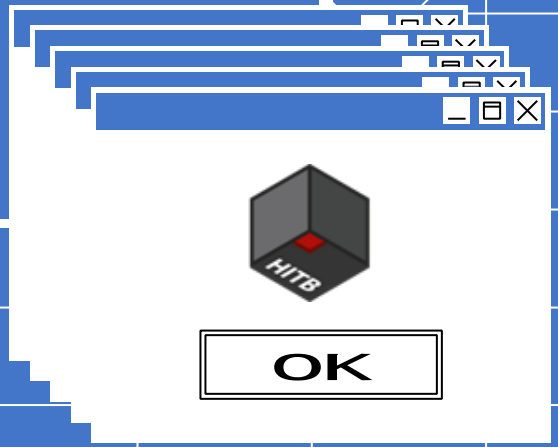
NVMe: New Vulnerabilities Made easy



Tal Lossos

Security Researcher
@CyberArk Labs

OS Internals :)

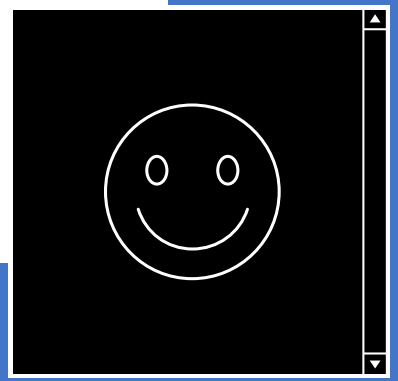
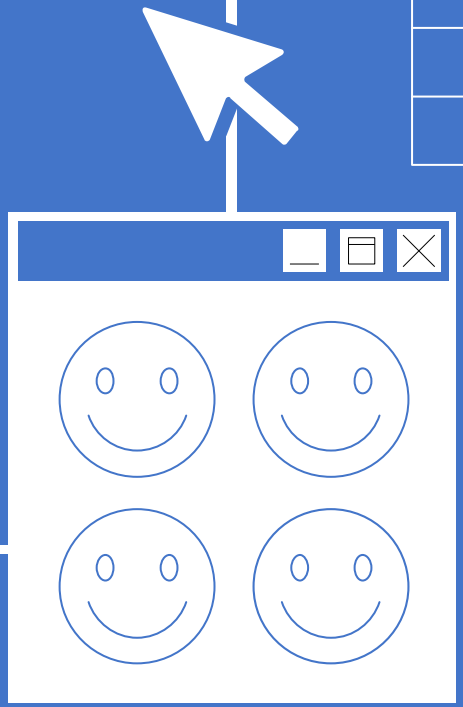


TABLE OF CONTENTS

01

Open-Source VR

Methodologies & More



Open Source Research

Source code

Easier to understand than by reversing

Static analysis

Write/Use tools for low-hanging-fruits

Debugging

Run it & debug on our machine!

Re-compiling

Adding debug snippets

Open Source “disadvantages”

Bug Bounty

Less (if at all)
than closed source

Overwhelming

So much code X.X

STRATEGY

STEP 1

Find code target

STEP 2

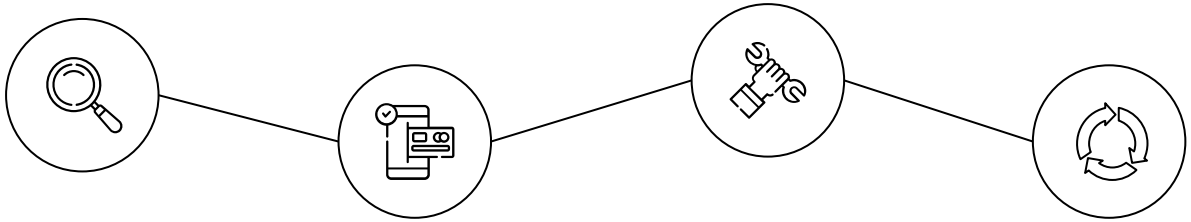
Static Analysis

STEP 3

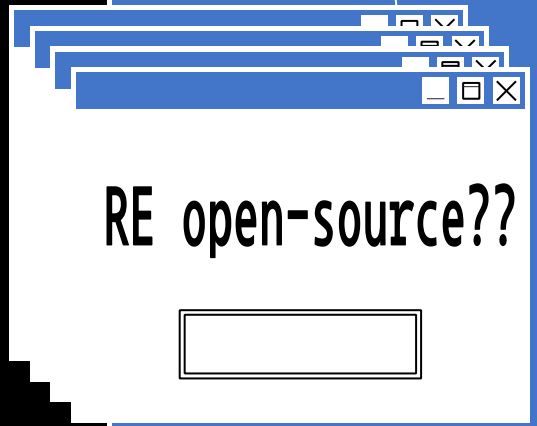
Compile, Build & Execute

STEP 4

Repeat (& consider fuzzing)

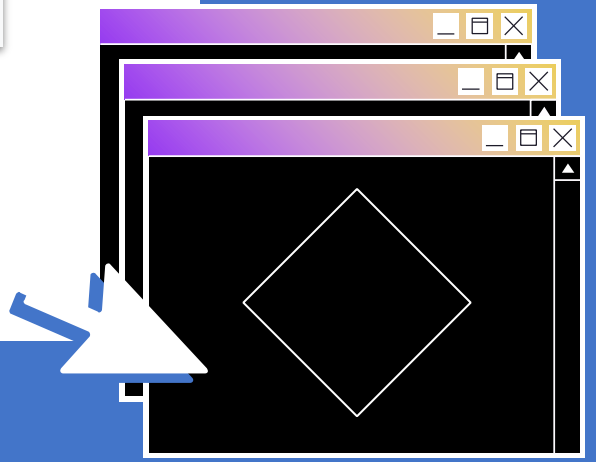


Reverse Engineering



Reverse Engineering

```
memcpy(to, from, size);
```



CVE-2022-29021

```
struct razer_report razer_chroma_extended_matrix_set_custom_frame2(
unsigned char row_index, unsigned char start_col, unsigned char stop_col, unsigned char *rgb_data, size_t packetLength)
{
    const size_t row_length = (size_t) (((stop_col + 1) - start_col) * 3);
    const size_t data_length = (packetLength != 0) ? packetLength : row_length + 5;
    struct razer_report report = get_razer_report(0x0F, 0x03, data_length);
    // ...
    memcpy(&report.arguments[5], rgb_data, row_length);

    return report;
}
```

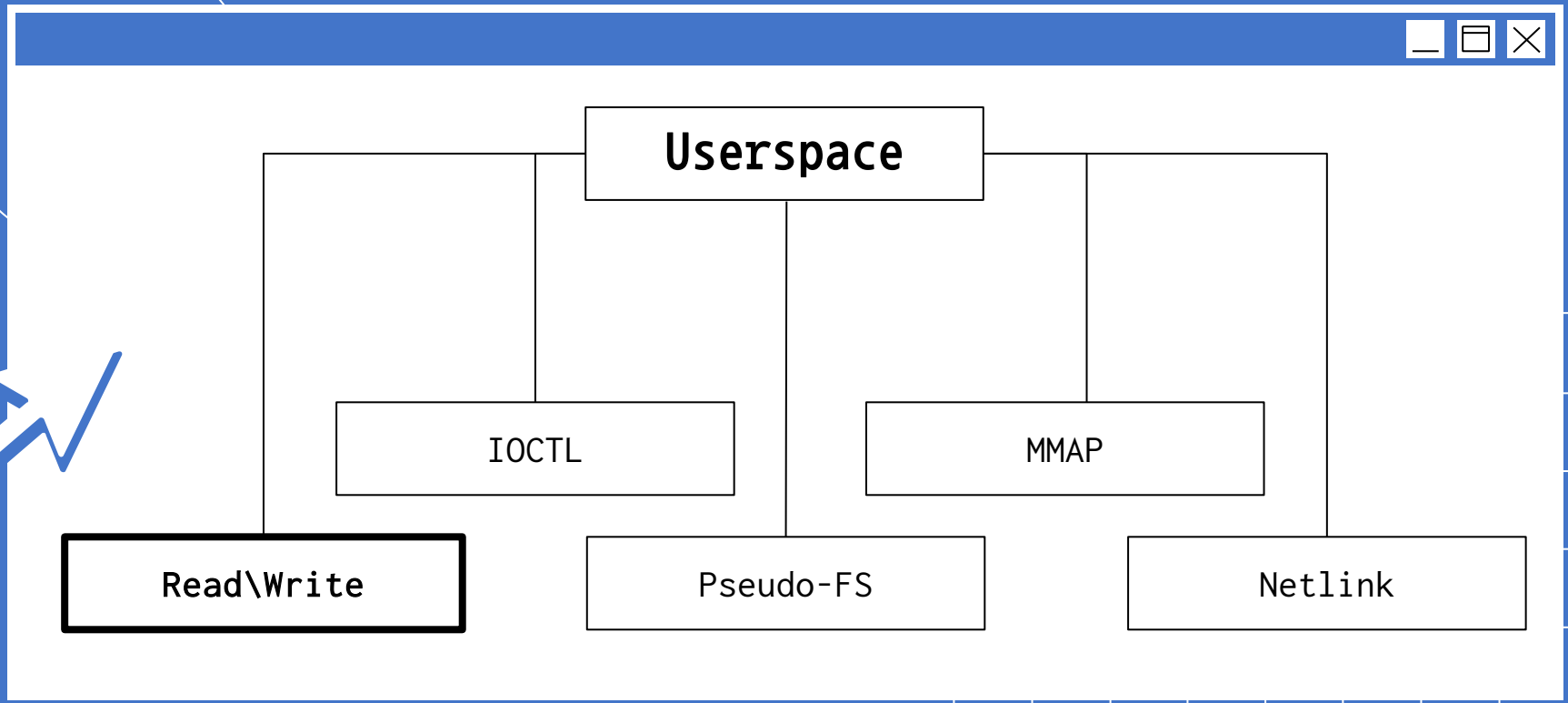
```
get_razer_report(&report, 0xFu, 3u, data_length);
report.transaction_id.id = 63;
report.arguments[2] = row_index;
report.arguments[3] = l_start_col;
report.arguments[4] = l_stop_col;
if ( row_length >= 8 )
{
  *(_QWORD *)&report.arguments[5] = *l2_rgb_data;
  *(_QWORD *)(&report.data_size + row_length) = *(_QWORD *)((char *)l2_rgb_data + row_length - 8);
  qmemcpy(&report.arguments[10], (char *)l2_rgb_data + 5, 8 * ((row_length - 5) >> 3));
}
```

