Let’s mess with Windows drivers

Jaanus Kääp
Clarified Security

Who, from, what, why?

Who: Jaanus Kääp

From: Clarified Security

What: Researcher & developer

Why: >100 CVE-s, mostly by Adobe & Microsoft

MSRC top list 2016-2020

Like to talk about security

Drivers research

- Privilege escalation importance
- Main pathways
  - IPC
  - Syscalls
  - Driver communication

Windows drivers

- Kernel and drivers
- Drivers basic usage
- Driver and device objects
- Types of drivers
- Driver stack

Communication with drivers

- Connection is made with DEVICE not driver
- Connecting with symbolic link - *registered*
- Connecting with device name - *\\?\GLOBALROOT\Device\%NAME%*
- Basic IO operations - *ReadFile WriteFile*
- Special commands - *DeviceIoControl*
    - Focusing on that

DeviceIoControl

```
BOOL DeviceIoControl(
  HANDLE       hDevice,
  DWORD        dwIoControlCode,
  LPVOID       lpInBuffer,
  DWORD        nInBufferSize,
  LPVOID       lpOutBuffer,
  DWORD        nOutBufferSize,
  LPDWORD      lpBytesReturned,
  LPOVERLAPPED lpOverlapped

)
```

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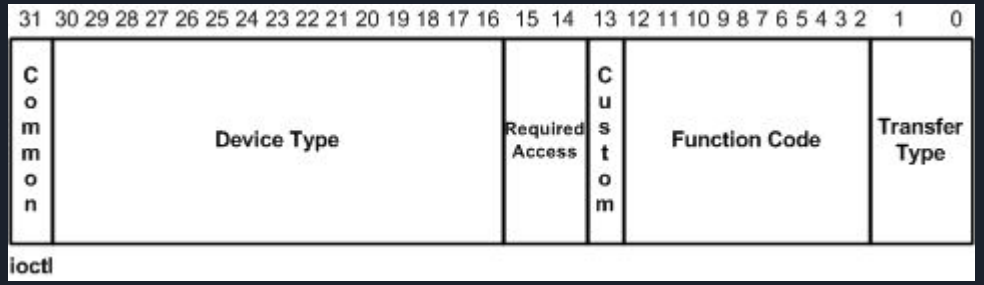
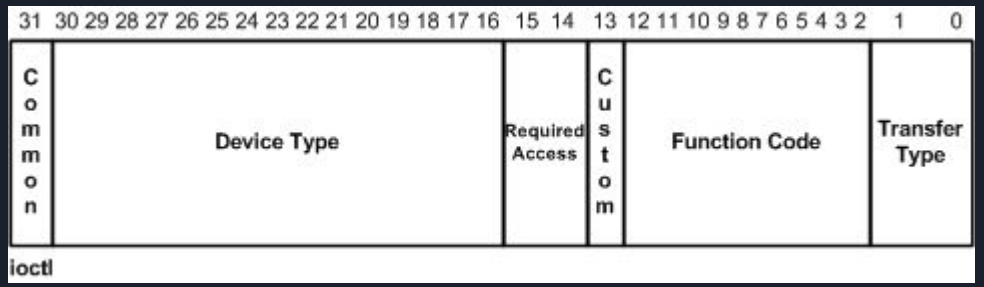
DeviceIoControl code



- Device type - as name says (>0x8000 for non MS)
- Requires access - none, read, write or read & write
- Function code - integer specifying the function called
- Transfer type - how data is transferred

