Kernel Hijacking Is Not an Option: MemoryRanger Comes to the Rescue Again

Igor Korkin

Independent Researcher

HITB LOCKDOWN 002
livestream
2020

WHOAMI

- PhD, speaker at the ADFSL conference since 2014 and the BlackHat
- Windows OS Kernel Security Researcher:
  - Rootkits and anti-rootkits
  - Bare-Metal Hypervisors vs. Attacks on Kernel Memory
- Fan of cross-disciplinary research — igorkorkin.blogspot.com
- Love traveling and powerlifting — 📷 igor.korkin

AGENDA: ATTACKS ON FILES

- Three attacks on kernel memory data:

Bypass file sharing access control:

1. Handle Table Hijacking
2. Hijacking NTFS structures

AGENDA: ATTACKS ON FILES+TOKENS

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Process Privilege Escalation:

3. Token Hijacking

AGENDA: ATTACKS ON FILES+TOKENS & MEMORYRANGER

- Three attacks on kernel memory data:

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Process Privilege Escalation:

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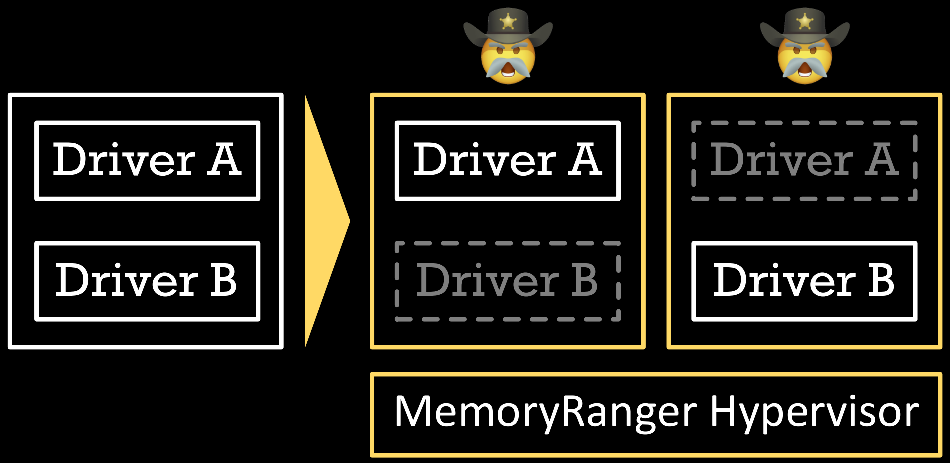
- MemoryRanger blocks kernel attacks:
  - It runs drivers in isolated kernel enclaves
  - It includes a new feature: Data-Only Enclave



Driver A

Driver B

Driver A

Driver B

Driver A

Driver B

MemoryRanger Hypervisor

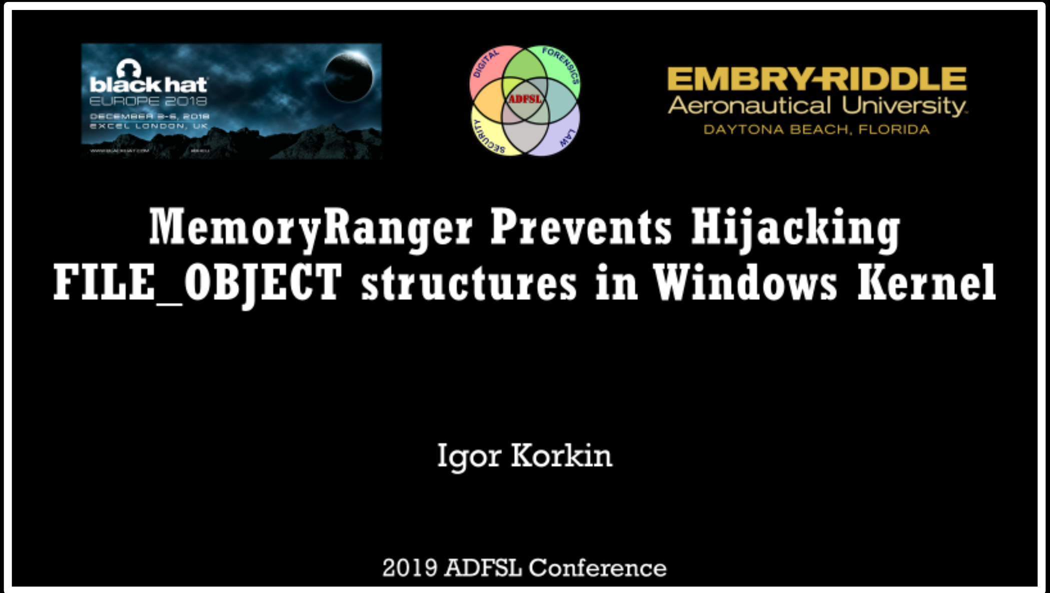
PREVIOUS RESEARCH ON MEMORYRANGER: PAPERS+SLIDES+DEMOS

black hat
EUROPE 2018
DECEMBER 3-6, 2018
EXCEL LONDON / UNITED KINGDOM

DIVIDE ET IMPERA:
MEMORY RANGER RUNS DRIVERS IN
ISOLATED KERNEL SPACES

Igor Korkin, Ph.D

#BHEU / @BLACK HAT EVENTS



black hat
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DIGITAL FORENSICS SECURITY LAW ADFSL

EMBRY-RIDDLE
Aeronautical University
DAYTONA BEACH, FLORIDA

MemoryRanger Prevents Hijacking
FILE_OBJECT structures in Windows Kernel

Igor Korkin

2019 ADFSL Conference

(2018) Divide et Impera: MemoryRanger Runs Drivers in Isolated Kernel Spaces

https://igorkorkin.blogspot.com/2018/12/divide-et-impera-memoryranger-runs.html

(2019) MemoryRanger Prevents Hijacking FILE_OBJECT Structures in Windows Kernel

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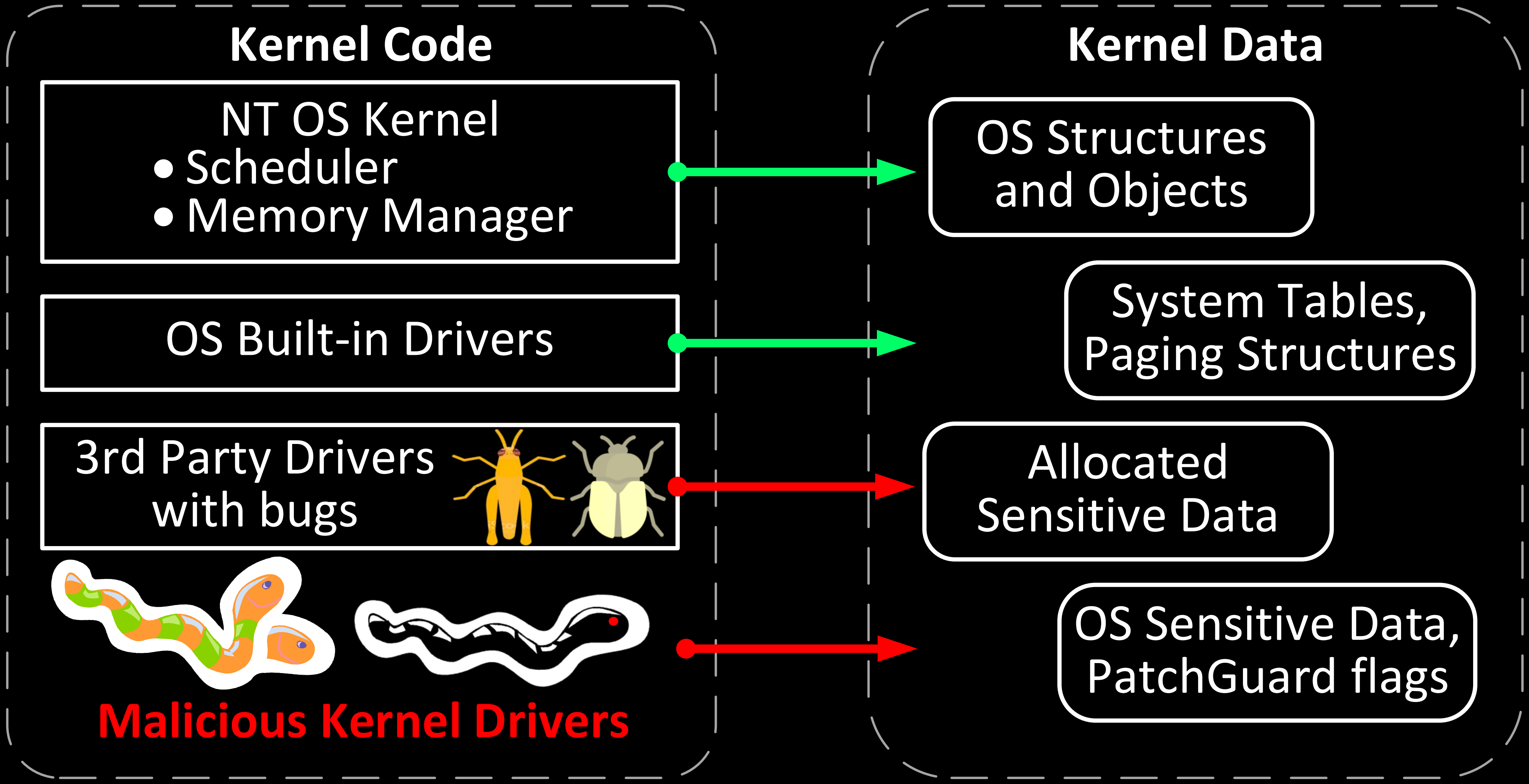
KERNEL DRIVERS CAN COMPROMISE THE OS SECURITY



