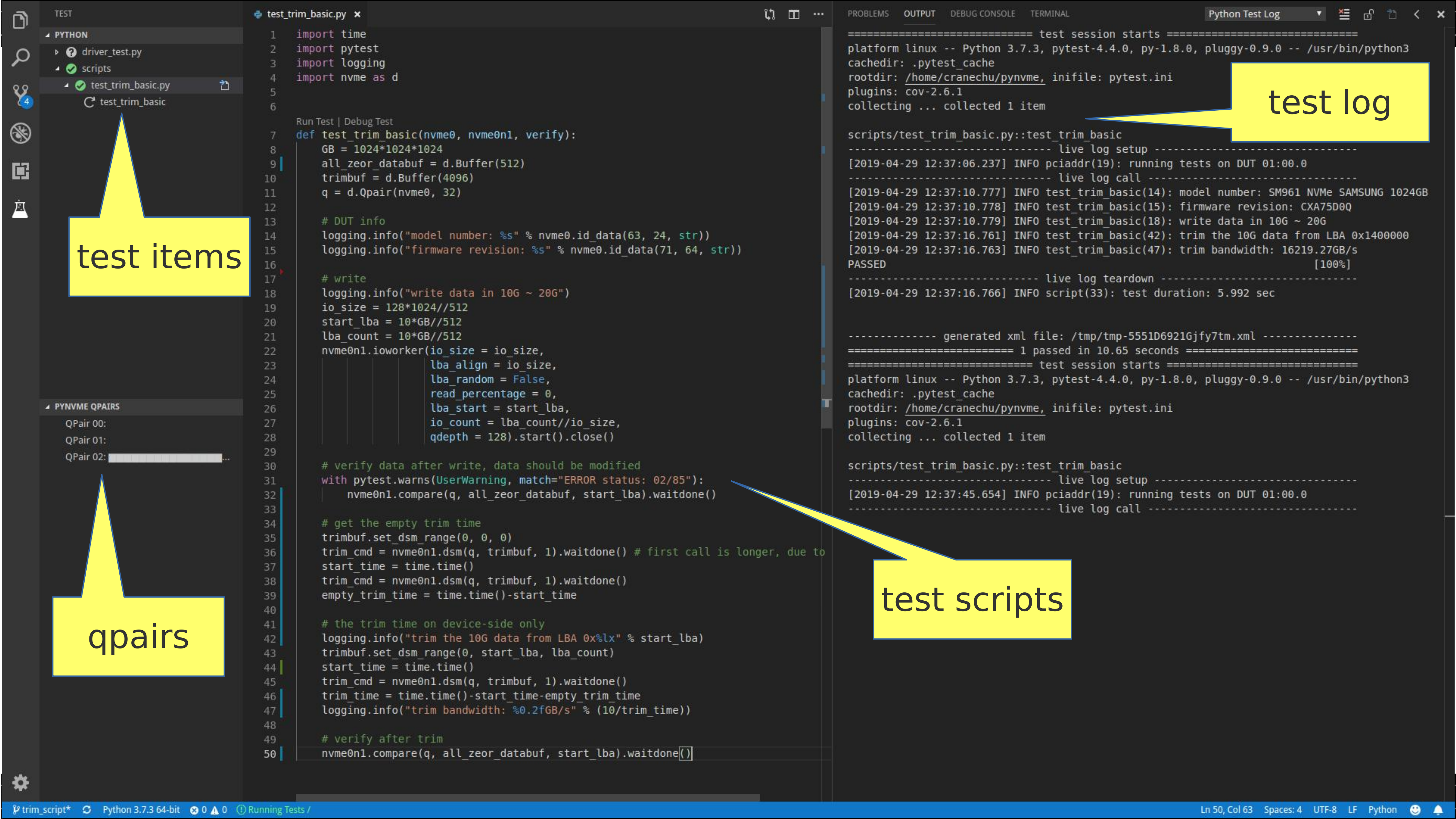
Visual Studio Code

- VSCode is the most popular IDE.
  - root user is not recommended by vscode, so users need to run sudo without a password: *sudo visudo*

- Pynvme also providers an extension to monitor device status and cmdlog in every qpair. To install the extension:
  - *code --install-extension pynvme-console-1.0.0.vsix*