DeviceIoControl code : transfer type

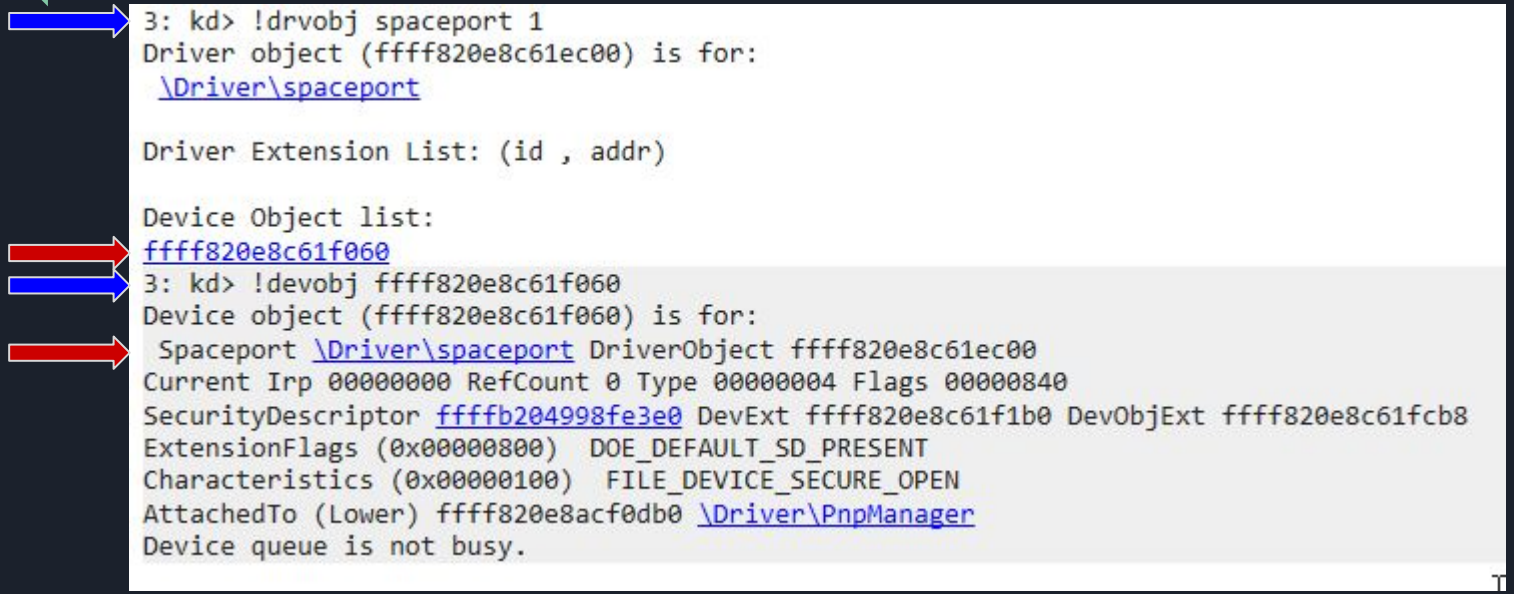


- METHOD_BUFFERED - in & out data is copied into kernel
- METHOD_IN_DIRECT - in buffer is provided as MDL
- METHOD_OUT_DIRECT - out buffer is provided as MDL
- METHOD_NEITHER - userland addresses are provided to driver, no additional protection

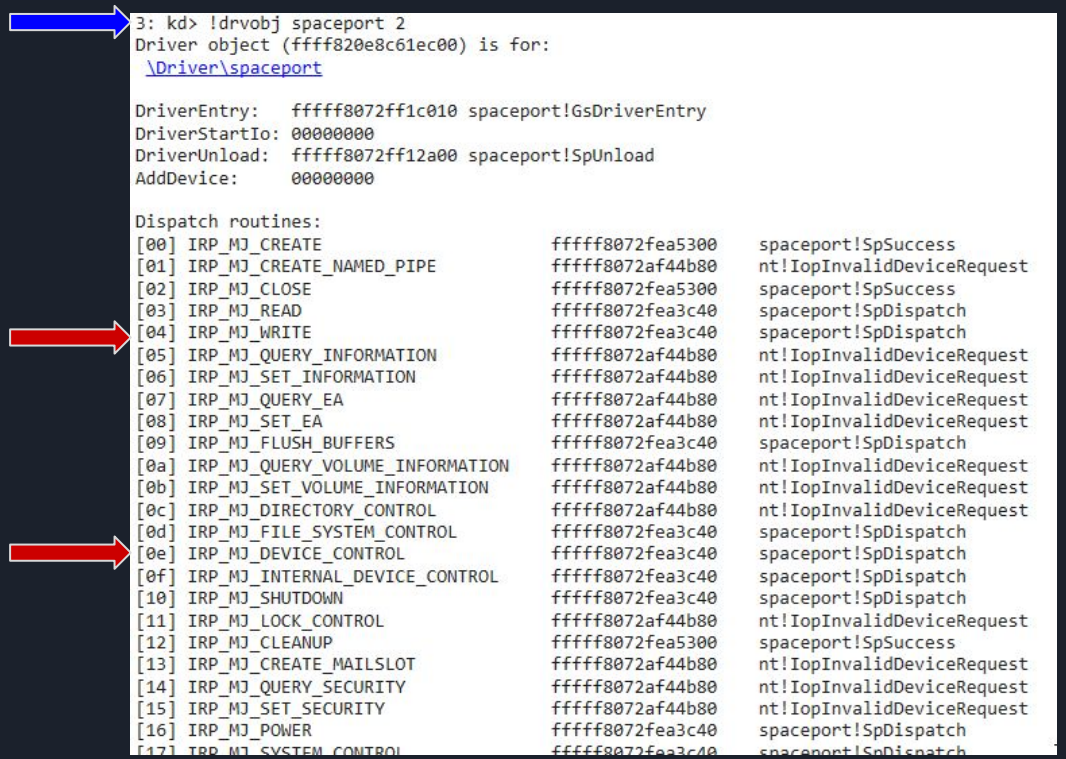
Debugging drivers

- Debugging Windows kernel
- Windbg
- !drvobj %DRIVER NAME OR ADDRESS% %FLAG%
  - Flag 0x1 - shows device objects
  - Flag 0x2 - shows dispatch routines
  - Flag 0x4 - shows extra info about device objects
- !devobj %DEVICE NAME OR ADDRESS%

Debugging drivers



Debugging drivers



```
3: kd> !drvobj spaceport 2
Driver object (ffff820e8c61ec00) is for:
 \Driver\spaceport

DriverEntry:   fffff8072ff1c010 spaceport!GsDriverEntry
DriverStartIo: 00000000
DriverUnload:  fffff8072ff12a00 spaceport!SpUnload
AddDevice:     00000000

Dispatch routines:
[00] IRP_MJ_CREATE                      fffff8072fea5300    spaceport!SpSuccess
[01] IRP_MJ_CREATE_NAMED_PIPE           fffff8072af44b80    nt!IopInvalidDeviceRequest
[02] IRP_MJ_CLOSE                       fffff8072fea5300    spaceport!SpSuccess
[03] IRP_MJ_READ                        fffff8072fea3c40    spaceport!SpDispatch
[04] IRP_MJ_WRITE                       fffff8072fea3c40    spaceport!SpDispatch
[05] IRP_MJ_QUERY_INFORMATION           fffff8072af44b80    nt!IopInvalidDeviceRequest
[06] IRP_MJ_SET_INFORMATION             fffff8072af44b80    nt!IopInvalidDeviceRequest
[07] IRP_MJ_QUERY_EA                    fffff8072af44b80    nt!IopInvalidDeviceRequest
[08] IRP_MJ_SET_EA                      fffff8072af44b80    nt!IopInvalidDeviceRequest
[09] IRP_MJ_FLUSH_BUFFERS               fffff8072fea3c40    spaceport!SpDispatch
[0a] IRP_MJ_QUERY_VOLUME_INFORMATION    fffff8072af44b80    nt!IopInvalidDeviceRequest
[0b] IRP_MJ_SET_VOLUME_INFORMATION      fffff8072af44b80    nt!IopInvalidDeviceRequest
[0c] IRP_MJ_DIRECTORY_CONTROL           fffff8072af44b80    nt!IopInvalidDeviceRequest
[0d] IRP_MJ_FILE_SYSTEM_CONTROL         fffff8072fea3c40    spaceport!SpDispatch
[0e] IRP_MJ_DEVICE_CONTROL              fffff8072fea3c40    spaceport!SpDispatch
[0f] IRP_MJ_INTERNAL_DEVICE_CONTROL     fffff8072fea3c40    spaceport!SpDispatch
[10] IRP_MJ_SHUTDOWN                    fffff8072fea3c40    spaceport!SpDispatch
[11] IRP_MJ_LOCK_CONTROL                fffff8072af44b80    nt!IopInvalidDeviceRequest
[12] IRP_MJ_CLEANUP                     fffff8072fea5300    spaceport!SpSuccess
[13] IRP_MJ_CREATE_MAILSLOT             fffff8072af44b80    nt!IopInvalidDeviceRequest
[14] IRP_MJ_QUERY_SECURITY              fffff8072af44b80    nt!IopInvalidDeviceRequest
[15] IRP_MJ_SET_SECURITY                fffff8072af44b80    nt!IopInvalidDeviceRequest
[16] IRP_MJ_POWER                       fffff8072fea3c40    spaceport!SpDispatch
[17] IRP_MJ_SYSTEM_CONTROL              fffff8072fea3c40    spaceport!SpDispatch
```