Kernel Code

NT OS Kernel
- Scheduler
- Memory Manager

OS Built-in Drivers

3rd Party Drivers with bugs

Malicious Kernel Drivers

Kernel Data

OS Structures and Objects

System Tables, Paging Structures

Allocated Sensitive Data

OS Sensitive Data, PatchGuard flags

KERNEL DRIVERS IN RECENT MALWARE ATTACKS ON WINDOWS

- RobbinHood Ransomware - 2020
  - Exploits a legitimate buggy driver to load a malware driver
  - Malware driver disables endpoint security products

1. Ransomware installs Gigabyte driver to kill antivirus products - https://www.zdnet.com/article/ransomware-installs-gigabyte-driver-to-kill-antivirus-products/
2. Nansh0u Miner Attack Infects 50K MS-SQL, PHPMyAdmin Servers - https://www.guardicore.com/2019/05/nansh0u-campaign-hackers-arsenal-grows-stronger/
3. Glupteba: Hidden Malware Delivery in Plain Sight - https://news.sophos.com/wp-content/uploads/2020/06/glupteba_final.pdf

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  - Uses a signed malware driver to protect itself from termination

- Glupteba includes rootkit to hide files and processes - 2020
  - Exploits a signed vulnerable driver to bypass the Kernel Patch Protection and Driver Signature Enforcement

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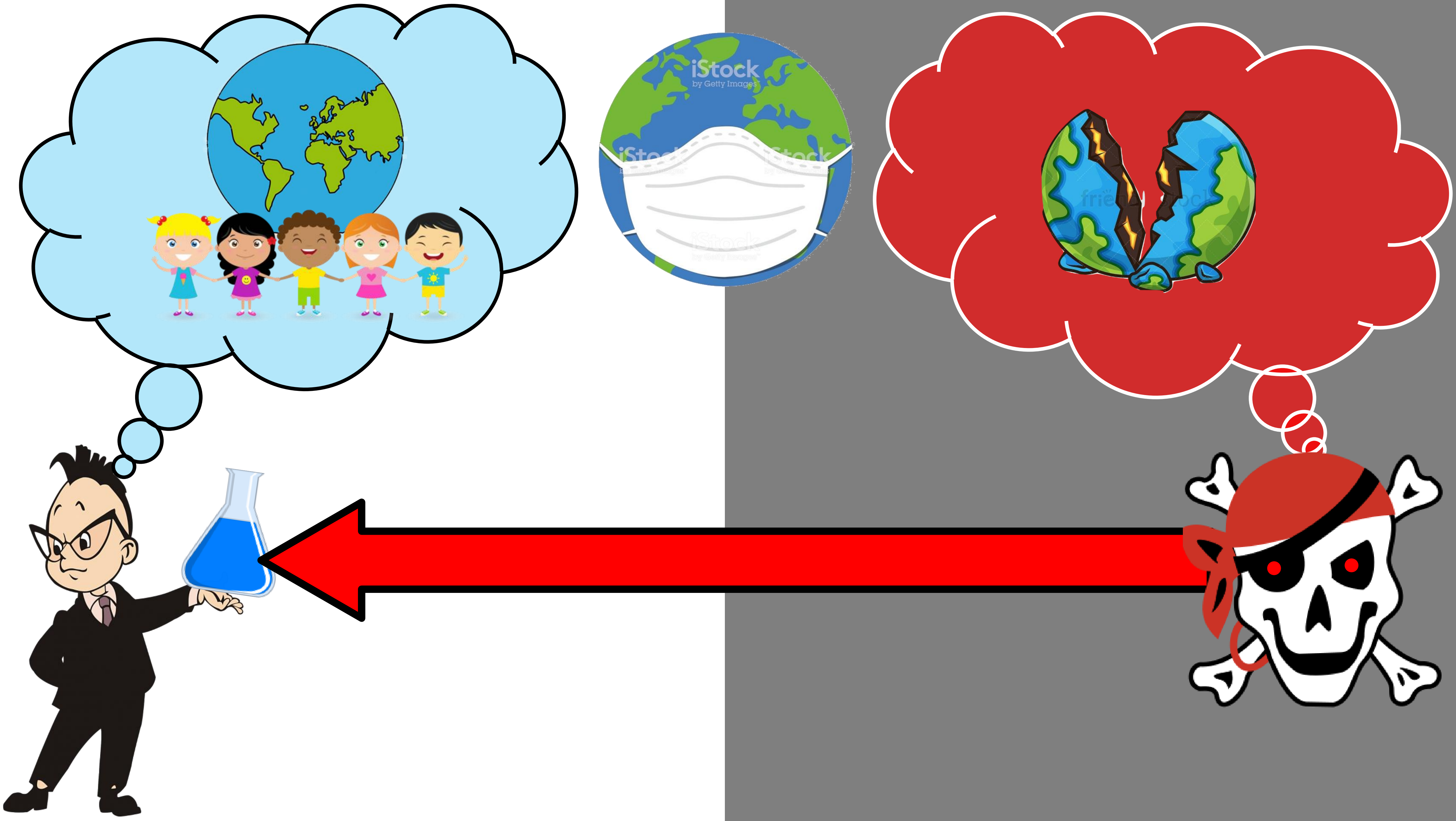
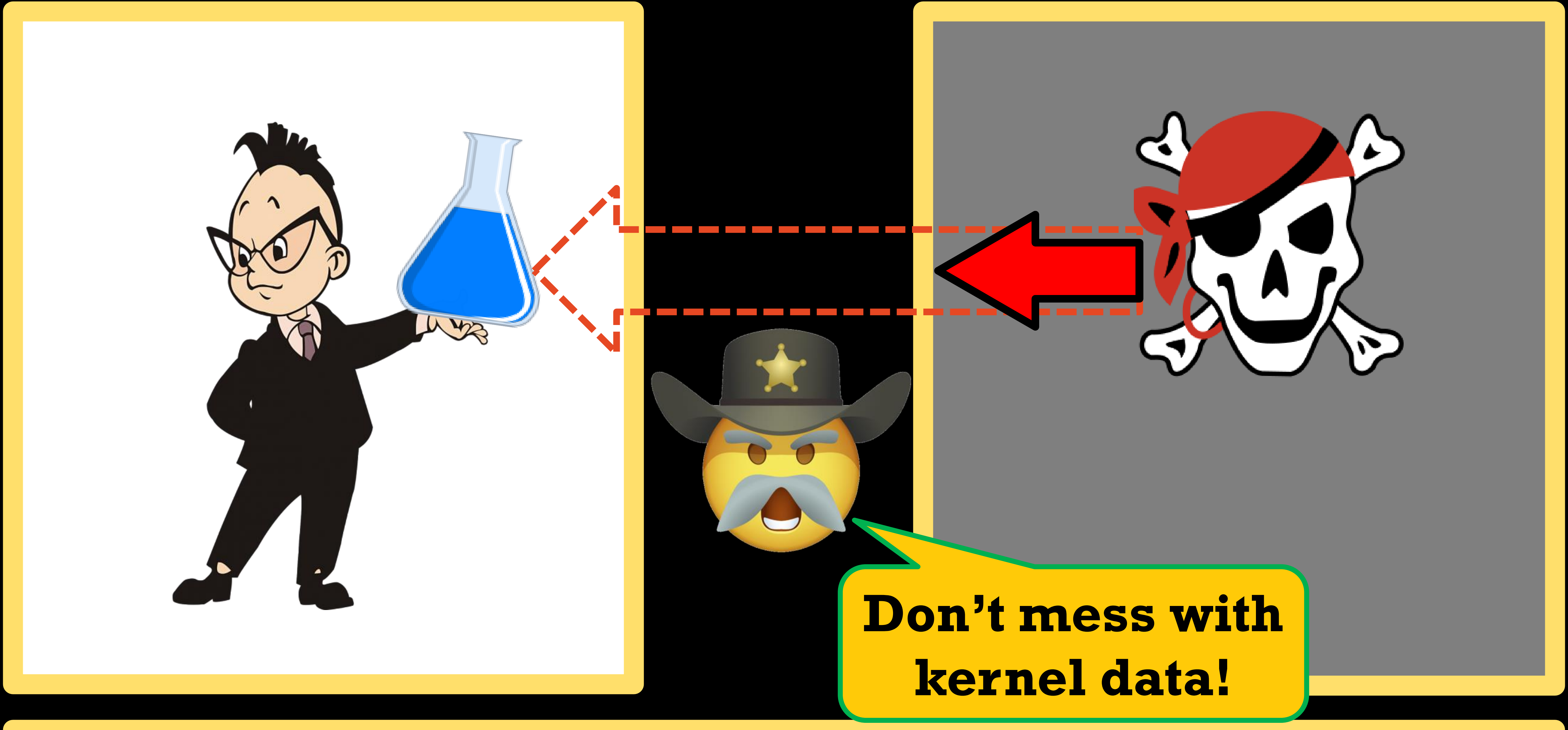