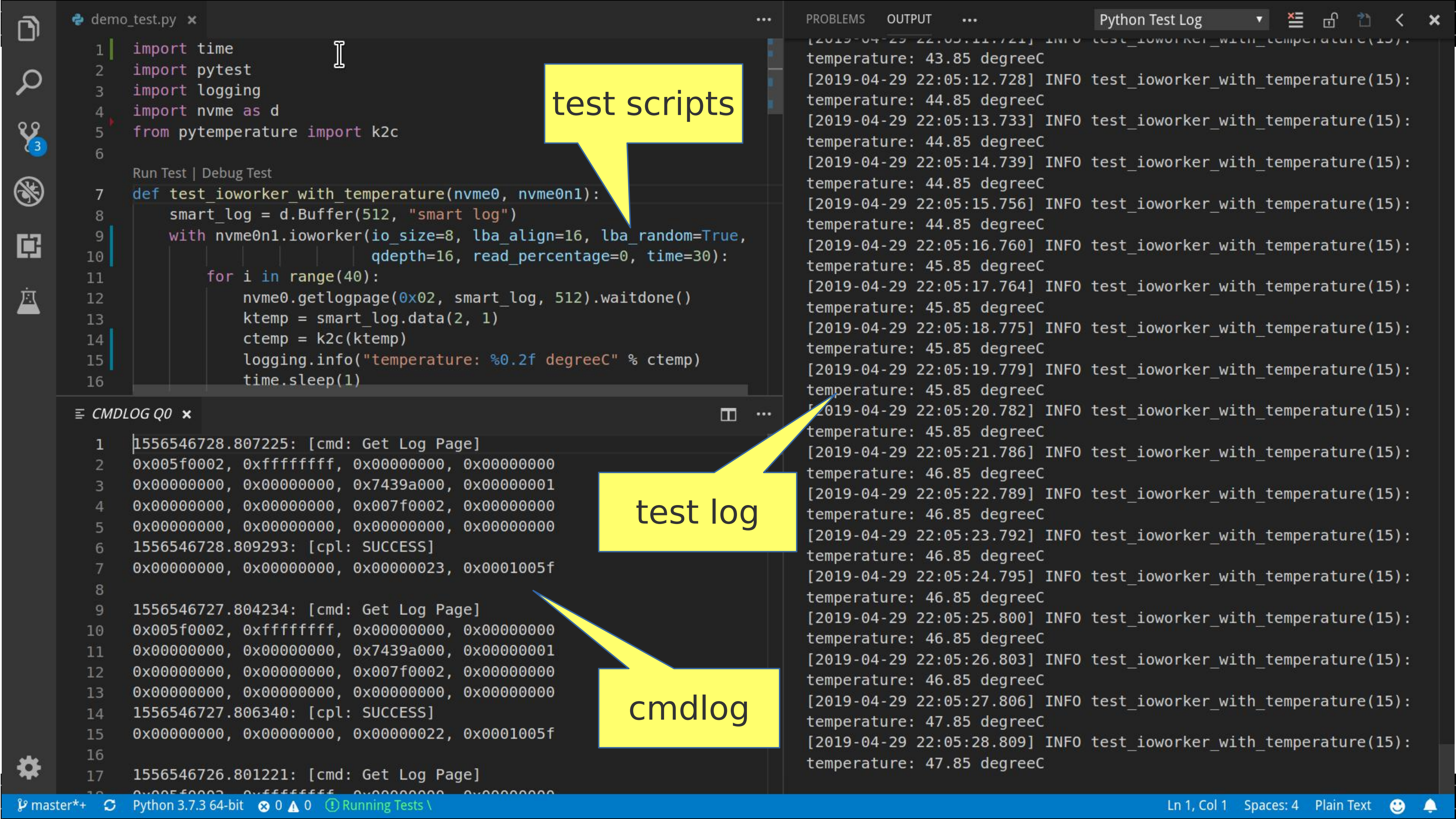
- Add DUT pci address to .vscode/settings.json
  - get the BDF address with *lspci*