Debugging drivers : handler routines

- NTSTATUS DriverIoControl(PDEVICE_OBJECT DeviceObject, PIRP Irp)
  - DeviceObject - pointer to device object
  - Irp - I/O Request Packets
- IRP structure is LARGE and filled with unions
- What is important?

Debugging drivers : IRP elements

!irp %IRP ADDRESS%

```
2: kd> !irp rdx
Irp is active with 2 stacks 2 is current (= 0xffff820e9221cef8)
 No Mdl: System buffer=ffff820e902e4000: Thread ffff820e910e2080:  Irp stack trace.
     cmd  flg cl Device   File     Completion-Context
 [N/A(0), N/A(0)]
            0  0 00000000 00000000 00000000-00000000

            Args: 00000000 00000000 00000000 00000000
>[IRP_MJ_DEVICE_CONTROL(e), N/A(0)]
            5  0 ffff820e8c61f060 ffff820e95e5fed0 00000000-00000000
           \Driver\spaceport
            Args: 00001b00 00000028 0xe70008 00000000
```

Debugging drivers : IRP elements

!irp %IRP ADDRESS%

I/O BUFFER

OUTPUT SIZE

INPUT SIZE

CODE

```
2: kd> !irp rdx
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           \Driver\spaceport
            Args: 00001b00 00000028 0xe70008 00000000
```

Debugging drivers : IRP elements

- Major function: byte at offset 0x0 from pointer at irp+0xB8
  - db poi(rdx + 0xB8) L1
- Control code: dword at offset 0x18 from pointer at irp+0xB8
  - dd poi(rdx + 0xB8) + 0x18 L1
- Input size: dword at offset 0x10 from pointer at irp+0xB8
  - dd poi(rdx + 0xB8) + 0x10 L1
- Output size: dword at offset 0x8 from pointer at irp+0xB8
  - dd poi(rdx + 0xB8) + 0x8 L1
- Input/output buffer: pointer at irp+0x18
  - db poi(rdx + 0x18)

Debugging drivers : IRP elements

```
2: kd> db poi(rdx + 0xB8) L1
ffff820e`9221cef8  0e                                              .
2: kd> dd poi(rdx + 0xB8) + 0x18 L1
ffff820e`9221cf10  00e70008
2: kd> dd poi(rdx + 0xB8) + 0x10 L1
ffff820e`9221cf08  00000028
2: kd> dd poi(rdx + 0xB8) + 0x8 L1
ffff820e`9221cf00  00001b00
2: kd> dp rdx+0x18 L1
ffff820e`9221cdf8  ffff820e`902e4000
2: kd> db poi(rdx + 0x18)
ffff820e`902e4000  28 00 00 00 3e 17 8a c2-de c1 eb 11 ab a6 80 6e  (...>..........n
ffff820e`902e4010  6f 6e 69 63 00 00 00 00-00 00 00 00 00 00 00 00  onic............
ffff820e`902e4020  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  ................
ffff820e`902e4030  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  ................
ffff820e`902e4040  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  ................
ffff820e`902e4050  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  ................
ffff820e`902e4060  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  ................
ffff820e`902e4070  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  ................
```