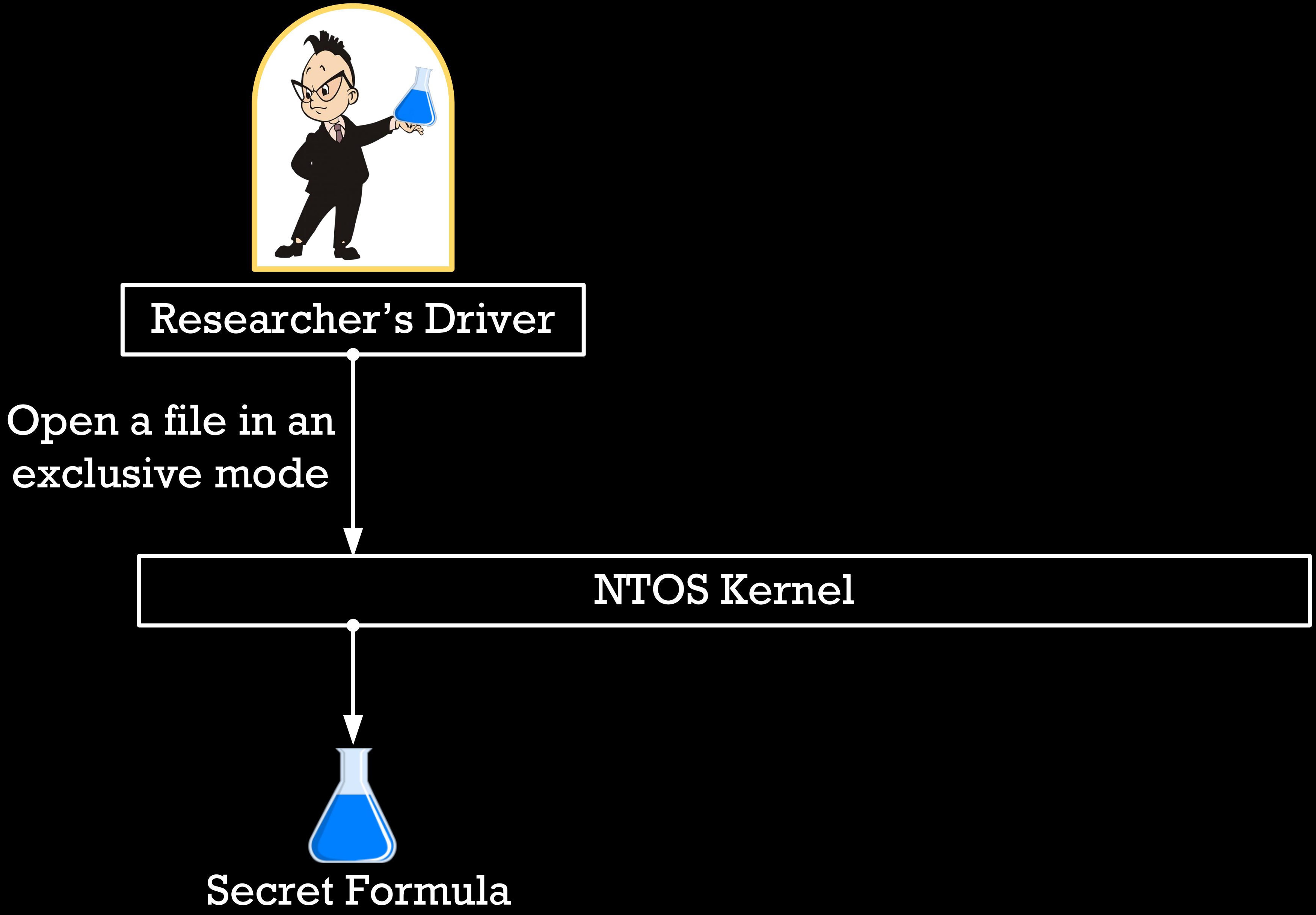


MemoryRanger

Episode 1

Bypass File Sharing Access Control via Hijacking File Structures

SCENARIO OF ATTACKS ON FILES



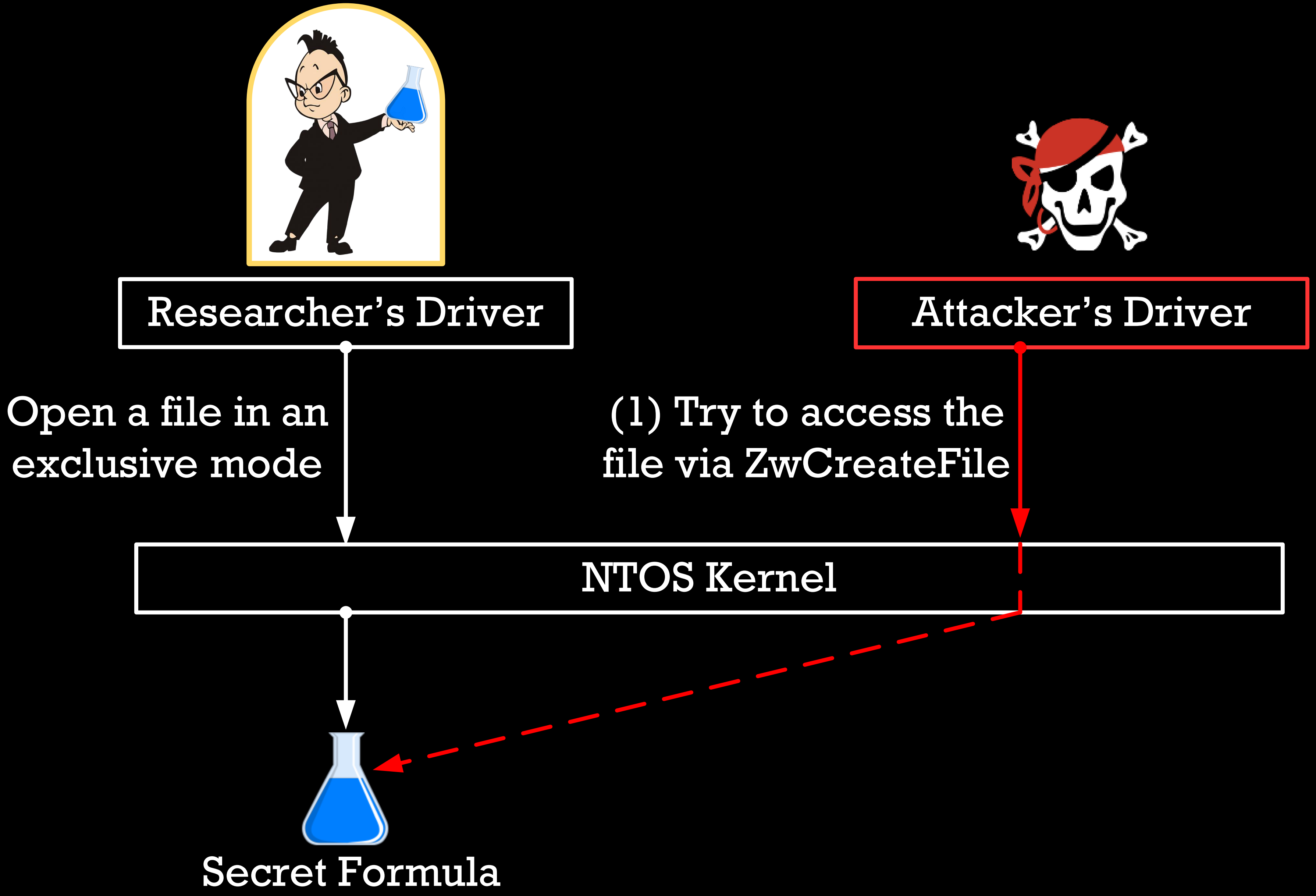
Researcher's Driver

Open a file in an exclusive mode

NTOS Kernel

Secret Formula

SCENARIO OF ATTACKS ON FILES