- *make setup; code .* # launch the vscode



```python
import time
import pytest
import logging
import nvme as d


def test_trim_basic(nvme0, nvme0n1, verify):
    GB = 1024*1024*1024
    all_zeor_databuf = d.Buffer(512)
    trimbuf = d.Buffer(4096)
    q = d.Qpair(nvme0, 32)

    # DUT info
    logging.info("model number: %s" % nvme0.id_data(63, 24, str))
    logging.info("firmware revision: %s" % nvme0.id_data(71, 64, str))

    # write
    logging.info("write data in 10G ~ 20G")
    io_size = 128*1024//512
    start_lba = 10*GB//512
    lba_count = 10*GB//512
    nvme0n1.ioworker(io_size = io_size,
                     lba_align = io_size,
                     lba_random = False,
                     read_percentage = 0,
                     lba_start = start_lba,
                     io_count = lba_count//io_size,
                     qdepth = 128).start().close()

    # verify data after write, data should be modified
    with pytest.warns(UserWarning, match="ERROR status: 02/85"):
        nvme0n1.compare(q, all_zeor_databuf, start_lba).waitdone()

    # get the empty trim time
    trimbuf.set_dsm_range(0, 0, 0)
    trim_cmd = nvme0n1.dsm(q, trimbuf, 1).waitdone() # first call is longer, due to
    start_time = time.time()
    trim_cmd = nvme0n1.dsm(q, trimbuf, 1).waitdone()
    empty_trim_time = time.time()-start_time

    # the trim time on device-side only
    logging.info("trim the 10G data from LBA 0x%lx" % start_lba)
    trimbuf.set_dsm_range(0, start_lba, lba_count)
    start_time = time.time()
    trim_cmd = nvme0n1.dsm(q, trimbuf, 1).waitdone()
    trim_time = time.time()-start_time-empty_trim_time
    logging.info("trim bandwidth: %0.2fGB/s" % (10/trim_time))

    # verify after trim
    nvme0n1.compare(q, all_zeor_databuf, start_lba).waitdone()
```