What to look for

- Memory corruptions
- Data leaks
- Logic flaws

Memory corruption

- Overflow
- Use after free
- Uninitialized values

Data leak

- Accidental leak
- Out of bound read
- Uninitialized values

Logic flaws

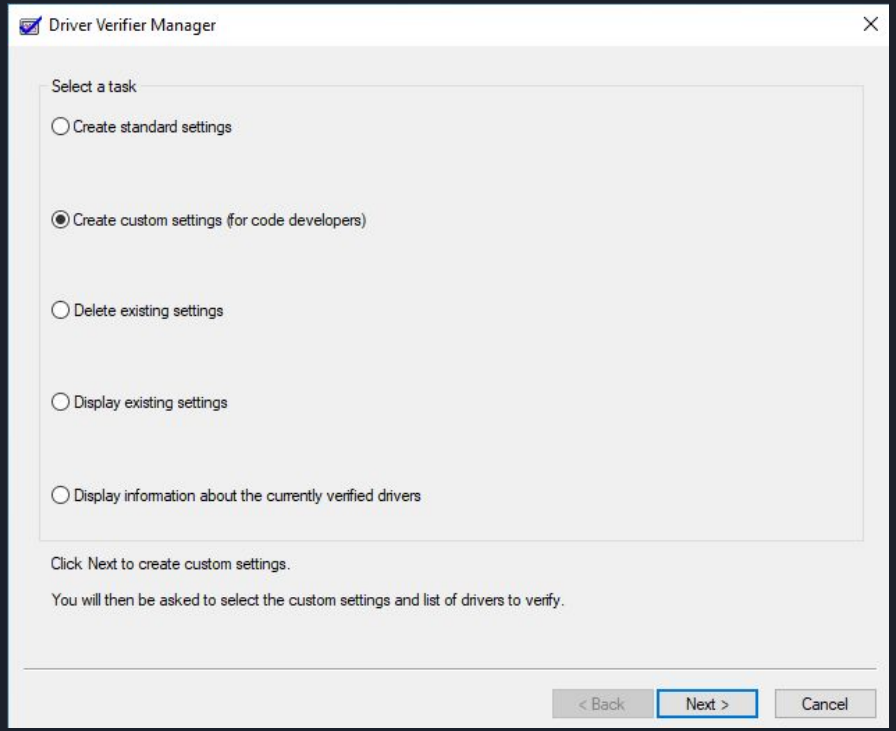
- Missing access checks
- Skippable checks
- Etc

Finding vulnerabilities

- Manual testing
- Blind dumb fuzzing
- Mutation based fuzzing
- Generation based fuzzing

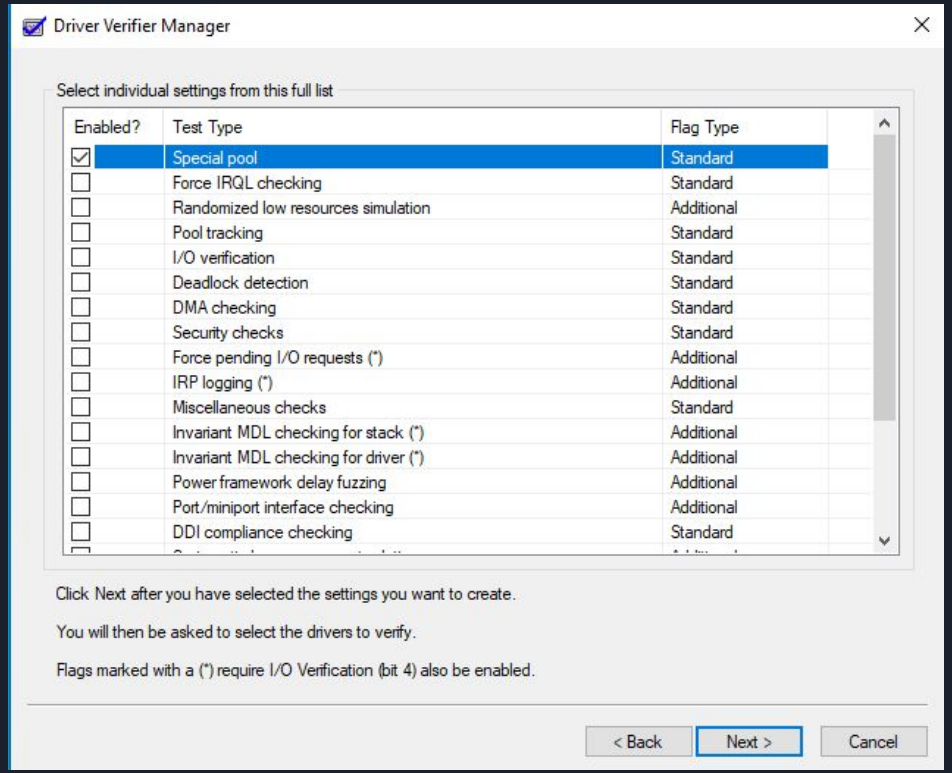
Single most important prerequisites

- verifier.exe
- Special pool



Single most important prerequisites

- verifier.exe
- Special pool



Special pool

- Like page heap or guard pages

Special pool

- Like page heap or guard pages

Special pool

- Like page heap or guard pages

Special pool

- Like page heap or guard pages
- Nonpageable memory and 2 VM pages
- Can be exhausted
- Additional configuration
  - “Verify start” vs “Verify end”
  - Use by pool tag
  - Use by size

Finding vulnerabilities

- Manual testing
- Blind dumb fuzzing
- Mutation based fuzzing
- Generation based fuzzing

Finding vulnerabilities

- **Manual testing**
  - Reverse engineering driver code
  - Combination of static and dynamic analysis
  - Can be combined with fuzzing
  - Often needed anyway to bypass some checks
- Blind dumb fuzzing
- Mutation based fuzzing
- Generation based fuzzing
- Coverage based fuzzing

Finding vulnerabilities

- Manual testing
- **Blind dumb fuzzing**
  - Stupid easy to setup
  - Small and possibly useless coverage
- Mutation based fuzzing
- Generation based fuzzing
- Coverage based fuzzing

Finding vulnerabilities

- Manual testing
- Blind dumb fuzzing
- **Mutation based fuzzing**
  - Need to record or create good inputs
  - Could have limits on coverage
- Generation based fuzzing
- Coverage based fuzzing

Finding vulnerabilities

- Manual testing
- Blind dumb fuzzing
- Mutation based fuzzing
- **Generation based fuzzing**
  - Biggest time investment - RE & dev
  - Covers only area covered by generation logic
  - Can be combined with other methods
- Coverage based fuzzing

Finding vulnerabilities

- Manual testing
- Blind dumb fuzzing
- Mutation based fuzzing
- Generation based fuzzing
- **Coverage based fuzzing**
  - Most complex to develop
  - Can be combined with other methods
  - Hardware support - Intel PT