Researcher's Driver

Attacker's Driver

Open a file in an exclusive mode

(1) Try to access the file via ZwCreateFile

NTOS Kernel

Secret Formula

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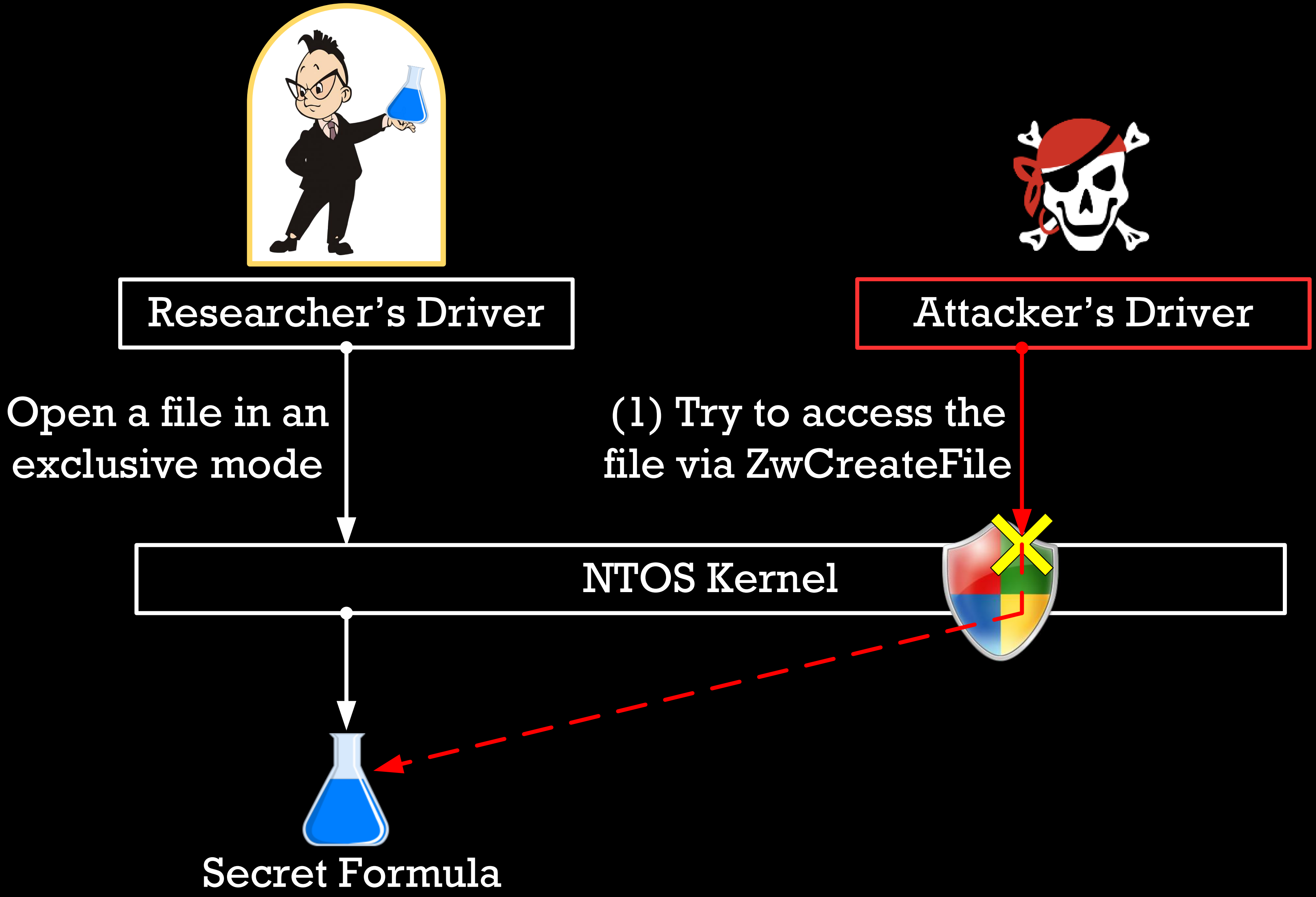

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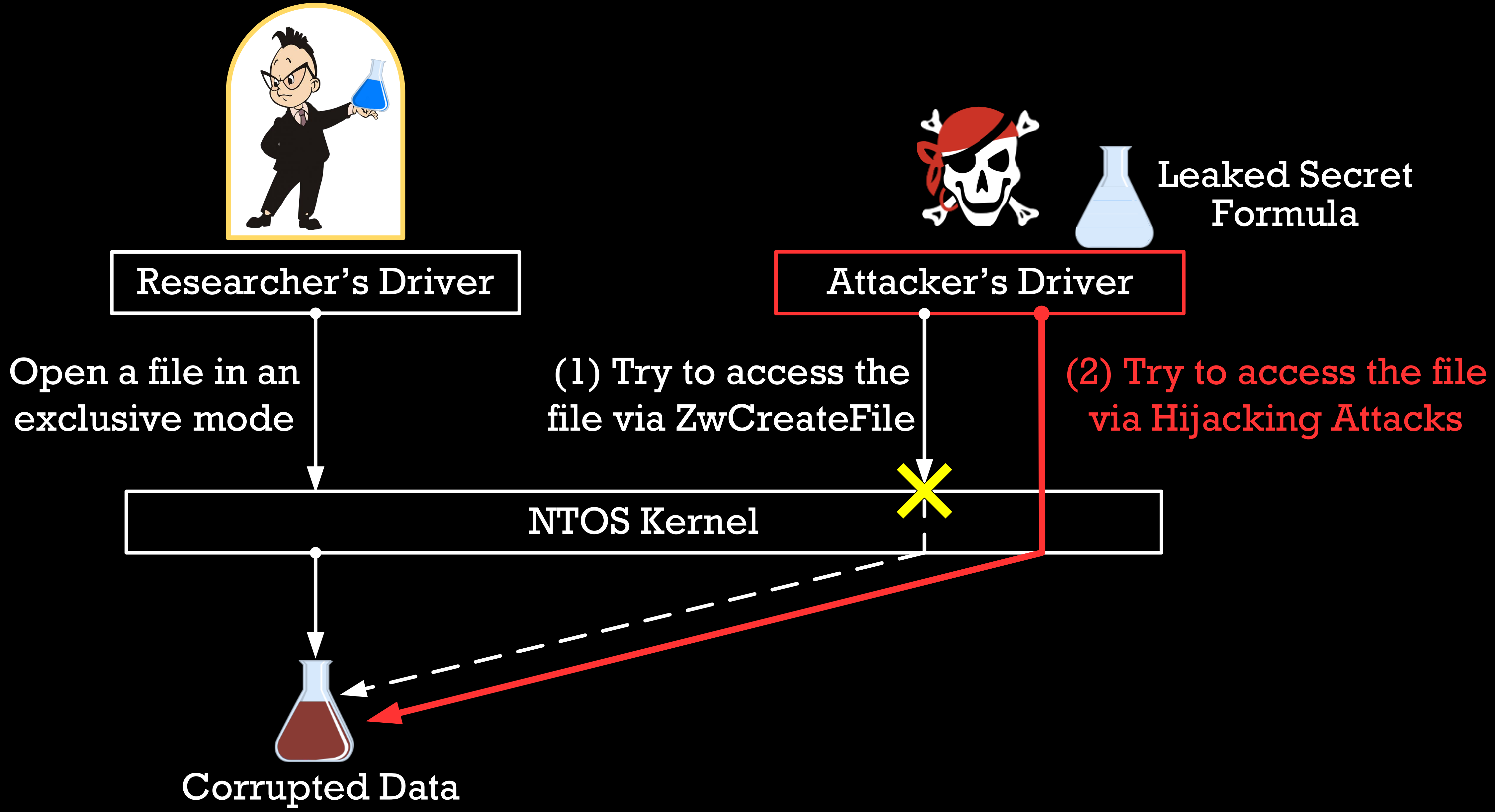