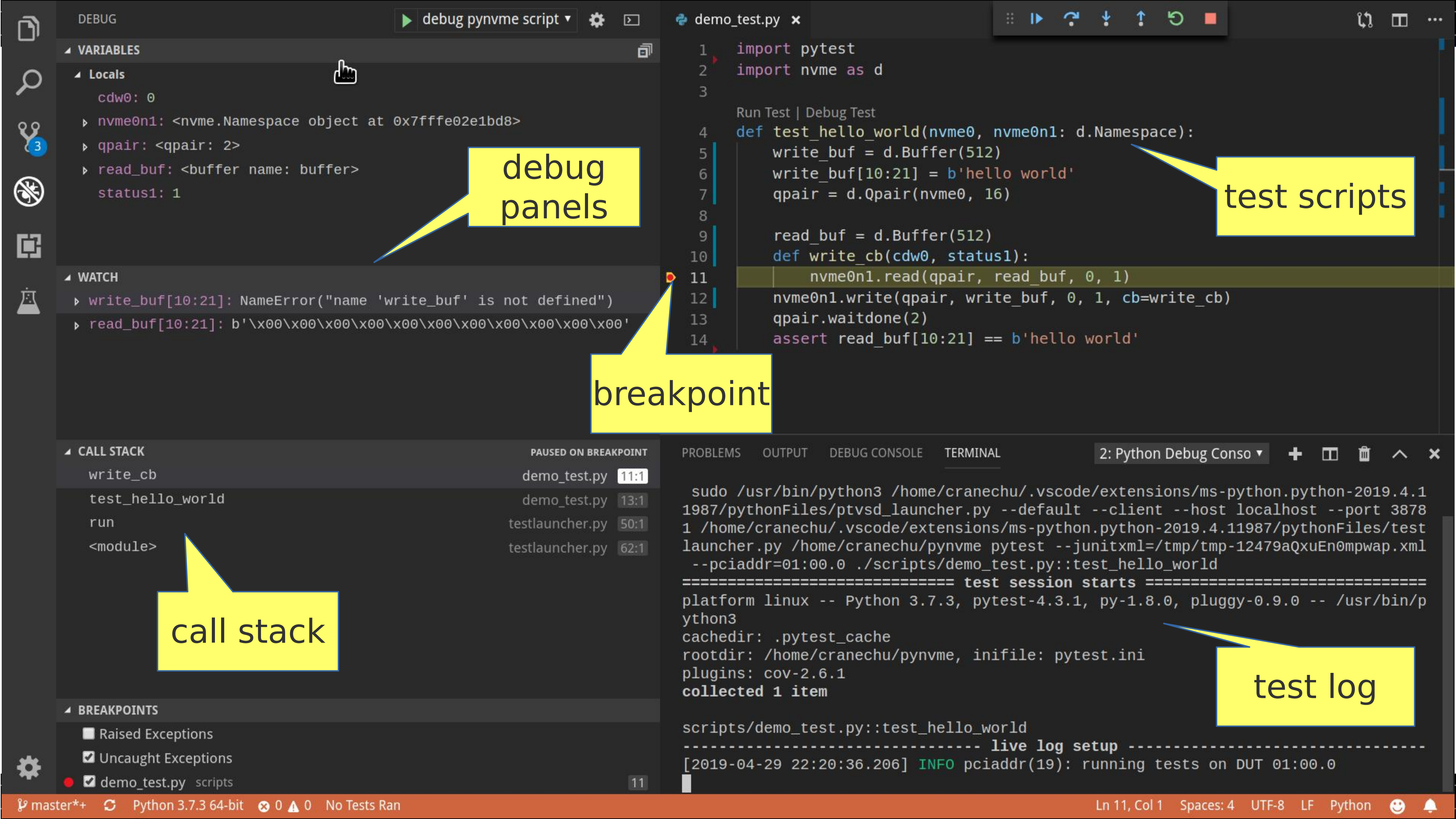
```
============================ test session starts ============================
platform linux -- Python 3.7.3, pytest-4.4.0, py-1.8.0, pluggy-0.9.0 -- /usr/bin/python3
cachedir: .pytest_cache
rootdir: /home/cranechu/pynvme, inifile: pytest.ini
plugins: cov-2.6.1
collecting ... collected 1 item

scripts/test_trim_basic.py::test_trim_basic
-------------------------------- live log setup --------------------------------
[2019-04-29 12:37:06.237] INFO pciaddr(19): running tests on DUT 01:00.0
-------------------------------- live log call ---------------------------------
[2019-04-29 12:37:10.777] INFO test_trim_basic(14): model number: SM961 NVMe SAMSUNG 1024GB
[2019-04-29 12:37:10.778] INFO test_trim_basic(15): firmware revision: CXA75D0Q
[2019-04-29 12:37:10.779] INFO test_trim_basic(18): write data in 10G ~ 20G
[2019-04-29 12:37:16.761] INFO test_trim_basic(42): trim the 10G data from LBA 0x1400000
[2019-04-29 12:37:16.763] INFO test_trim_basic(47): trim bandwidth: 16219.27GB/s
PASSED                                                                    [100%]
------------------------------ live log teardown -------------------------------
[2019-04-29 12:37:16.766] INFO script(33): test duration: 5.992 sec


-------------- generated xml file: /tmp/tmp-5551D6921Gjfy7tm.xml --------------
========================= 1 passed in 10.65 seconds ==========================
============================ test session starts ============================
platform linux -- Python 3.7.3, pytest-4.4.0, py-1.8.0, pluggy-0.9.0 -- /usr/bin/python3
cachedir: .pytest_cache
rootdir: /home/cranechu/pynvme, inifile: pytest.ini
plugins: cov-2.6.1
collecting ... collected 1 item

scripts/test_trim_basic.py::test_trim_basic
-------------------------------- live log setup --------------------------------
[2019-04-29 12:37:45.654] INFO pciaddr(19): running tests on DUT 01:00.0
-------------------------------- live log call ---------------------------------
```



```python
import time
import pytest
import logging
import nvme as d
from pytemperature import k2c

def test_ioworker_with_temperature(nvme0, nvme0n1):
    smart_log = d.Buffer(512, "smart log")
    with nvme0n1.ioworker(io_size=8, lba_align=16, lba_random=True,
                          qdepth=16, read_percentage=0, time=30):
        for i in range(40):
            nvme0.getlogpage(0x02, smart_log, 512).waitdone()
            ktemp = smart_log.data(2, 1)
            ctemp = k2c(ktemp)