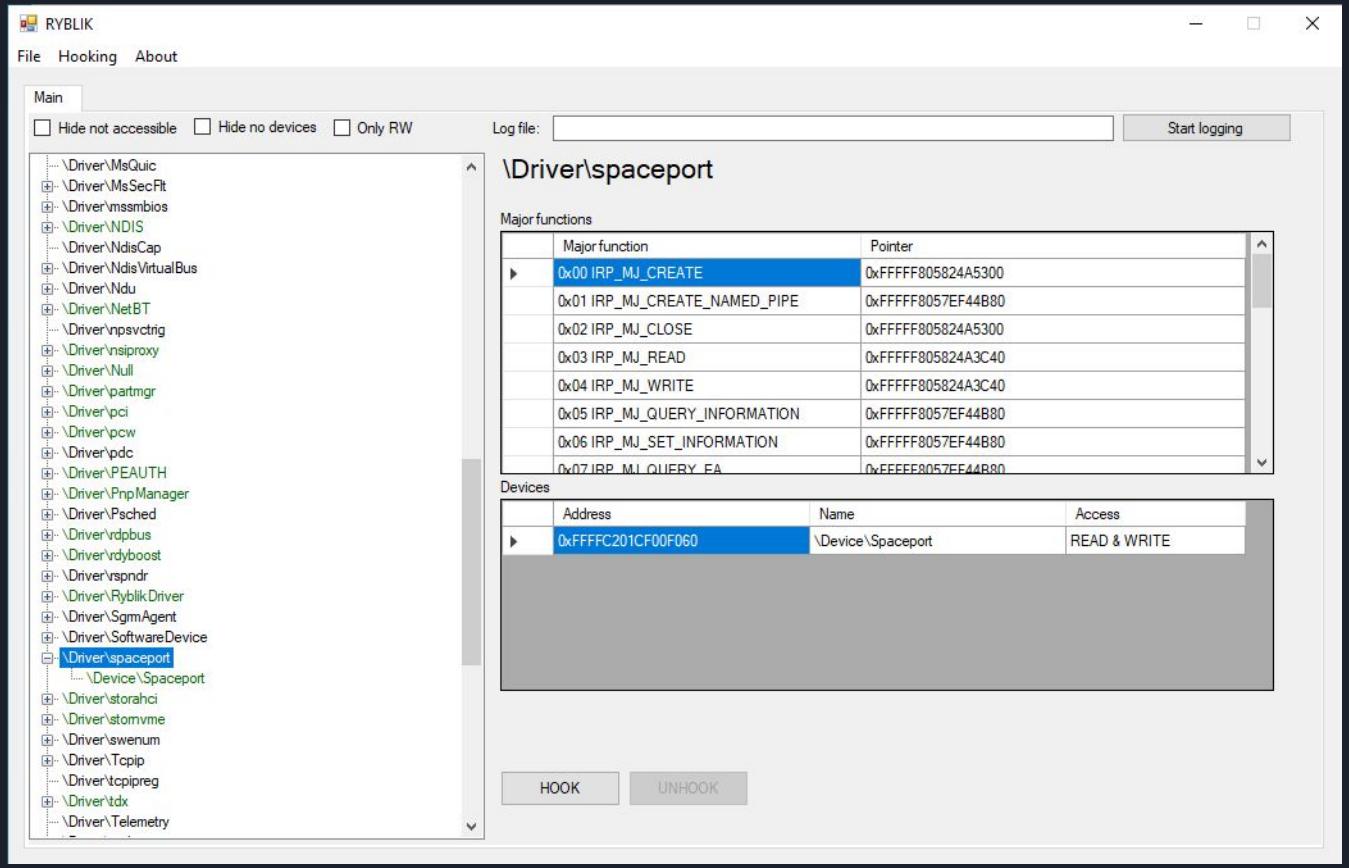
Testing tools

- Lot of existing fuzzers
- RE with Windbg & IDA
- Develop own tools for testing
  - Scripting for quick tests
  - C++ or similar for fast fuzzing
- Bit more generic tool from me :)

Windows ScrewDriver

- GUI & implementation DLL
- Gives list of drivers and devices
- Can easily make request to drivers
- Can record traffic to drivers
- Can help detect supported codes
- Can help detect expected structure values
- Lot of small functionalities to help RE