FORTIFY_SOURCE

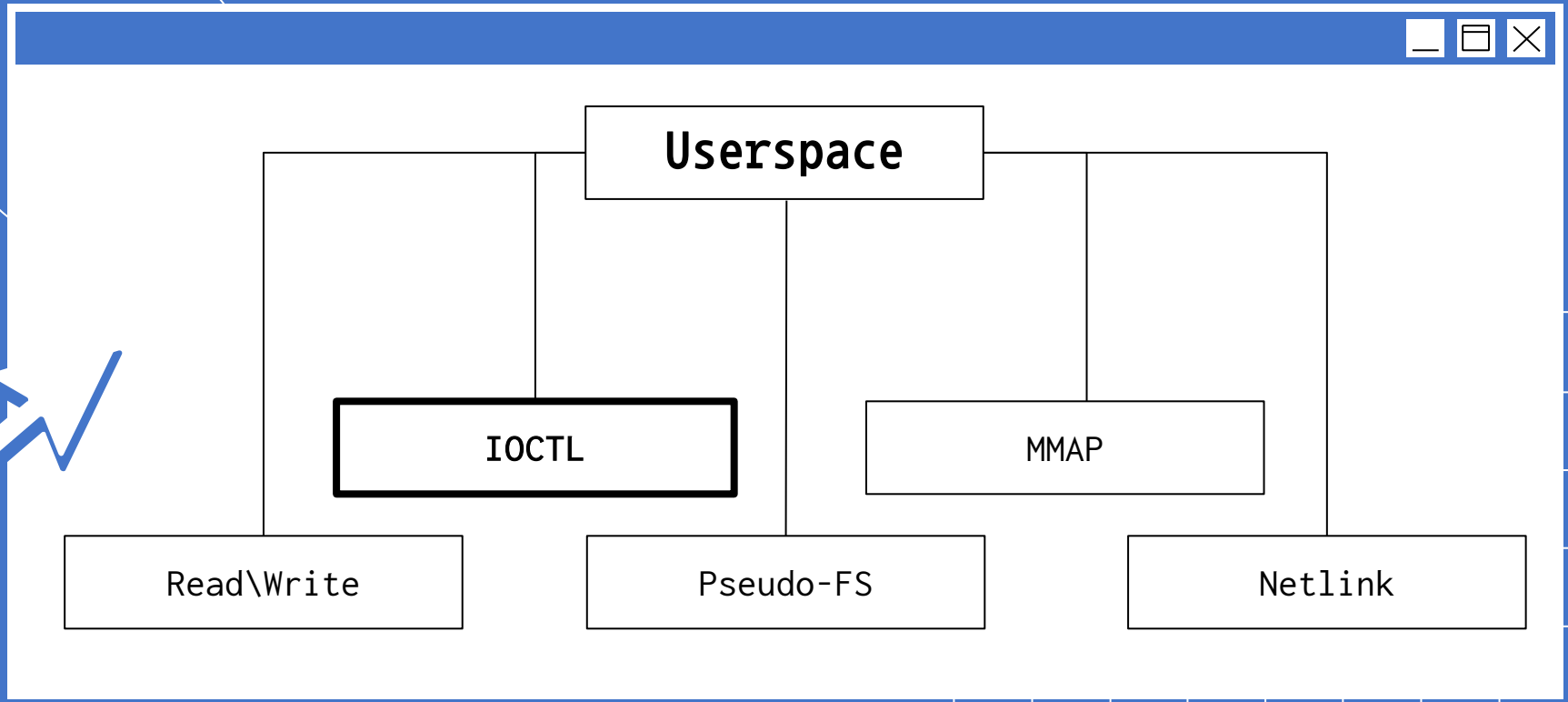
```
get_razer_report(&report, 0xFu, 3u, data_length);
report.transaction_id.id = 63;
report.arguments[2] = row_index;
report.arguments[3] = l_start_col;
report.arguments[4] = l_stop_col;
if ( row_length > 0x4D )
  return razer_chroma_extended_matrix_set_custom_frame2_cold();
if ( row_length >= 8 )
{
  *&report.arguments[5] = *l2_rgb_data;
  *(&report.data_size + row_length) = *(l2_rgb_data + row_length - 8);
  qmemcpy(&report.arguments[10], l2_rgb_data + 5, 8 * ((row_length - 5) >> 3));
}
```

“ Dumb ” Fuzzing?