            logging.info("temperature: %0.2f degreeC" % ctemp)
            time.sleep(1)
```

```
1556546728.807225: [cmd: Get Log Page]
0x005f0002, 0xffffffff, 0x00000000, 0x00000000
0x00000000, 0x00000000, 0x7439a000, 0x00000001
0x00000000, 0x00000000, 0x007f0002, 0x00000000
0x00000000, 0x00000000, 0x00000000, 0x00000000
1556546728.809293: [cpl: SUCCESS]
0x00000000, 0x00000000, 0x00000023, 0x0001005f

1556546727.804234: [cmd: Get Log Page]
0x005f0002, 0xffffffff, 0x00000000, 0x00000000
0x00000000, 0x00000000, 0x7439a000, 0x00000001
0x00000000, 0x00000000, 0x007f0002, 0x00000000
0x00000000, 0x00000000, 0x00000000, 0x00000000
1556546727.806340: [cpl: SUCCESS]
0x00000000, 0x00000000, 0x00000022, 0x0001005f

1556546726.801221: [cmd: Get Log Page]
```

```
temperature: 43.85 degreeC
[2019-04-29 22:05:12.728] INFO test_ioworker_with_temperature(15):
temperature: 44.85 degreeC
[2019-04-29 22:05:13.733] INFO test_ioworker_with_temperature(15):
temperature: 44.85 degreeC
[2019-04-29 22:05:14.739] INFO test_ioworker_with_temperature(15):
temperature: 44.85 degreeC
[2019-04-29 22:05:15.756] INFO test_ioworker_with_temperature(15):
temperature: 44.85 degreeC
[2019-04-29 22:05:16.760] INFO test_ioworker_with_temperature(15):
temperature: 45.85 degreeC
[2019-04-29 22:05:17.764] INFO test_ioworker_with_temperature(15):
temperature: 45.85 degreeC
[2019-04-29 22:05:18.775] INFO test_ioworker_with_temperature(15):
temperature: 45.85 degreeC
[2019-04-29 22:05:19.779] INFO test_ioworker_with_temperature(15):
temperature: 45.85 degreeC
[2019-04-29 22:05:20.782] INFO test_ioworker_with_temperature(15):
temperature: 45.85 degreeC
[2019-04-29 22:05:21.786] INFO test_ioworker_with_temperature(15):
temperature: 46.85 degreeC
[2019-04-29 22:05:22.789] INFO test_ioworker_with_temperature(15):
temperature: 46.85 degreeC
[2019-04-29 22:05:23.792] INFO test_ioworker_with_temperature(15):
temperature: 46.85 degreeC
[2019-04-29 22:05:24.795] INFO test_ioworker_with_temperature(15):
temperature: 46.85 degreeC
[2019-04-29 22:05:25.800] INFO test_ioworker_with_temperature(15):
temperature: 46.85 degreeC
[2019-04-29 22:05:26.803] INFO test_ioworker_with_temperature(15):
temperature: 46.85 degreeC
[2019-04-29 22:05:27.806] INFO test_ioworker_with_temperature(15):
temperature: 47.85 degreeC
[2019-04-29 22:05:28.809] INFO test_ioworker_with_temperature(15):
temperature: 47.85 degreeC
```



```
cdw0: 0
nvme0n1: <nvme.Namespace object at 0x7fffe02e1bd8>
qpair: <qpair: 2>
read_buf: <buffer name: buffer>
status1: 1
```