Researcher's Driver

Attacker's Driver

Leaked Secret Formula

Open a file in an exclusive mode

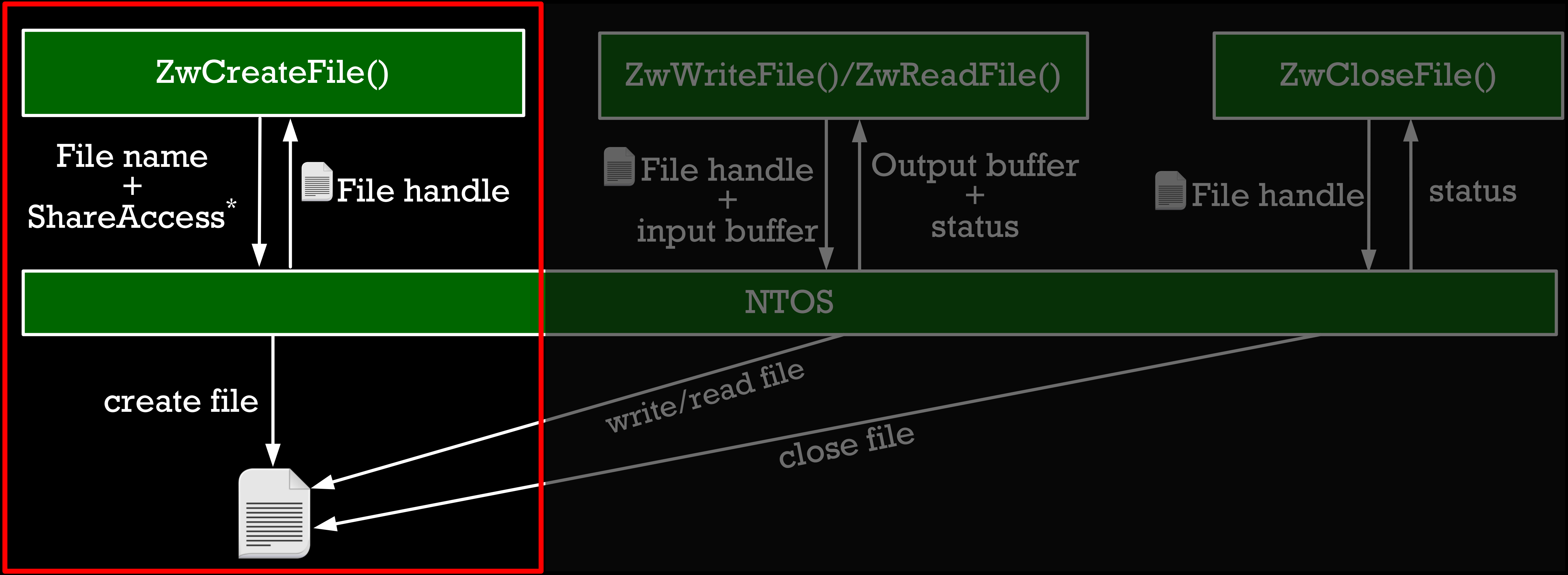
(1) Try to access the file via ZwCreateFile

(2) Try to access the file via Hijacking Attacks

NTOS Kernel

Corrupted Data

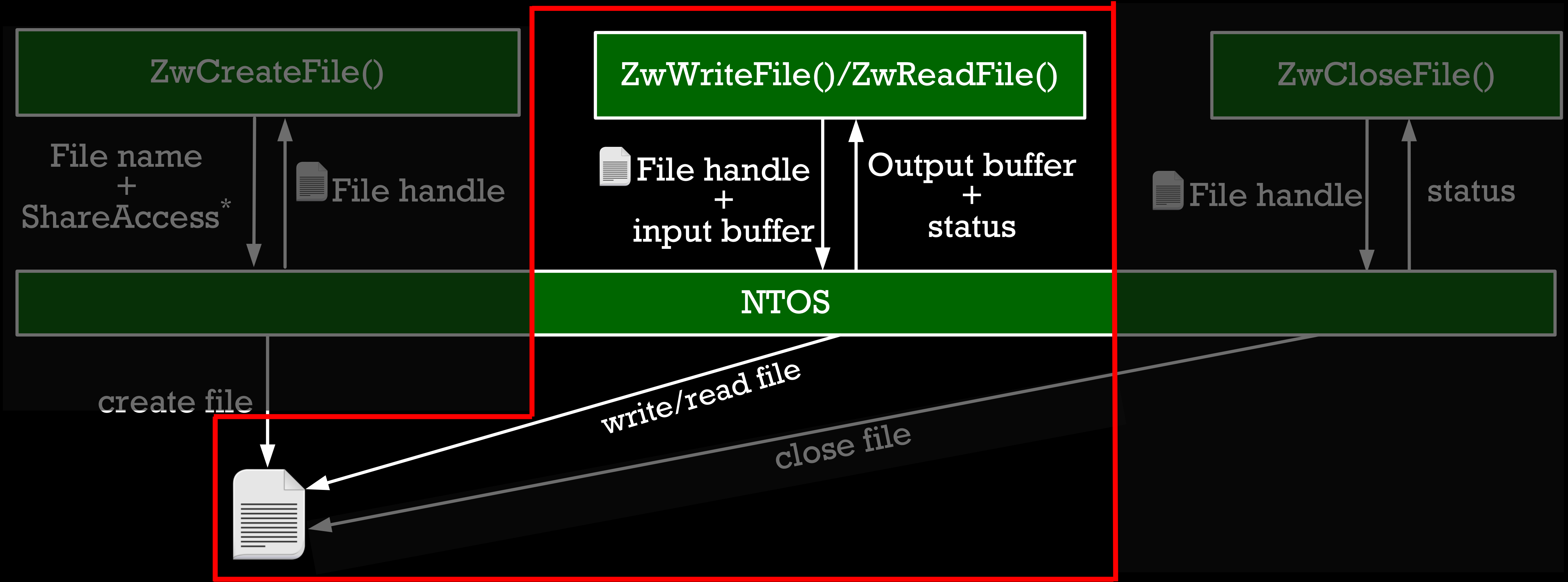
FILE SYSTEM KERNEL API ROUTINES



NTSTATUS ZwCreateFile(…, ShareAccess, …);

- ShareAccess flag determines whether other drivers can access the opened file.

FILE SYSTEM KERNEL API ROUTINES



ZwCreateFile()

File name
+
ShareAccess*

File handle

ZwWriteFile()/ZwReadFile()

File handle
+
input buffer

Output buffer
+
status

ZwCloseFile()

File handle

status

NTOS

create file

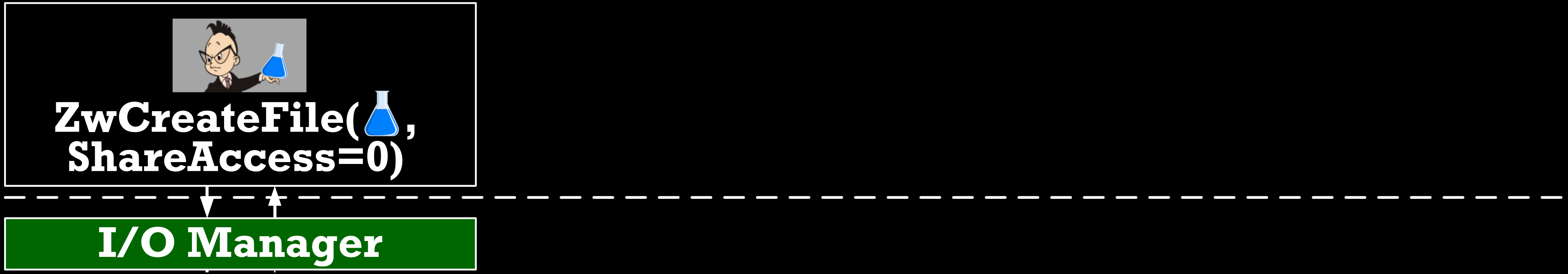
write/read file

close file

INTERNALS OF ZwCreateFile

ZwCreateFile(🧪, ShareAccess=0)