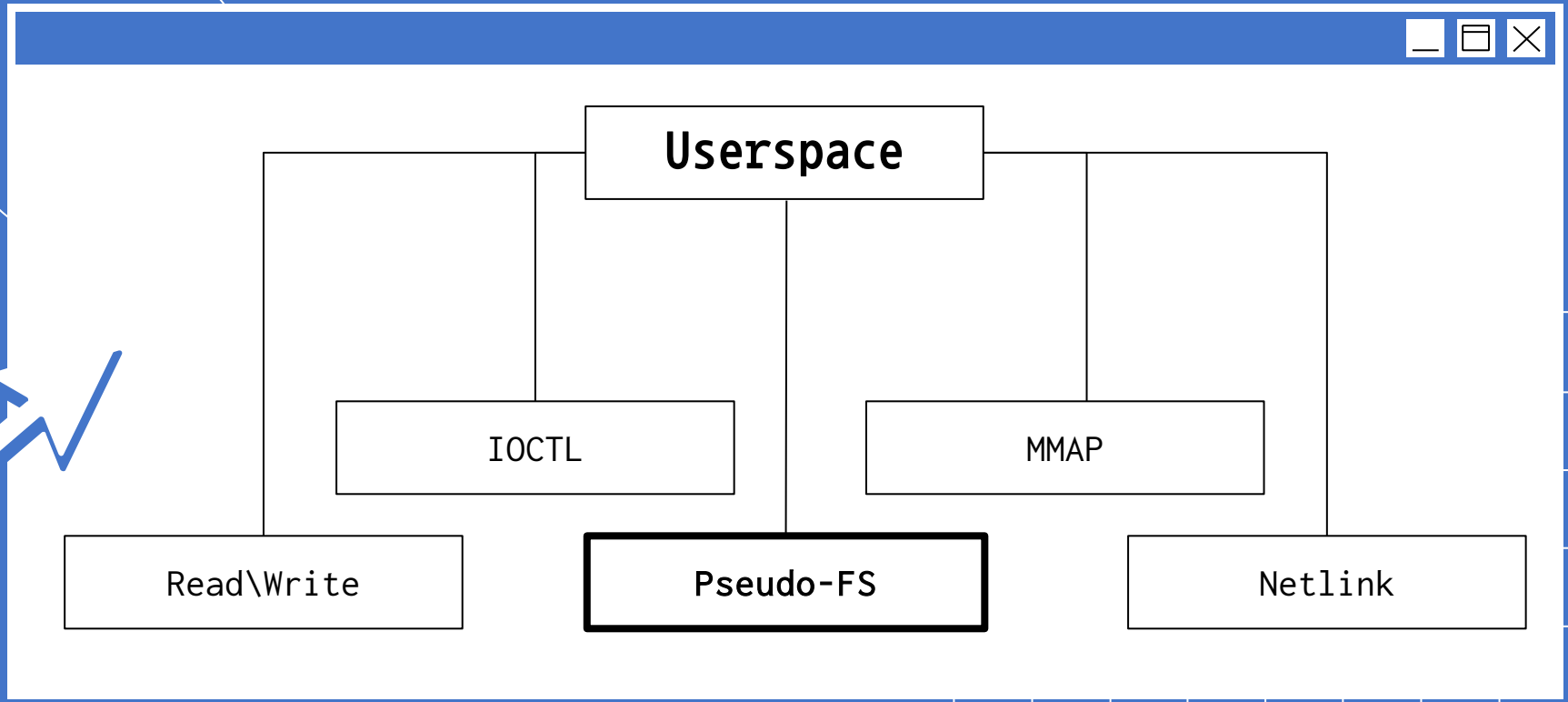
Linux kernel communication



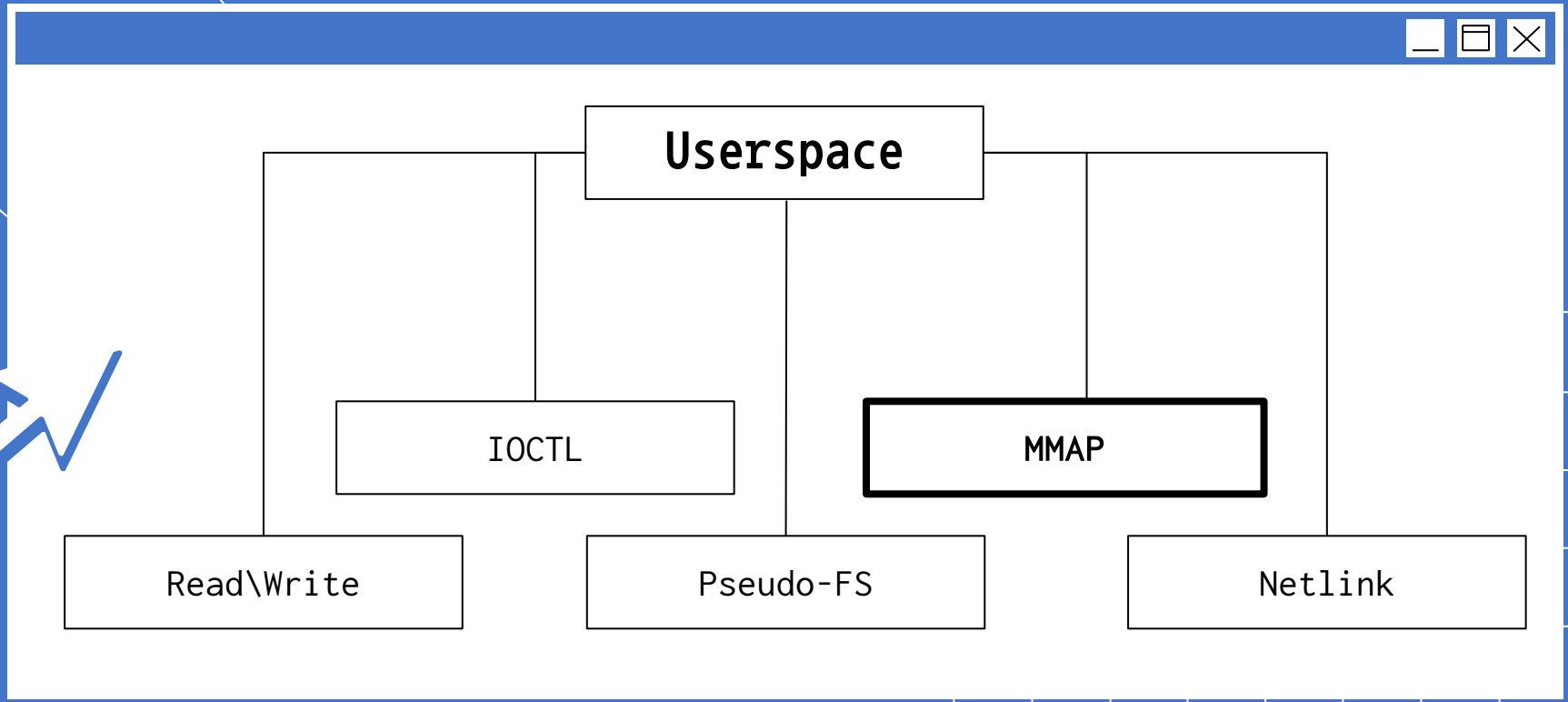
Linux kernel communication



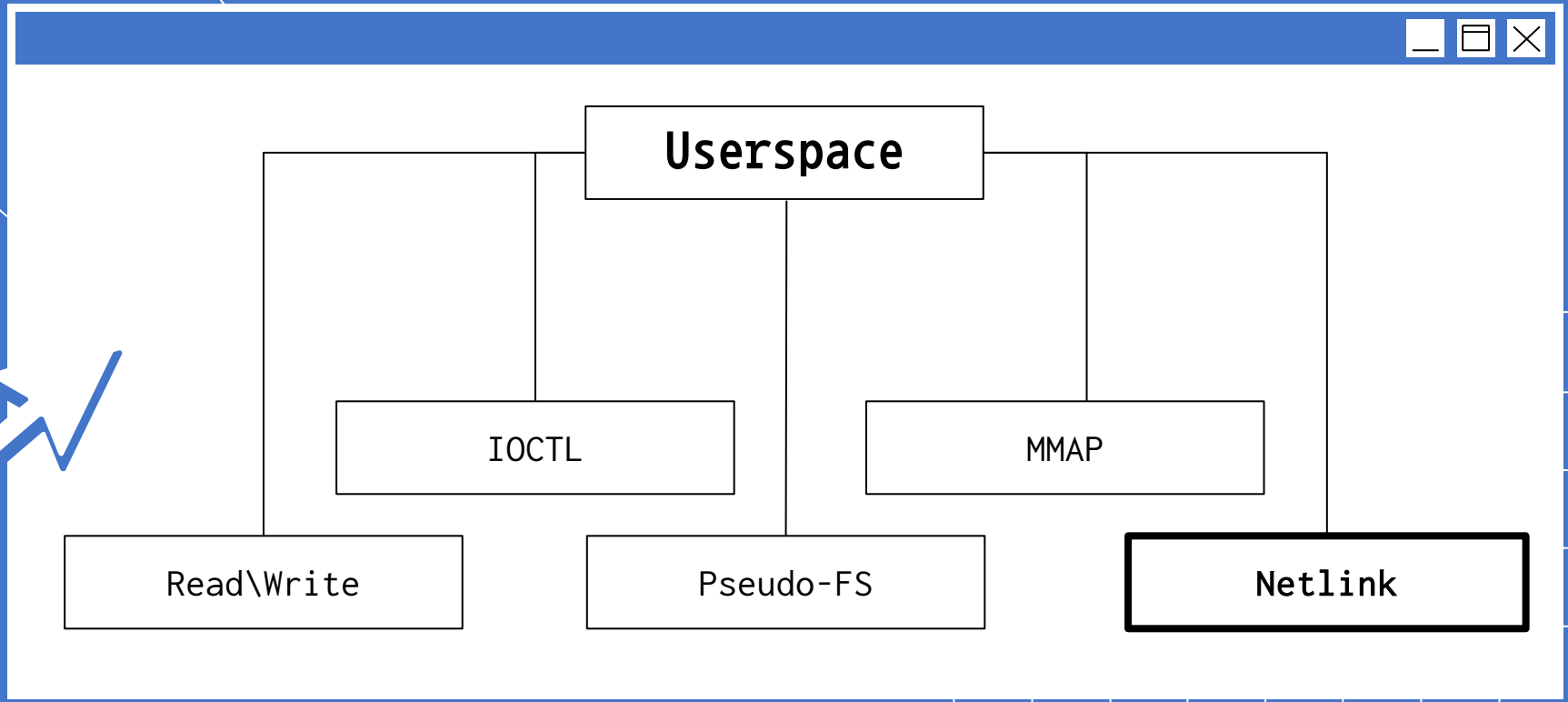
Linux kernel communication



Linux kernel communication



Linux kernel communication



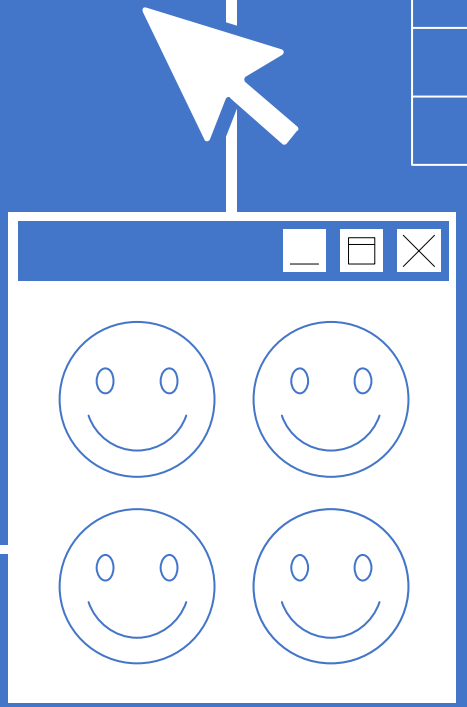
Example - CVE-2022-29021

```
files = list(Path(path).rglob('matrix*'))

def fuzzer(max_length: int = 100, char_start: int = 32, char_range: int = 32) -> str:
    string_length = random.randrange(0, max_length + 1)
    out = ""
    for i in range(0, string_length):
        out += chr(random.randrange(char_start, char_start + char_range))
    return bytes(out, "utf-8")

while True:
    f = random.choice(files)
    i = fuzzer()
    print(f'trying file - {f}, input - {i}')
    with open(f, 'wb') as ff:
        ff.write(i)
```

02

SCA

Yes, Static code Analysis



“SCA commonly refers to the running of tools that attempt to highlight possible vulnerabilities within the source-code”

—OWASP

Available tools

C/CPP

Clang
cppcheck

Python

Pylint
Mypy

JS

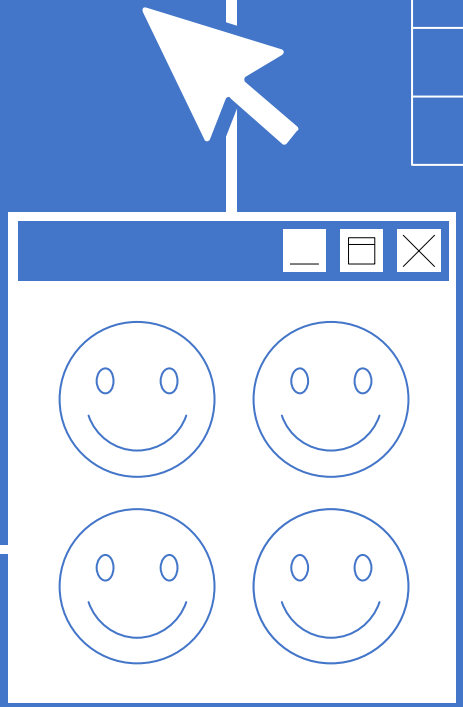
ESLint
JSLint

CodeQL

03

SCA vs Kernel

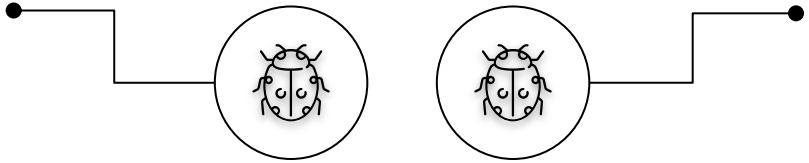
The Linux kernel, ofc.