Windows ScrewDriver



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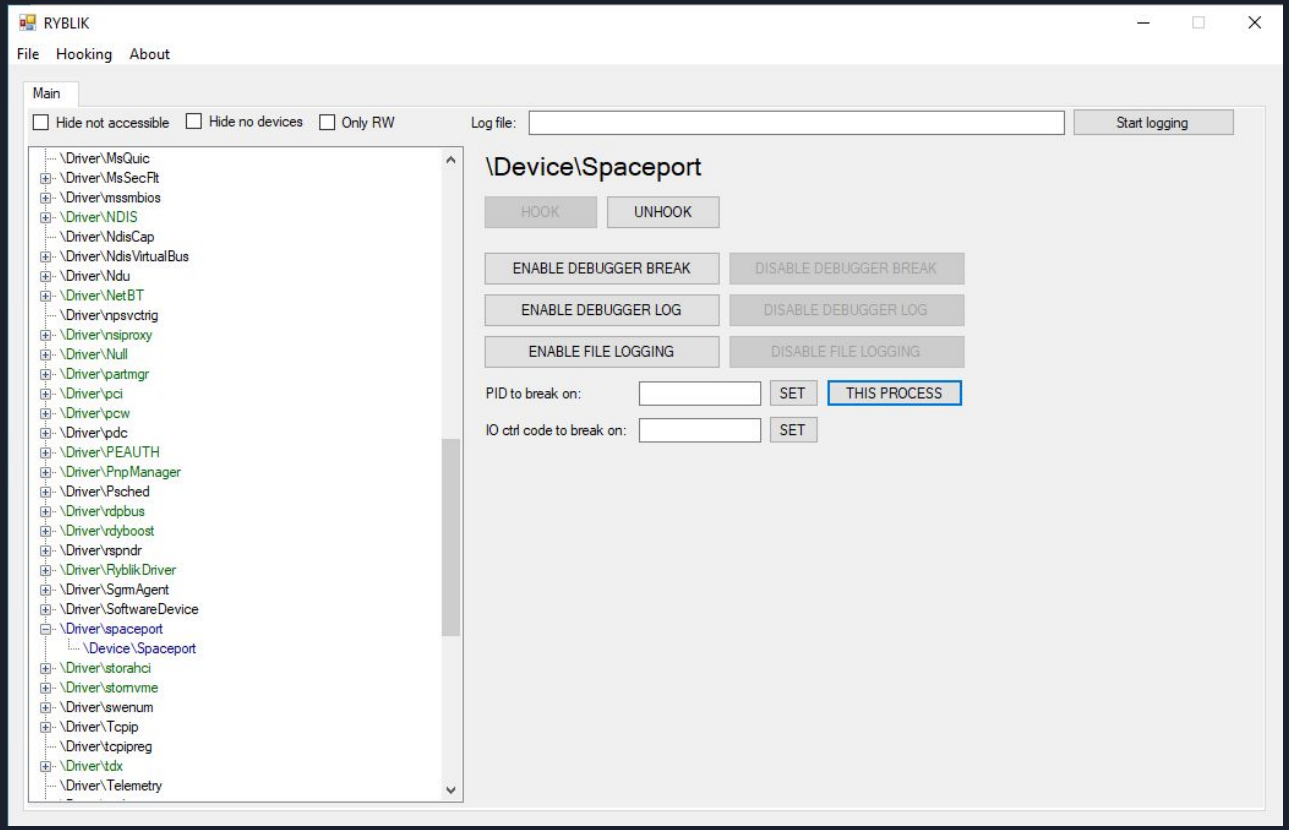

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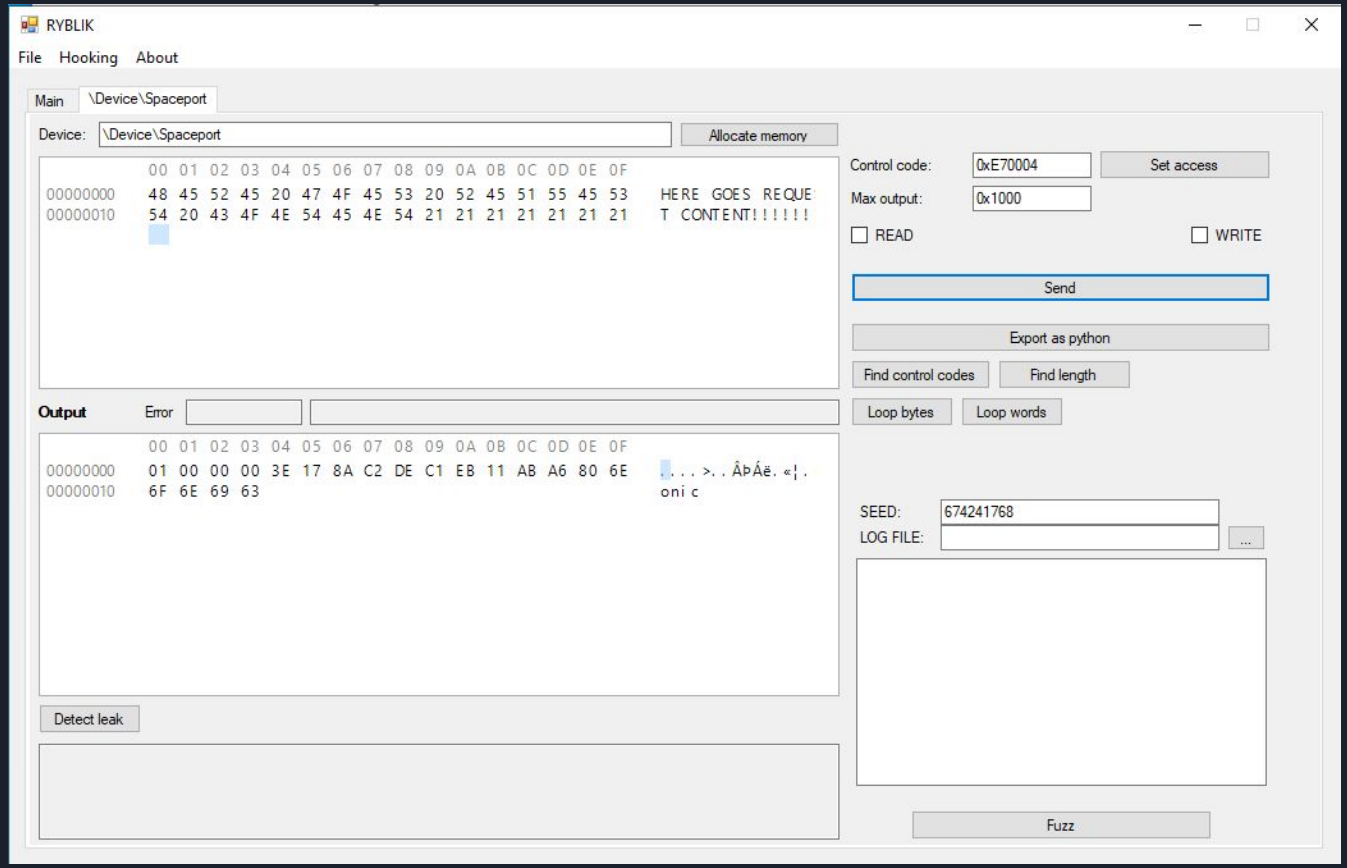