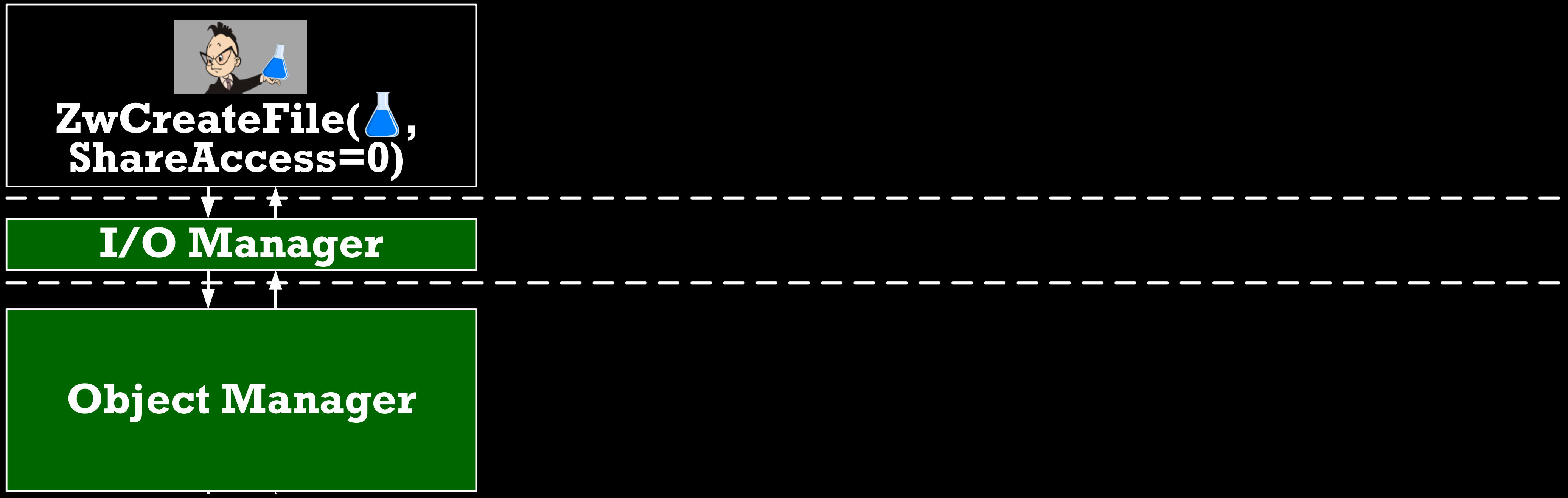
INTERNALS OF ZwCreateFile



ZwCreateFile(🧪, ShareAccess=0)

I/O Manager

INTERNALS OF ZwCreateFile

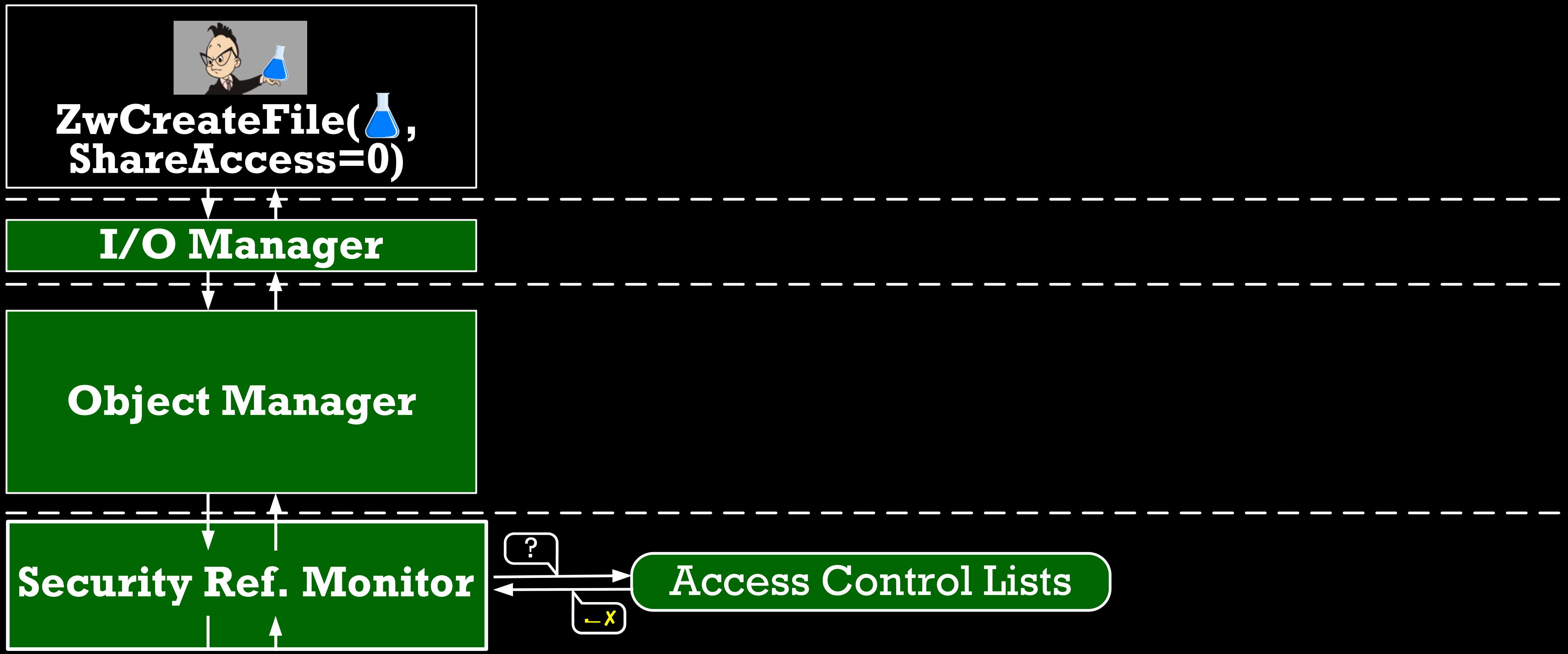


ZwCreateFile(🧪, ShareAccess=0)

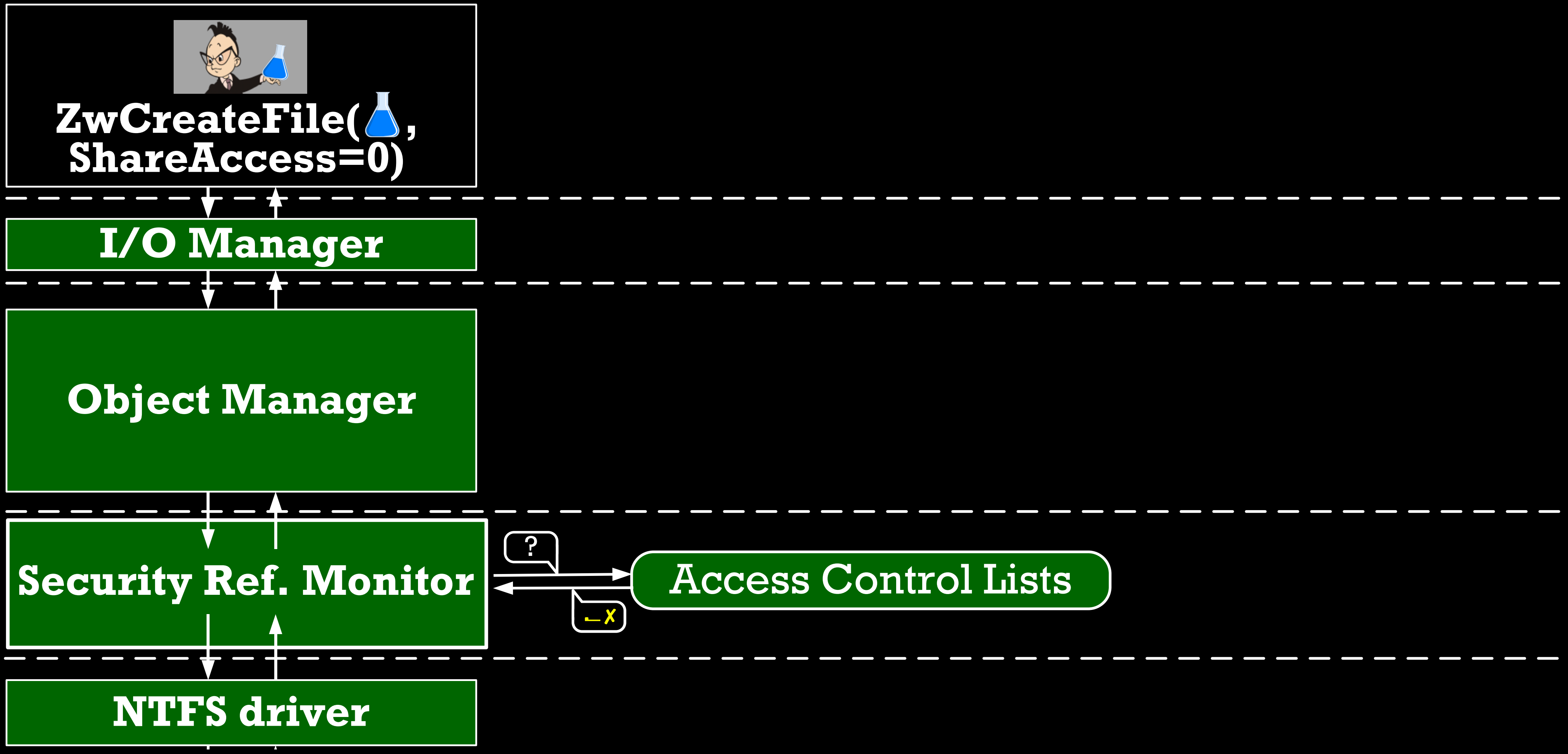
I/O Manager

Object Manager

INTERNALS OF ZwCreateFile



INTERNALS OF ZwCreateFile



ZwCreateFile(🧪, ShareAccess=0)