Memory Corruption Bugs

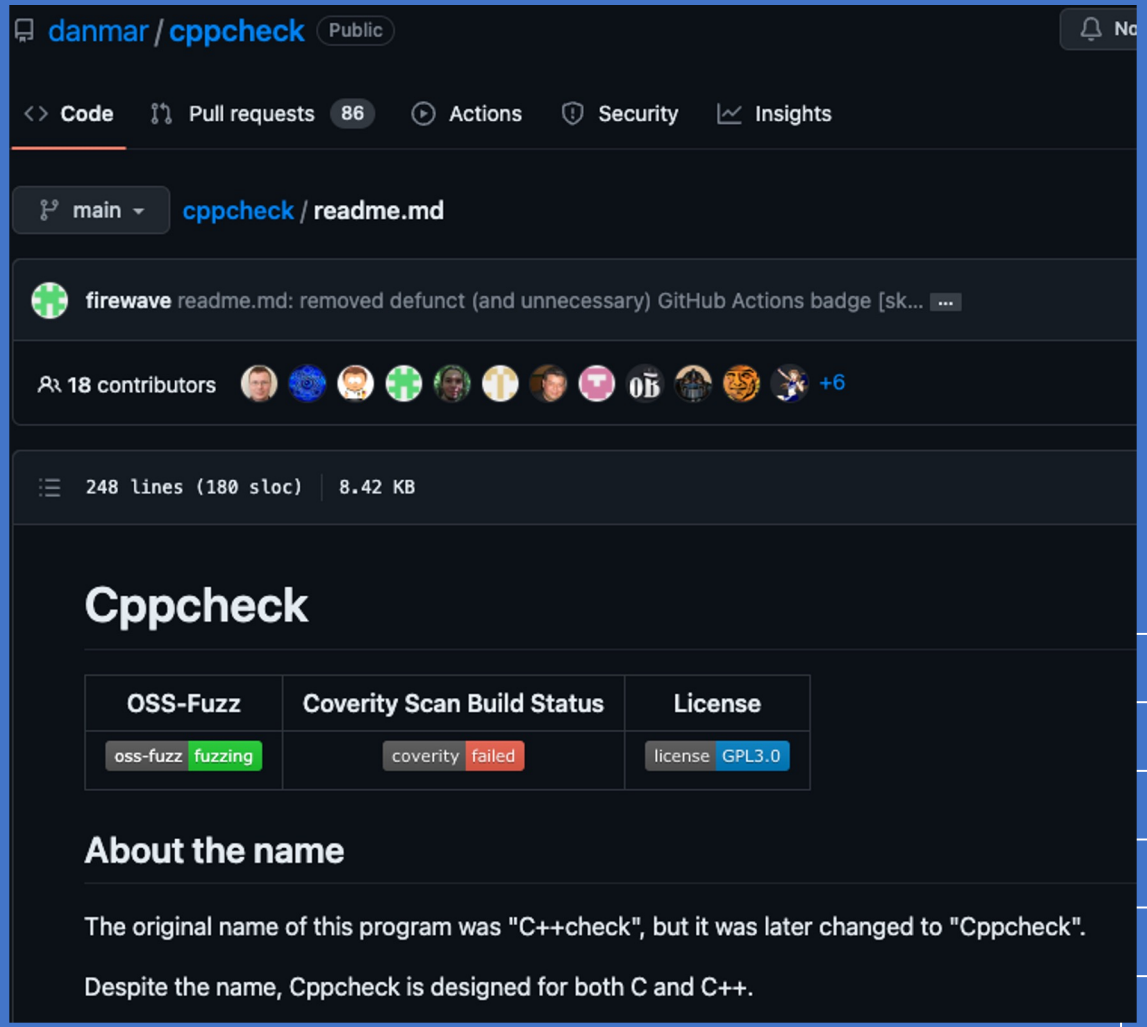
Buffer Overflow / Underflow

Integer Overflow / Underflow



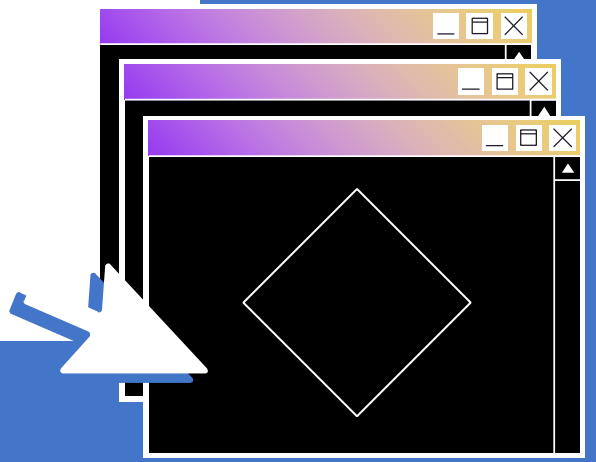
Null PTR Dereference

Uninitialized variables


danmar / cppcheck
Public
Code
Pull requests 86
Actions
Security
Insights
main
cppcheck / readme.md
firewave readme.md: removed defunct (and unnecessary) GitHub Actions badge [sk...
18 contributors
+6
248 lines (180 sloc)
8.42 KB
Cppcheck
OSS-Fuzz
Coverity Scan Build Status
License
oss-fuzz fuzzing
coverity failed
license GPL3.0
About the name
The original name of this program was "C++check", but it was later changed to "Cppcheck".
Despite the name, Cppcheck is designed for both C and C++.

cppcheck

```
cppcheck source/XXX.c
```

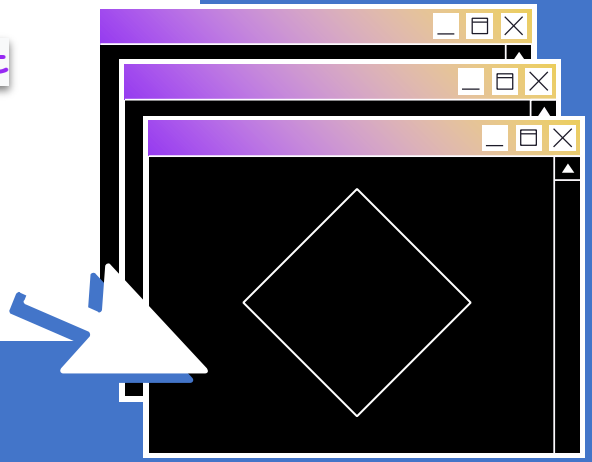


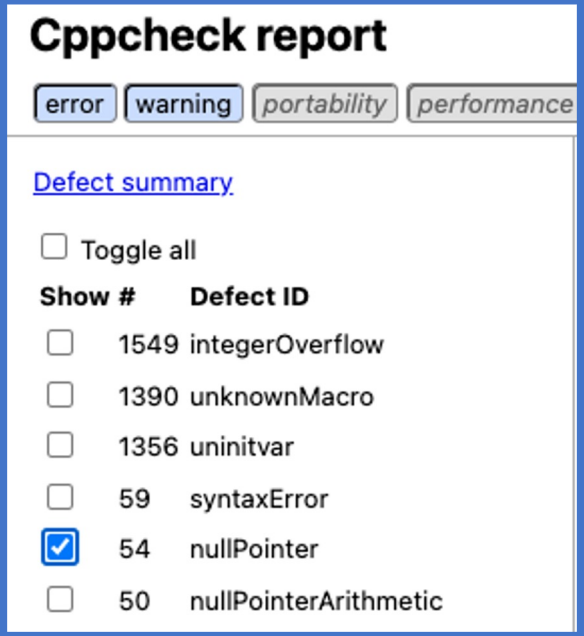
cppcheck

```
./cppcheck source/XXX.c –xml 2>check.xml
```

```
htmlreport/cppcheck-htmlreport –
file=check.xml –report-dir=check_report
```

```
firefox check_report/index.html
```




Cppcheck report
error
warning
portability
performance
Defect summary
Toggle all
Show #
Defect ID
1549 integerOverflow
1390 unknownMacro
1356 uninitvar
59 syntaxError
54 nullPointer
50 nullPointerArithmetic

../linux/drivers/nvme/target/auth.c

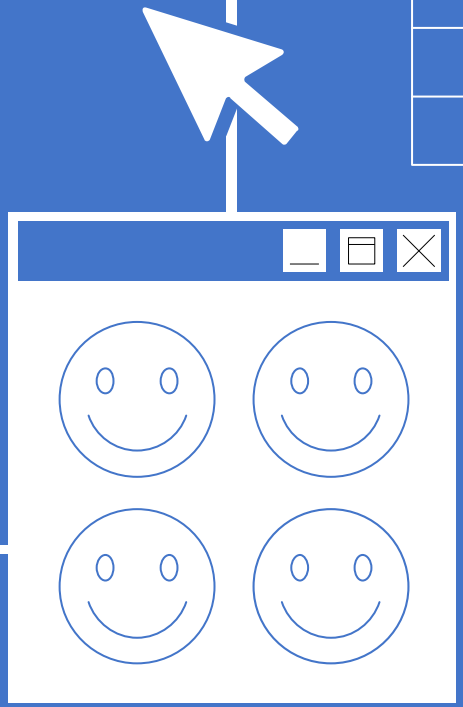
201	nullPointer	476	warning	Possible null pointer dereference: ctrl->ctrl_key

```
ctrl->ctrl_key = nvme_auth_extract_key(host->dhchap_ctrl_secret + 10,
                                       host->dhchap_ctrl_key_hash);
if (IS_ERR(ctrl->ctrl_key)) {
        ret = PTR_ERR(ctrl->ctrl_key);
        ctrl->ctrl_key = NULL; <--- Assignment 'ctrl->ctrl_key=NULL', assigned value is 0
}
pr_debug("%s: using ctrl hash %s key %*ph\n", __func__,
         ctrl->ctrl_key->hash > 0 ? <--- Null pointer dereference
         nvme_auth_hmac_name(ctrl->ctrl_key->hash) : "none",
         (int)ctrl->ctrl_key->len, ctrl->ctrl_key->key);
```

04

Hunting for Bugs

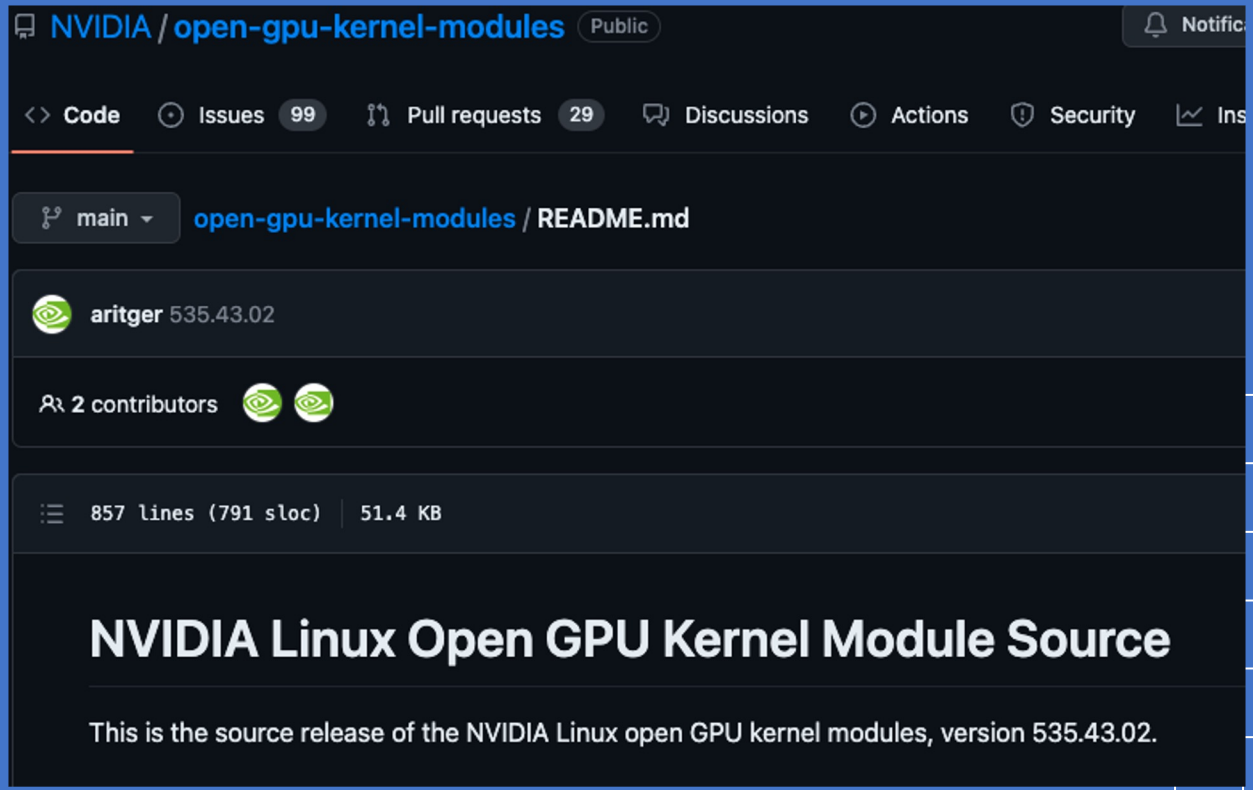
(using SCA)