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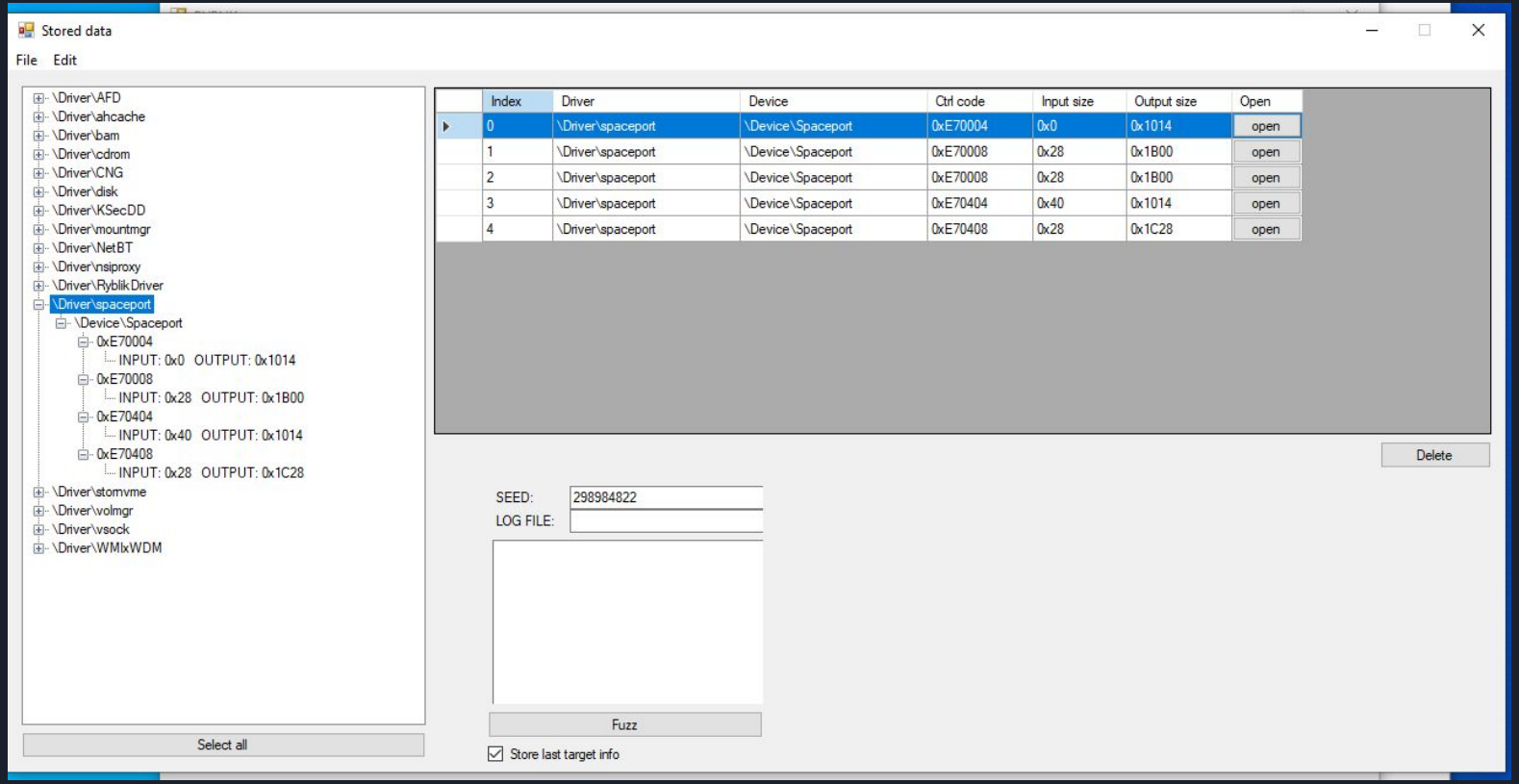

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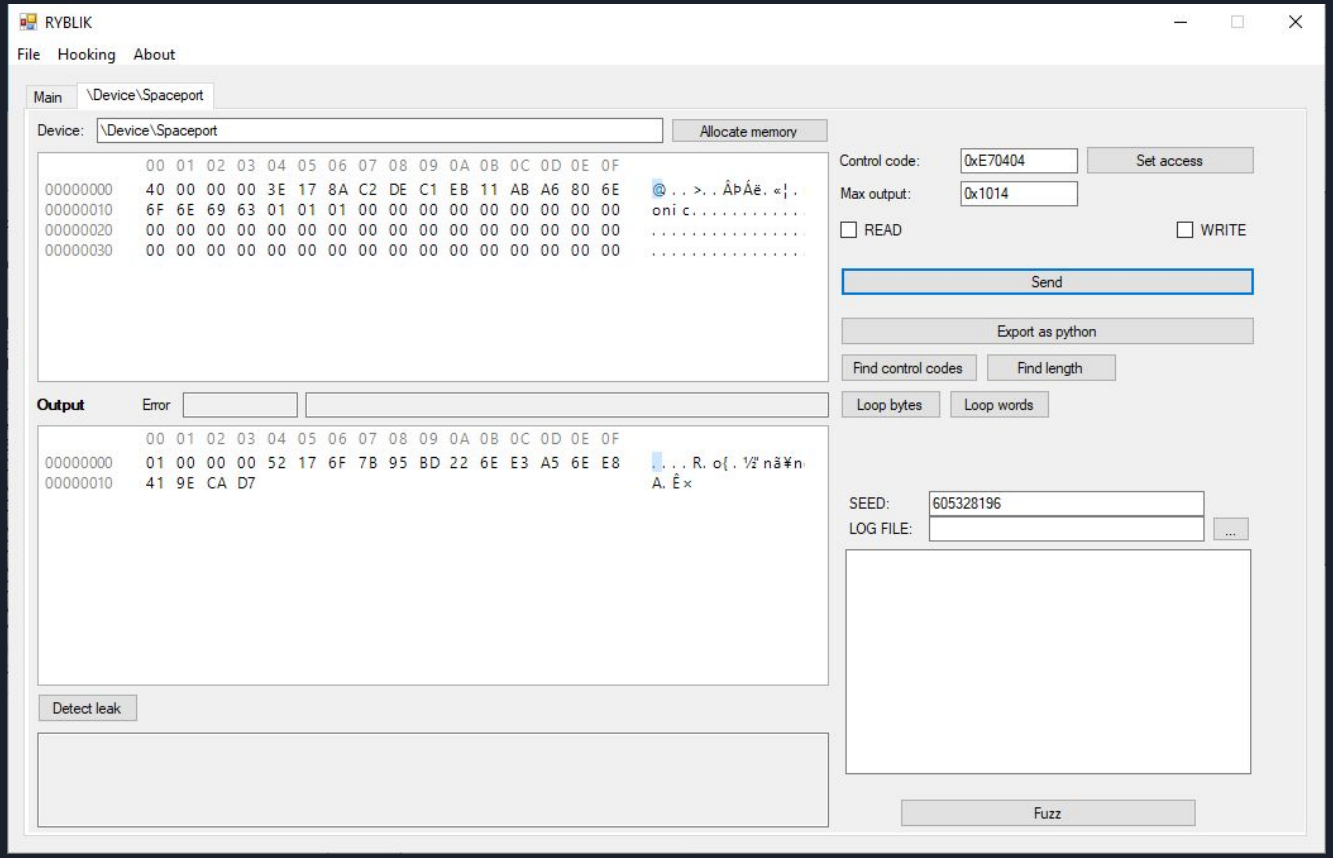