I/O Manager

Object Manager

Security Ref. Monitor

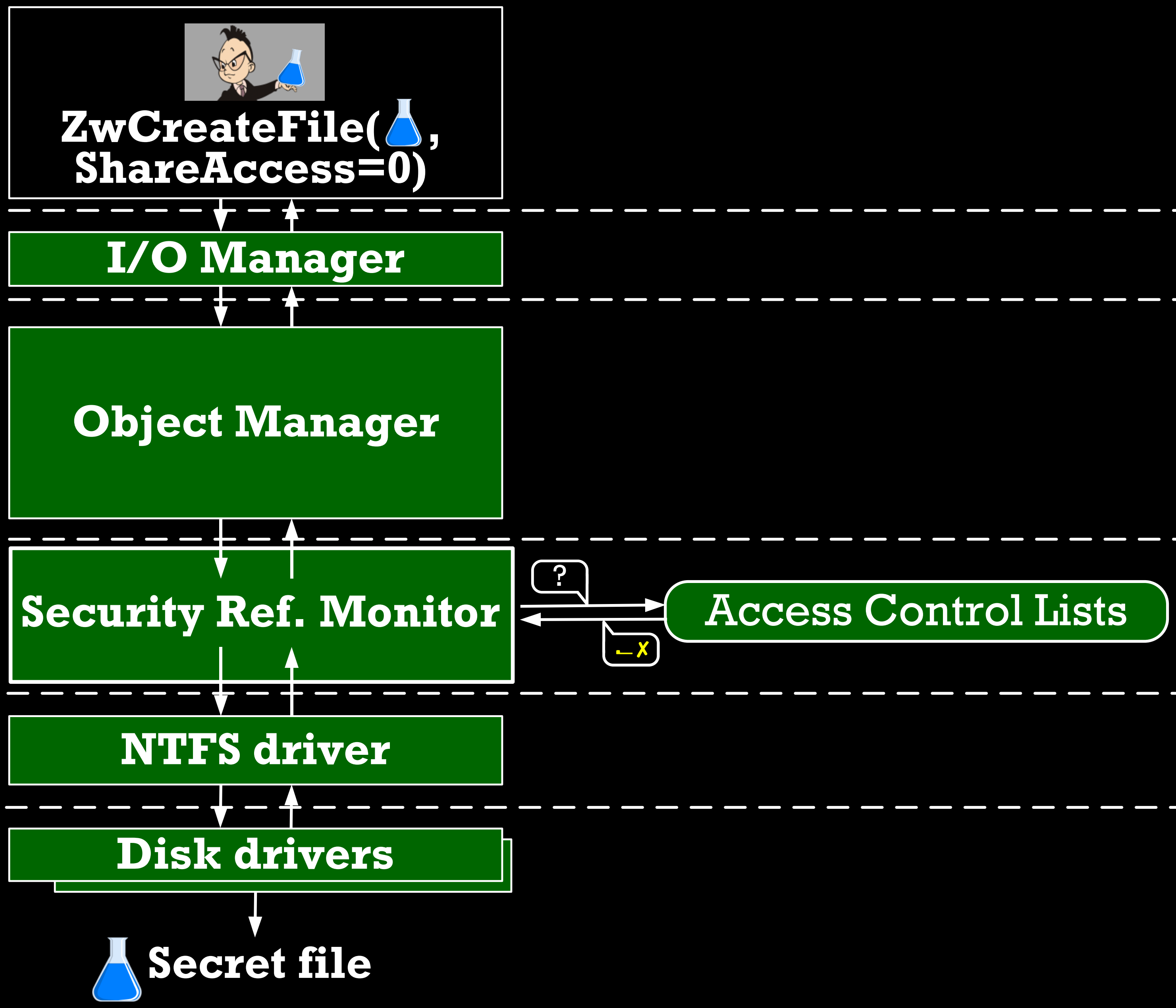
?

Access Control Lists

✗

NTFS driver

INTERNALS OF ZwCreateFile



ZwCreateFile(🧪, ShareAccess=0)

I/O Manager

Object Manager

Security Ref. Monitor

?

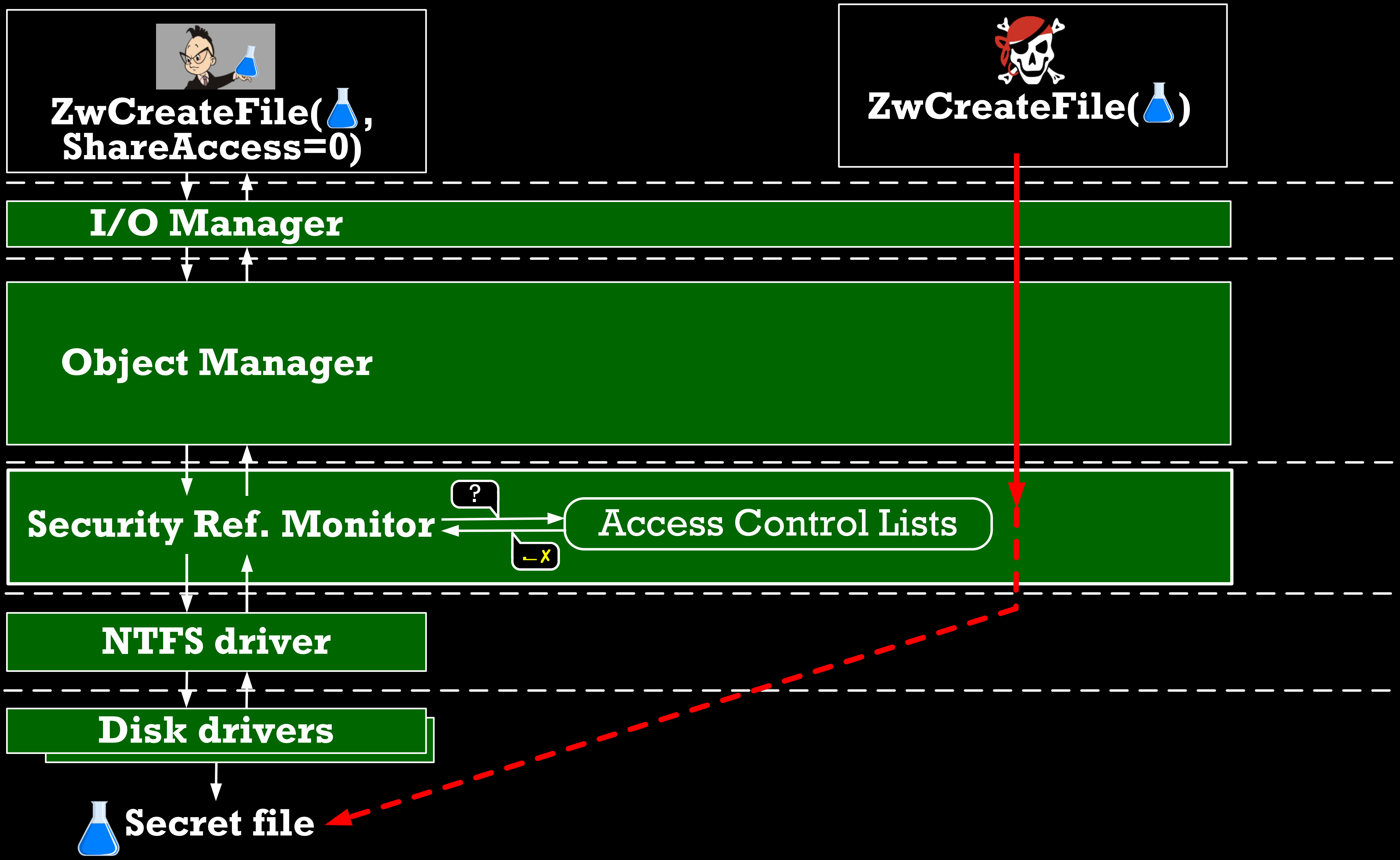
Access Control Lists

NTFS driver

Disk drivers

🧪 Secret file

SECURITY REFERENCE MONITOR PREVENTS ILLEGAL ACCESS



ZwCreateFile(🧪, ShareAccess=0)