SCA failed attempt

```
struct razer_report razer_chroma_extended_matrix_set_custom_frame2(
unsigned char row_index, unsigned char start_col, unsigned char stop_col, unsigned char *rgb_data, size_t packetLength)
{
    const size_t row_length = (size_t) (((stop_col + 1) - start_col) * 3);
    const size_t data_length = (packetLength != 0) ? packetLength : row_length + 5;
    struct razer_report report = get_razer_report(0x0F, 0x03, data_length);
    // ...
    memcpy(&report.arguments[5], rgb_data, row_length);

    return report;
}
```

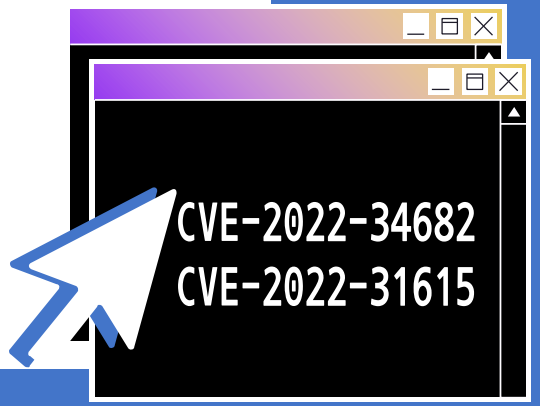
NVidia open-source drivers



Nvidia vulnerabilities

```
void NV_API_CALL nv_acpi_methods_uninit(void)
{
    struct acpi_device *device = NULL;
```

```
#if defined(NV_ACPI_BUS_GET_DEVICE_PRESENT)
    acpi_bus_get_device(nvif_parent_gpu_handle, &device);

    nv_uninstall_notifier(device->driver_data, nv_acpi_event);
#endif

    device->driver_data = NULL;
    nvif_parent_gpu_handle = NULL;

    return;
```



```c
int acpi_bus_get_device(acpi_handle handle, struct acpi_device **device)
{
        return acpi_get_device_data(handle, device, NULL);
}
```

```c
static int acpi_get_device_data(acpi_handle handle, struct acpi_device **device,
                                void (*callback)(void *))
{
        acpi_status status;

        if (!device)
                return -EINVAL;

        *device = NULL;

        status = acpi_get_data_full(handle, acpi_scan_drop_device,
                                    (void **)device, callback);
        if (ACPI_FAILURE(status) || !*device) {
                ACPI_DEBUG_PRINT((ACPI_DB_INFO, "No context for object [%p]\n",
                                  handle));
                return -ENODEV;
        }
        return 0;
}
```

Linux kernel

Linus Torvalds Comments On The NTFS Linux Driver Situation

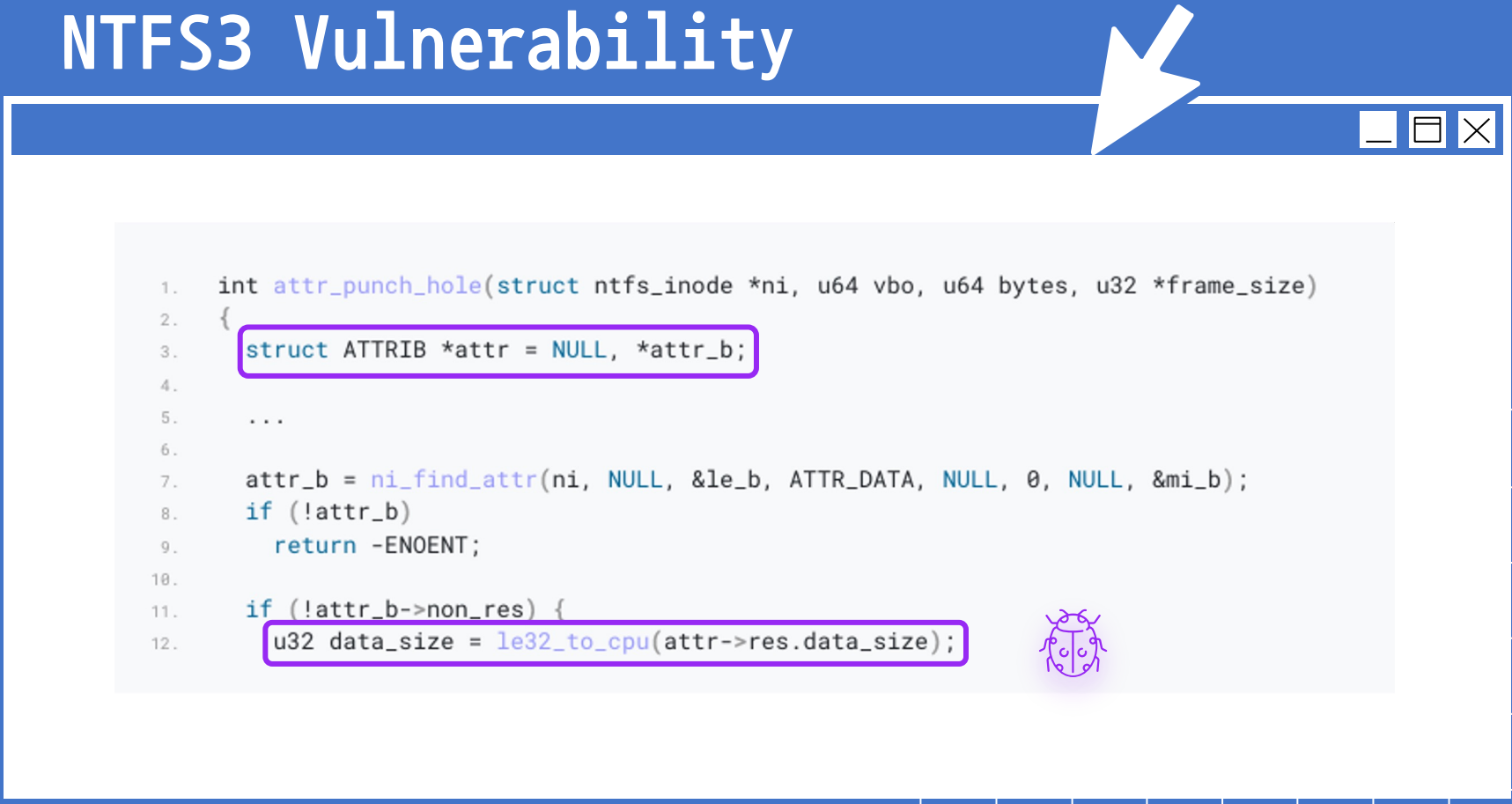
Written by Michael Larabel in Linux Storage on 28 April 2022 at 07:11 AM EDT. 47 Comments

As written about earlier this week, concerns have been raised over the "new" NTFS Linux driver that it's effectively unmaintained already less than one year after being mainlined. Linus Torvalds has since commented on the matter and opens up the door for other developers to maintain it.

NTFS3 Vulnerability

```
1.  int attr_punch_hole(struct ntfs_inode *ni, u64 vbo, u64 bytes, u32 *frame_size)
2.  {
3.    struct ATTRIB *attr = NULL, *attr_b;
4.
5.    ...
6.
7.    attr_b = ni_find_attr(ni, NULL, &le_b, ATTR_DATA, NULL, 0, NULL, &mi_b);
8.    if (!attr_b)
9.      return -ENOENT;
10.
11.   if (!attr_b->non_res) {
12.     u32 data_size = le32_to_cpu(attr->res.data_size);
```

NTFS3 Vulnerability



```
1.  int attr_punch_hole(struct ntfs_inode *ni, u64 vbo, u64 bytes, u32 *frame_size)
2.  {
3.    struct ATTRIB *attr = NULL, *attr_b;
4.
5.    ...
6.
7.    attr_b = ni_find_attr(ni, NULL, &le_b, ATTR_DATA, NULL, 0, NULL, &mi_b);
8.    if (!attr_b)
9.      return -ENOENT;
10.
11.   if (!attr_b->non_res) {
12.     u32 data_size = le32_to_cpu(attr->res.data_size);
```

The Linux Kernel and the Cursed Driver

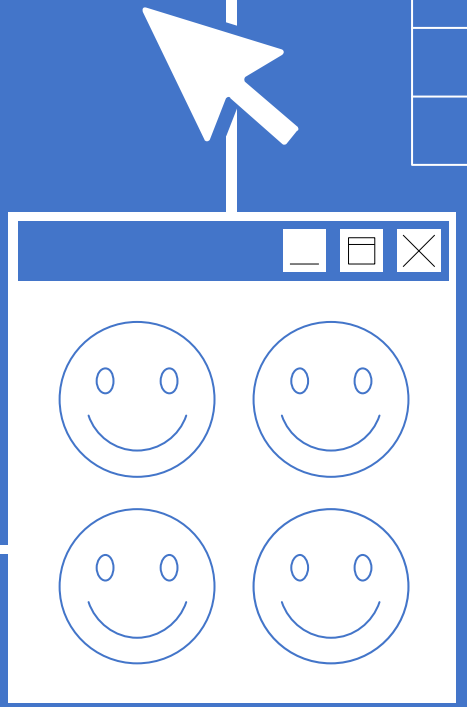
Alon Zahavi | 2/7/23

Share This!