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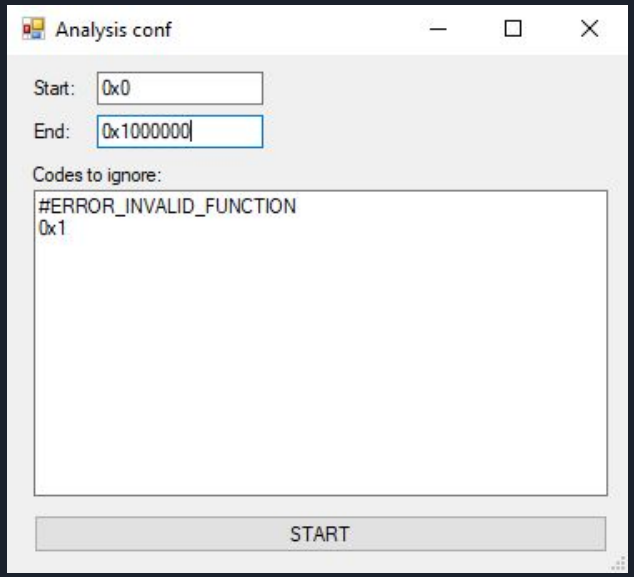

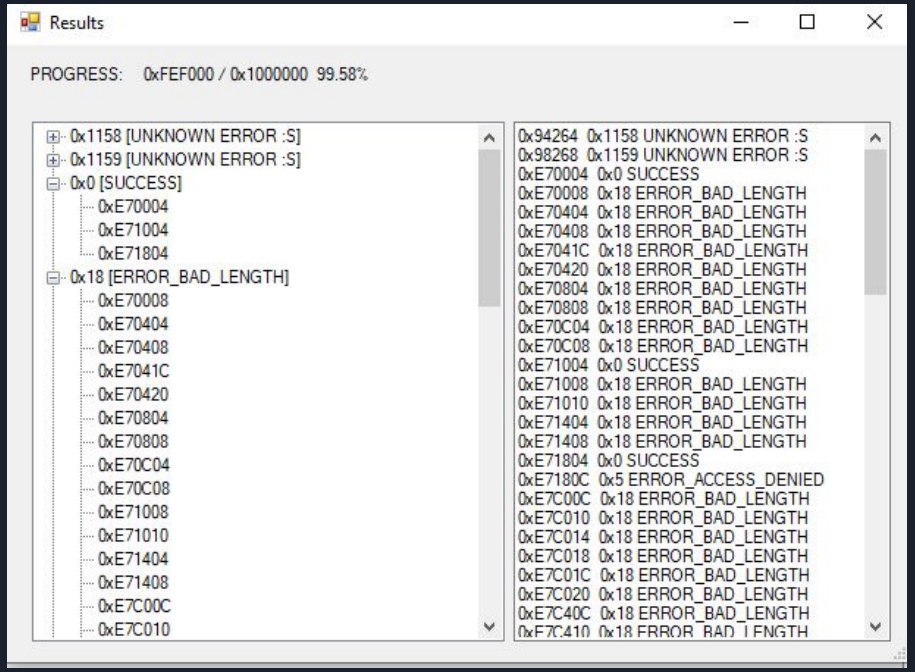

Windows ScrewDriver

- Helps speed up manual testing
- Can be used to fuzz or create fuzzing base
- Can be used to record valid input for mutational fuzzing or RE
- Will be extended in following years
    - New tools (so it’s actually a TOOLSET)

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- **For BSides Tallinn participants:**
  3 day FREE trial and after that only 1200EUR/MONTH

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- **JUST KIDDING! It's free and open source under MIT license**
  https://github.com/JaanusKaapPublic/Windows-ScrewDriver

What if you find something

- Microsoft Windows Insider Preview Bounty Program
  - Bug has to exist in latest Dev Channel build
  - If device accessible from sandbox, then up to 20 000$
  - Otherwise up to 5 000$
  - DON'T believe "Denial of Service $500" bounty, it's a lie
- ZDI
- Zerodium up to 80 000$
- Full disclosure to piss of lot of people

- If you find something with my tools
  - Let me know later if possible - it's nice to know
  - Donate something to any reasonable charity

Thank you!

-