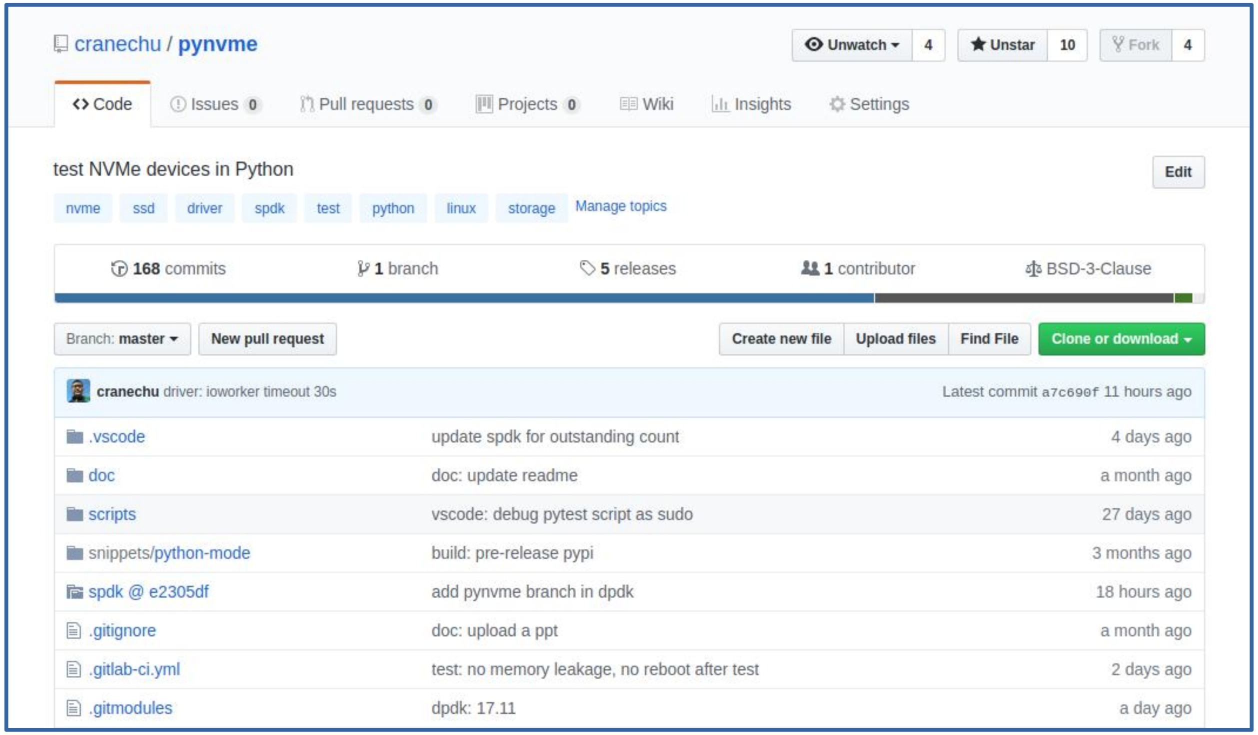
```
write_buf[10:21]: NameError("name 'write_buf' is not defined")
read_buf[10:21]: b'\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00'
```

```
write_cb            demo_test.py   11:1
test_hello_world    demo_test.py   13:1
run                 testlauncher.py  50:1
<module>            testlauncher.py  62:1
```

```python
import pytest
import nvme as d

def test_hello_world(nvme0, nvme0n1: d.Namespace):
    write_buf = d.Buffer(512)
    write_buf[10:21] = b'hello world'
    qpair = d.Qpair(nvme0, 16)

    read_buf = d.Buffer(512)
    def write_cb(cdw0, status1):
        nvme0n1.read(qpair, read_buf, 0, 1)
    nvme0n1.write(qpair, write_buf, 0, 1, cb=write_cb)
    qpair.waitdone(2)
    assert read_buf[10:21] == b'hello world'
```

```
 sudo /usr/bin/python3 /home/cranechu/.vscode/extensions/ms-python.python-2019.4.1
1987/pythonFiles/ptvsd_launcher.py --default --client --host localhost --port 3878
1 /home/cranechu/.vscode/extensions/ms-python.python-2019.4.11987/pythonFiles/test
launcher.py /home/cranechu/pynvme pytest --junitxml=/tmp/tmp-12479aQxuEn0mpwap.xml
 --pciaddr=01:00.0 ./scripts/demo_test.py::test_hello_world
============================== test session starts ===============================
platform linux -- Python 3.7.3, pytest-4.3.1, py-1.8.0, pluggy-0.9.0 -- /usr/bin/p
ython3
cachedir: .pytest_cache
rootdir: /home/cranechu/pynvme, inifile: pytest.ini
plugins: cov-2.6.1
collected 1 item

scripts/demo_test.py::test_hello_world
-------------------------------- live log setup ---------------------------------
[2019-04-29 22:20:36.206] INFO pciaddr(19): running tests on DUT 01:00.0
```

pynvme is OPEN


cranechu / pynvme

test NVMe devices in Python

nvme ssd driver spdk test python linux storage Manage topics

168 commits · 1 branch · 5 releases · 1 contributor · BSD-3-Clause

cranechu driver: ioworker timeout 30s — Latest commit a7c690f 11 hours ago

.vscode	update spdk for outstanding count	4 days ago
doc	doc: update readme	a month ago
scripts	vscode: debug pytest script as sudo	27 days ago
snippets/python-mode	build: pre-release pypi	3 months ago
spdk @ e2305df	add pynvme branch in dpdk	18 hours ago
.gitignore	doc: upload a ppt	a month ago
.gitlab-ci.yml	test: no memory leakage, no reboot after test	2 days ago
.gitmodules	dpdk: 17.11	a day ago

https://github.com/cranechu/pynvme