05

NVMe

101 & exploitation



News from the source

nvme: In-band authentication support

From:	Hannes Reinecke <hare-AT-suse.de>
To:	Sagi Grimberg <sagi-AT-grimberg.me>
Subject:	[PATCHv8 00/12] nvme: In-band authentication support
Date:	Thu, 02 Dec 2021 16:23:46 +0100
Message-ID:	<20211202152358.60116-1-hare@suse.de>
Cc:	Christoph Hellwig <hch-AT-lst.de>, Keith Busch <keith.busch-AT-wdc.com>, linux-nvme-AT-lists.infradead.org, linux-crypto-AT-vger.kernel.org, Hannes Reinecke <hare-AT-suse.de>
Archive-link:	Article

../linux/drivers/nvme/target/auth.c

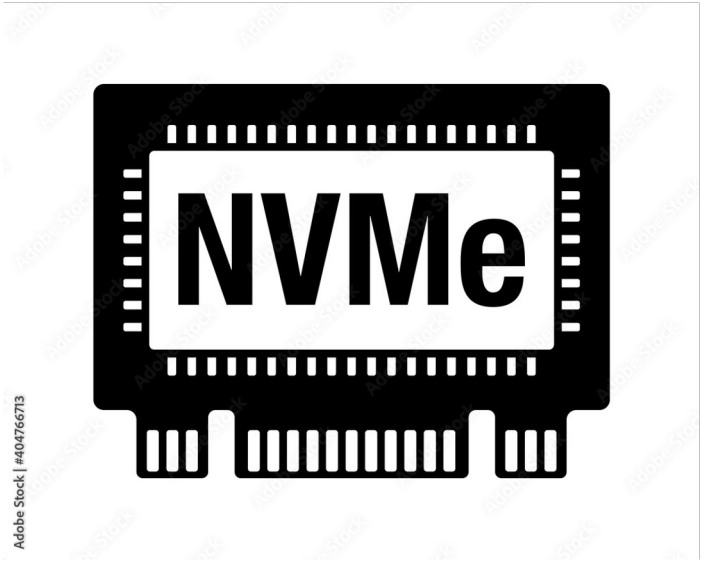
201	nullPointer	476	warning	Possible null pointer dereference: ctrl->ctrl_key

```
ctrl->ctrl_key = nvme_auth_extract_key(host->dhchap_ctrl_secret + 10,
                                       host->dhchap_ctrl_key_hash);
if (IS_ERR(ctrl->ctrl_key)) {
        ret = PTR_ERR(ctrl->ctrl_key);
        ctrl->ctrl_key = NULL;
}
pr_debug("%s: using ctrl hash %s key %*ph\n", __func__,
         ctrl->ctrl_key->hash > 0 ?
         nvme_auth_hmac_name(ctrl->ctrl_key->hash) : "none",
         (int)ctrl->ctrl_key->len, ctrl->ctrl_key->key);
```

```
ctrl->ctrl_key = nvme_auth_extract_key(host->dhchap_ctrl_secret + 10,
                                       host->dhchap_ctrl_key_hash);
if (IS_ERR(ctrl->ctrl_key)) {
        ret = PTR_ERR(ctrl->ctrl_key);
        ctrl->ctrl_key = NULL;
}
pr_debug("%s: using ctrl hash %s key %*ph\n", __func__,
         ctrl->ctrl_key->hash > 0 ?
         nvme_auth_hmac_name(ctrl->ctrl_key->hash) : "none",
         (int)ctrl->ctrl_key->len, ctrl->ctrl_key->key);
```

NVMe 101

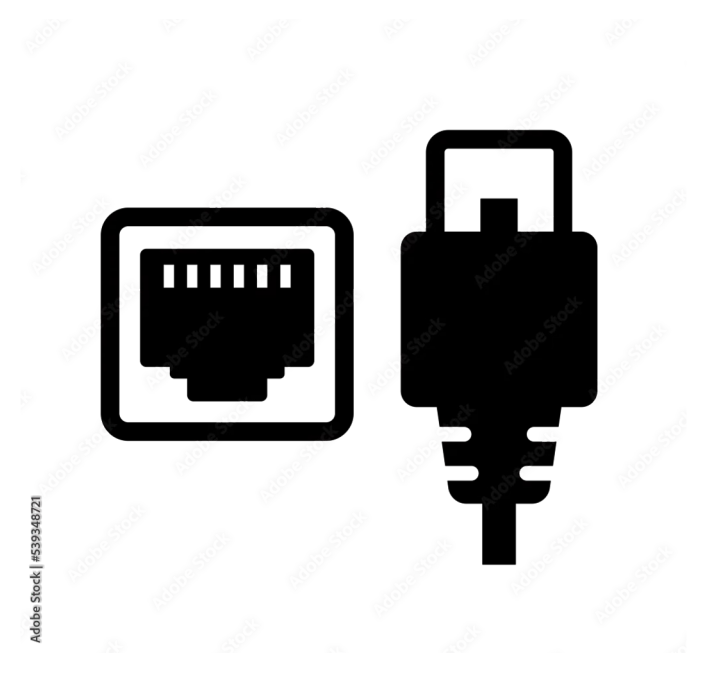
NVMe



NVMe

Nonvolatile Memory Express protocol, a transport protocol for accessing nonvolatile storage media over PCIe.

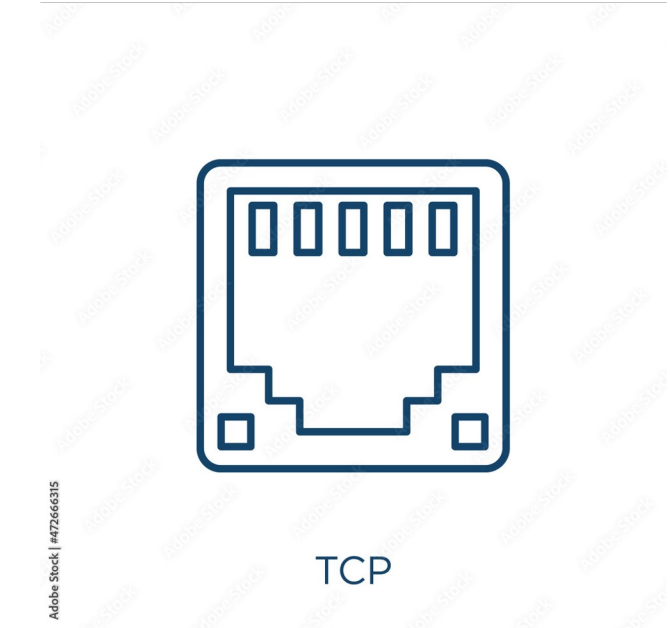
NVMe-oF



NVMe-oF

Extension of NVMe which enables NVMe-based communication over connections other than PCIe, like FC or Ethernet (over fabric).

NVMe-TC



NVMe-TCP

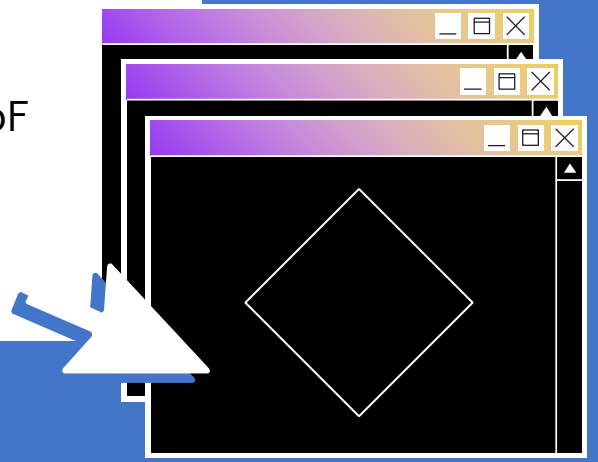
Definition of NVMe-oF for TCP specifically.

NVMeXXX

NVMe - Protocol / Specification

NVMe-oF - Extension of NVMe to allow non-PCIe communication

NVMe-TCP - an implementation of NVMe-oF for TCP

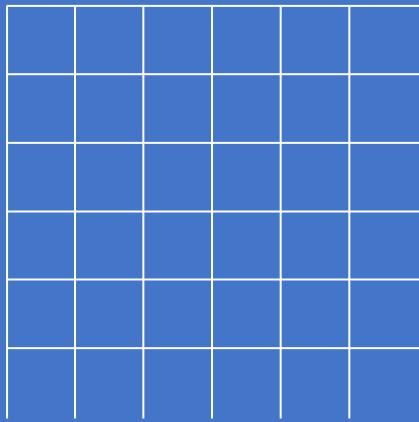


NVMe-where?

Amazon EBS and NVMe on Linux instances

PDF | RSS

EBS volumes are exposed as NVMe block devices on instances built on the Nitro System. The device names are `/dev/nvme0n1`, `/dev/nvme1n1`, and so on. The device names that you specify in a block device mapping are renamed using NVMe device names (`/dev/nvme[0-26]n1`). The block device driver can assign NVMe device names in a different order than you specified for the volumes in the block device mapping.



Amazon EBS and NVMe on Linux instances

PDF | RSS

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Announcing the new Ebsv5 VM sizes offering 2X remote storage performance with NVMe-Public Preview

Microsoft

Amazon EBS and NVMe on Linux instances

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Microsoft

NetApp NVMe solutions: Customer-focused technology leadership

Need help addressing your most stringent SLOs and business challenges? Look no further than our end-to-end NVMe-FC SAN solutions. They deliver the highest throughput and fastest response times yet for your enterprise workloads. And with new NVMe/TCP over traditional ethernet networks, the benefits keep rolling in.

Amazon EBS and NVMe on Linux instances

PDF | RSS

EBS volumes are exposed as NVMe block devices on instances built on the Nitro System. The device names are `/dev/nvme0n1`, `/dev/nvme1n1`, and so on. The device names that you specify in a block device mapping are renamed using NVMe device names (`/dev/nvme[0-26]n1`). The block device driver can assign NVMe device names in a different order than you specified for the volumes in the block device mapping.

Announcing the new Ebsv5 VM sizes offering 2X remote storage performance with NVMe-Public Preview

Microsoft

NetApp NVMe solutions: Customer-focused technology leadership

Need help addressing your most stringent SLOs and business challenges? Look no further than our end-to-end NVMe-FC SAN solutions. They deliver the highest throughput and fastest response times yet for your enterprise workloads. And with new NVMe/TCP over traditional ethernet networks, the benefits keep rolling in.

Linux Driver Information

The Linux NVMe™ driver is open source and included as part of the Linux Kernel, which can be found here https://github.com/torvalds/linux/tree/master/drivers/nvme

NVMe architecture works out of the box in every major operating system, including all mainstream Linux distributions. Please check on specific feature support with the distros, e.g. Red Hat Enterprise Linux, Ubuntu. NVMe technology has been supported since kernel 3.3, and at the time had been backported to 2.6. Intel released some history of the Linux NVMe drivers stack in 2015 here:

Exploitation

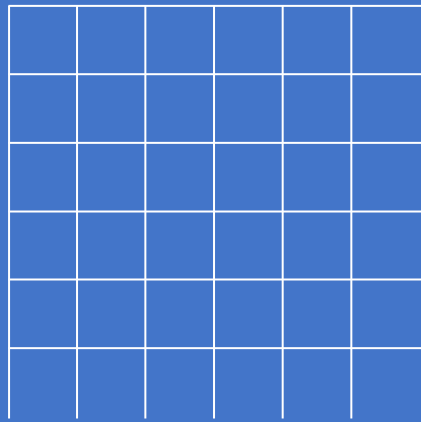
NULL PTR dereference

```
int nvmet_setup_auth(struct nvmet_ctrl *ctrl)
```

```
ctrl->ctrl_key = nvme_auth_extract_key(host->dhchap_ctrl_secret + 10,
                                       host->dhchap_ctrl_key_hash);
if (IS_ERR(ctrl->ctrl_key)) {
        ret = PTR_ERR(ctrl->ctrl_key);
        ctrl->ctrl_key = NULL;
}
pr_debug("%s: using ctrl hash %s key %*ph\n", __func__,
        ctrl->ctrl_key->hash > 0 ?
        nvme_auth_hmac_name(ctrl->ctrl_key->hash) : "none",
        (int)ctrl->ctrl_key->len, ctrl->ctrl_key->key);
```

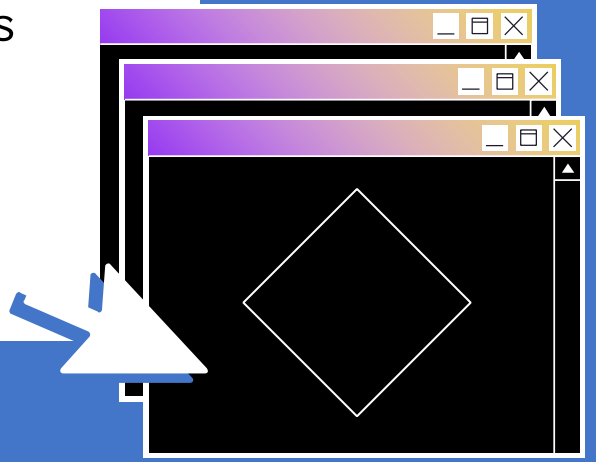
Invalid key

```
key_len = base64_decode(secret, allocated_len, key->key);
if (key_len < 0) {
        pr_debug("base64 key decoding error %d\n",
                 key_len);
        ret = key_len;
        goto out_free_secret;
}

if (key_len != 36 && key_len != 52 &&
    key_len != 68) {
        pr_err("Invalid key len %d\n", key_len);
        ret = -EINVAL;
        goto out_free_secret;
}
```



Exploiting NULL ptr dereference

- **mmap_min_addr** - min allowed address to map
- **SMEP/SMAP** - disable exec/access to userspace from kernel
- **panic_on_oops**



Project Zero

News and updates from the Project Zero team at Google

Thursday, January 19, 2023

Exploiting null-dereferences in the Linux kernel

Posted by Seth Jenkins, Project Zero

NVMe Exploitation

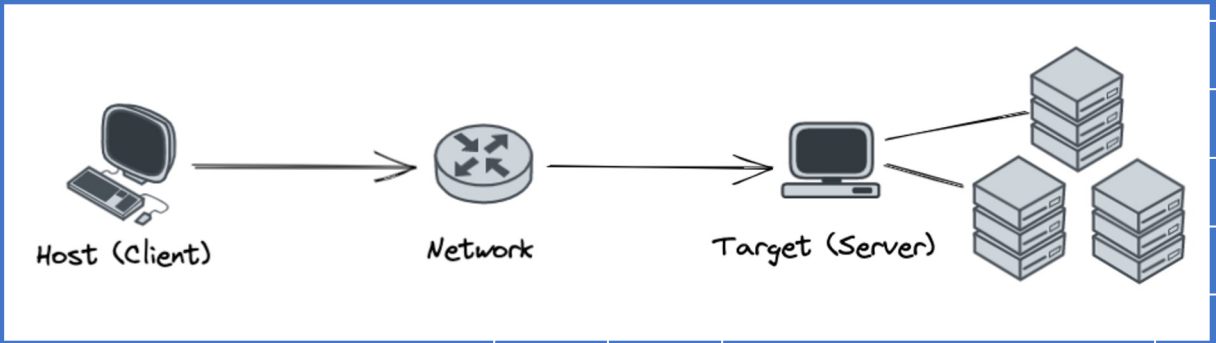
NVMe-TCP reference in commit notes

Hi all,

recent updates to the NVMe spec have added definitions for in-band authentication, and seeing that it provides some real benefit especially for NVMe-TCP here's an attempt to implement it.

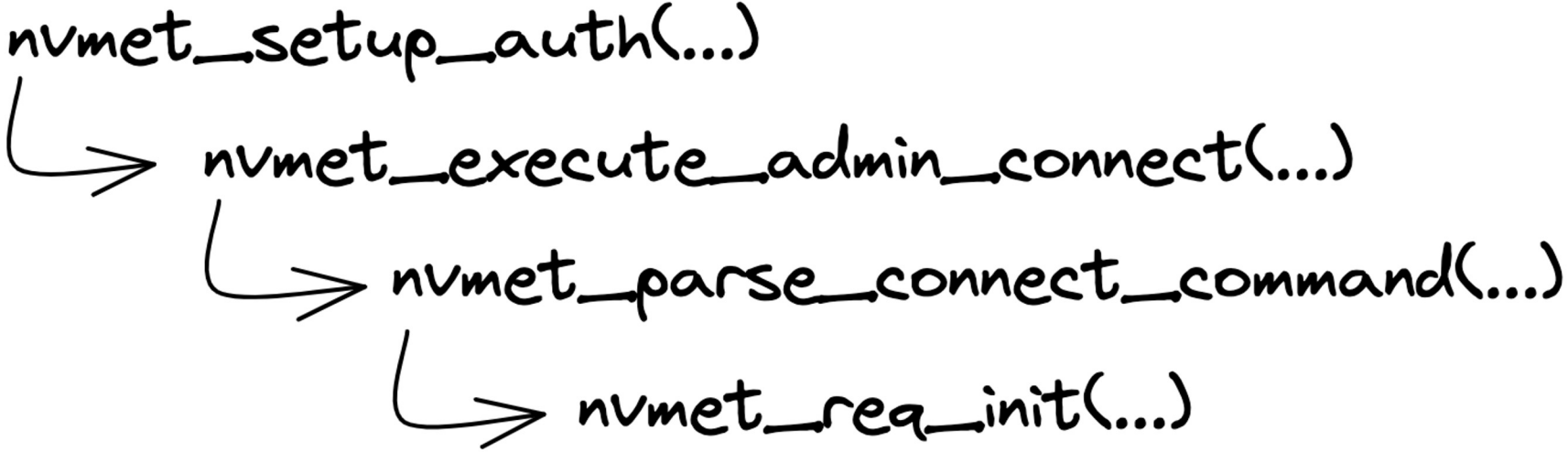
/ drivers / nvme

Parent directory	
common	
host	
target	
Kconfig	179 bytes
Makefile	113 bytes



```
ctrl->ctrl_key = nvme_auth_extract_key(host->dhchap_ctrl_secret + 10,
                                       host->dhchap_ctrl_key_hash);
if (IS_ERR(ctrl->ctrl_key)) {
        ret = PTR_ERR(ctrl->ctrl_key);
        ctrl->ctrl_key = NULL;
}
pr_debug("%s: using ctrl hash %s key %*ph\n", __func__,
         ctrl->ctrl_key->hash > 0 ?
         nvme_auth_hmac_name(ctrl->ctrl_key->hash) : "none",
         (int)ctrl->ctrl_key->len, ctrl->ctrl_key->key);
```

Call stack


nvmet_setup_auth(...)
nvmet_execute_admin_connect(...)
nvmet_parse_connect_command(...)
nvmet_req_init(...)

```
bool nvmet_req_init(struct nvmet_req *req, struct nvmet_cq *cq,
                    struct nvmet_sq *sq, const struct nvmet_fabrics_ops *ops)
{
        u8 flags = req->cmd->common.flags;
        u16 status;

        req->cq = cq;
        req->sq = sq;
        req->ops = ops;
        req->sg = NULL;
        req->metadata_sg = NULL;
        req->sg_cnt = 0;
```

NVMe-oF:

Referenced in 6 files:

drivers/nvme/target/core.c, line 980

drivers/nvme/target/fc.c, line 2549

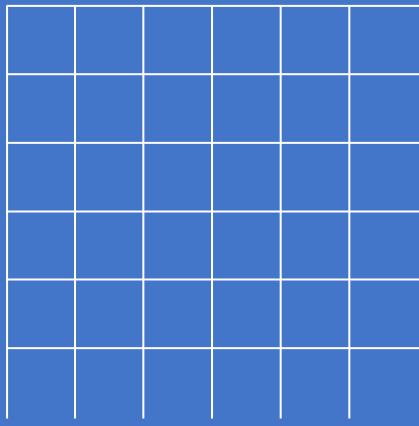
drivers/nvme/target/loop.c

- line 151
- line 184

drivers/nvme/target/rdma.c, line 988

drivers/nvme/target/tcp.c, line 999

drivers/nvme/target/trace.h, line 61



NVMe-TCP

```
static int nvmet_tcp_try_recv_pdu(struct nvmet_tcp_queue *queue)
{
        struct nvme_tcp_hdr *hdr = &queue->pdu.cmd.hdr;
        int len;
        struct kvec iov;
        struct msghdr msg = { .msg_flags = MSG_DONTWAIT };

recv:
        iov.iov_base = (void *)&queue->pdu + queue->offset;
        iov.iov_len = queue->left;
        len = kernel_recvmsg(queue->sock, &msg, &iov, 1,
                        iov.iov_len, msg.msg_flags);
```

NVMe
Environment setup

setup --help

- NVMe / NVMe-TCP

setup --help

- NVMe / NVMe-TCP - Google (**EASY**)

setup --help

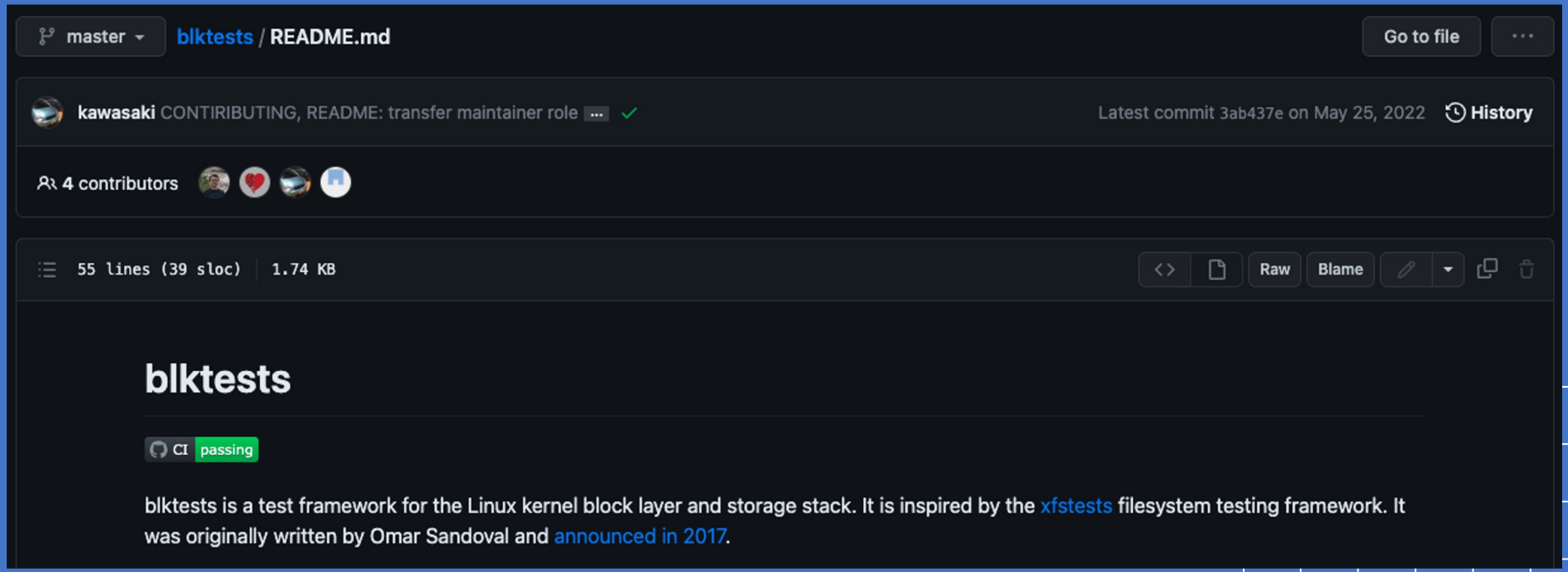
- NVMe / NVMe-TCP - Google (**EASY**)
- Authentication

setup --help

- NVMe / NVMe-TCP - Google (**EASY**)
- Authentication - Kernel Sources (**HARD**)

setup --help

- NVMe / NVMe-TCP - Google (**EASY**)
- Authentication - Kernel Sources (**HARD**)
- blktest framework :) (**EASY**)

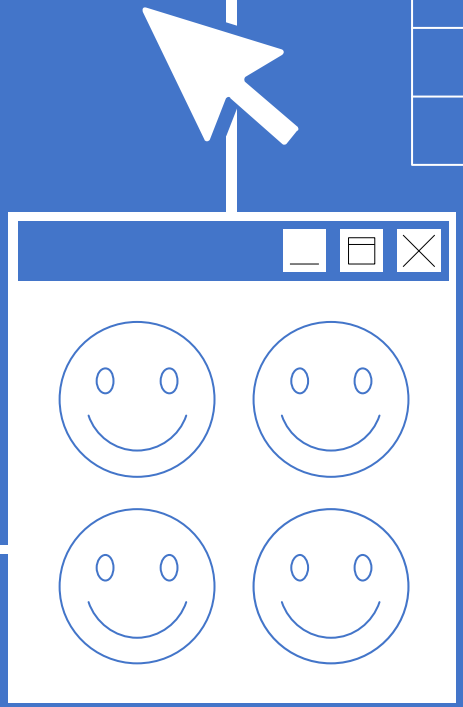

master
blktests / README.md
Go to file
kawasaki CONTIRIBUTING, README: transfer maintainer role ...
Latest commit 3ab437e on May 25, 2022
History
4 contributors
55 lines (39 sloc)
1.74 KB
Raw
Blame
blktests
CI passing
blktests is a test framework for the Linux kernel block layer and storage stack. It is inspired by the xfstests filesystem testing framework. It was originally written by Omar Sandoval and announced in 2017.

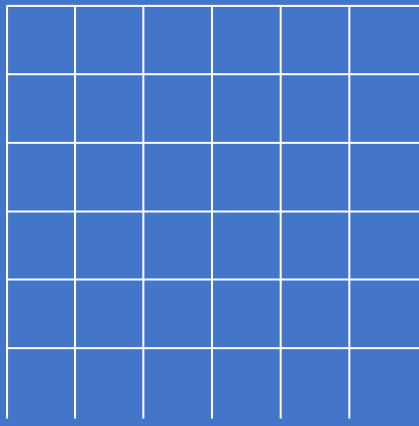
```
_create_nvmet_host() {
        local nvmet_subsystem="$1"
        local nvmet_hostnqn="$2"
        local nvmet_hostkey="$3"
        local nvmet_ctrlkey="$4"
        local cfs_path="${NVMET_CFS}/subsystems/${nvmet_subsystem}"
        local host_path="${NVMET_CFS}/hosts/${nvmet_hostnqn}"

        mkdir "${host_path}"
        echo 0 > "${cfs_path}/attr_allow_any_host"
        ln -s "${host_path}" "${cfs_path}/allowed_hosts/${nvmet_hostnqn}"
        if [[ "${nvmet_hostkey}" ]] ; then
                echo "${nvmet_hostkey}" > "${host_path}/dhchap_key"
        fi
        if [[ "${nvmet_ctrlkey}" ]] ; then
                echo "${nvmet_ctrlkey}" > "${host_path}/dhchap_ctrl_key"
        fi
}
```

06

Demo

Or 2

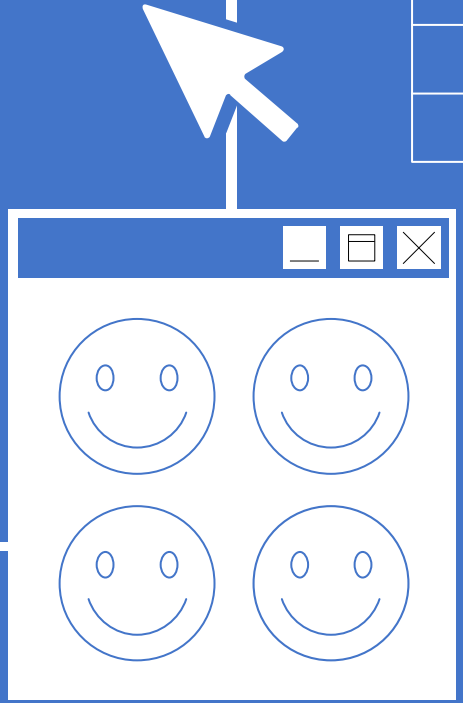




06

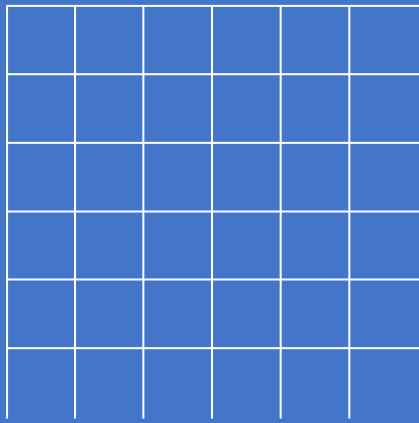
Demo N.2

From Remote DoS to
Pre-Auth Remote DoS



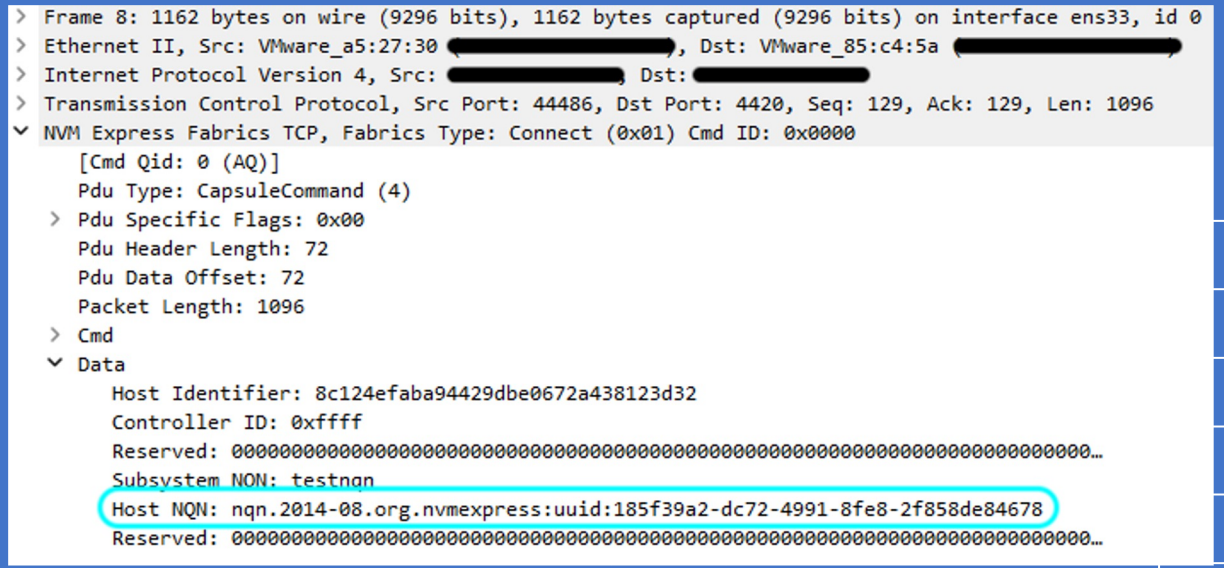
Authorization

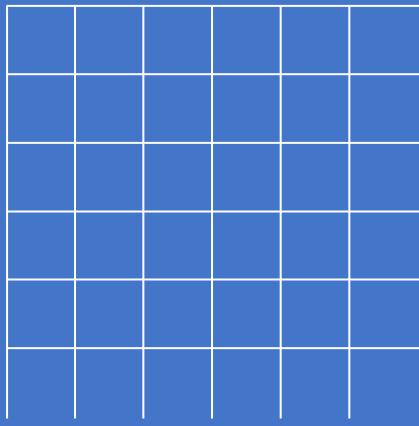
```
[30749.638602] nvme nvme0: Connect for subsystem testnqn is not allowed, hostnqn: AAAA
```



Authorization

```
[30749.638602] nvme nvme0: Connect for subsystem testnqn is not allowed, hostnqn: AAAA
```





TIMELINE

Fix

Reported the vulnerabilities which were patched

CVE

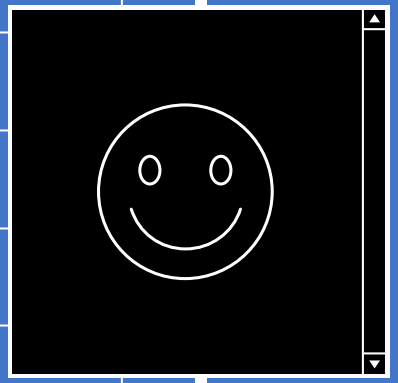
CVE-2023-0122
CVE-2022-4842
& more..

Blogpost

Wrap-up

- Open source research might be a bit overwhelming - focus is the key
- If no documentation available, search for tests
- SCA is still a powerful tool for low-hanging-fruits!

THANKS!



@TalLossos