ZwCreateFile(🧪)

I/O Manager

Object Manager

Security Ref. Monitor

Access Control Lists

NTFS driver

Disk drivers

🧪 Secret file

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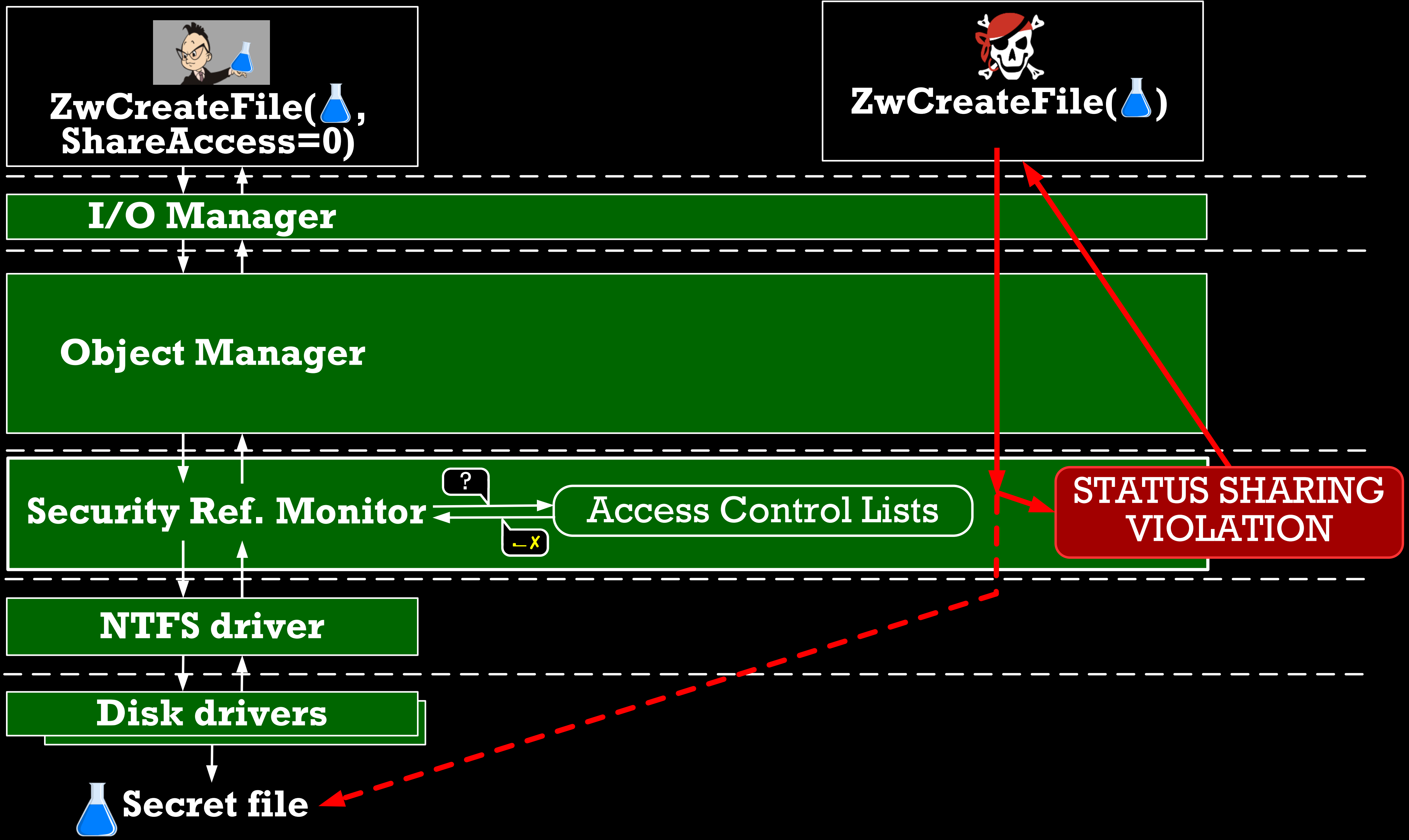


ZwCreateFile(🧪,
ShareAccess=0)

ZwCreateFile(🧪)

I/O Manager

Object Manager

Security Ref. Monitor

Access Control Lists

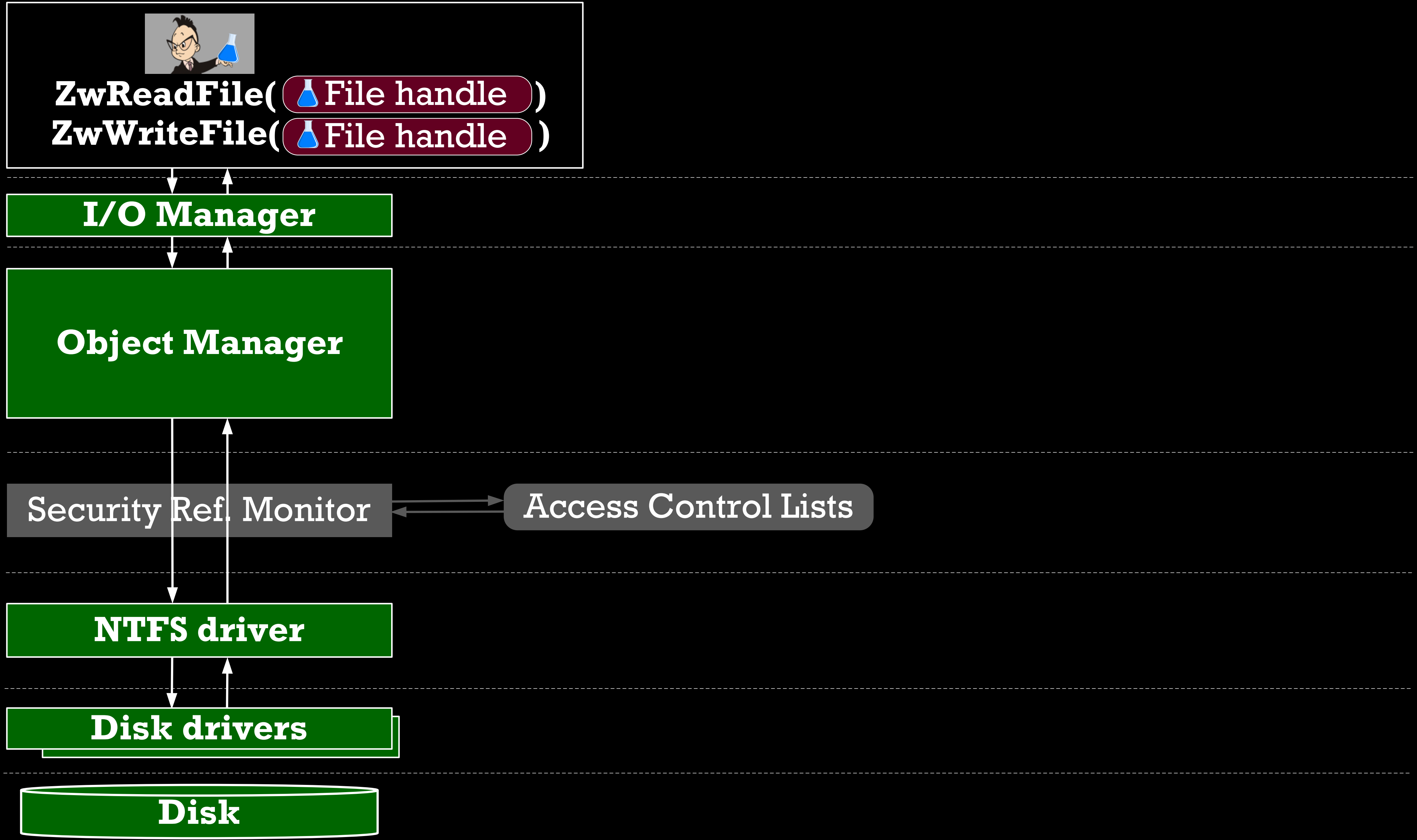
STATUS SHARING VIOLATION

NTFS driver

Disk drivers

🧪 Secret file

INTERNALS OF ZwReadFile/ZwWriteFile



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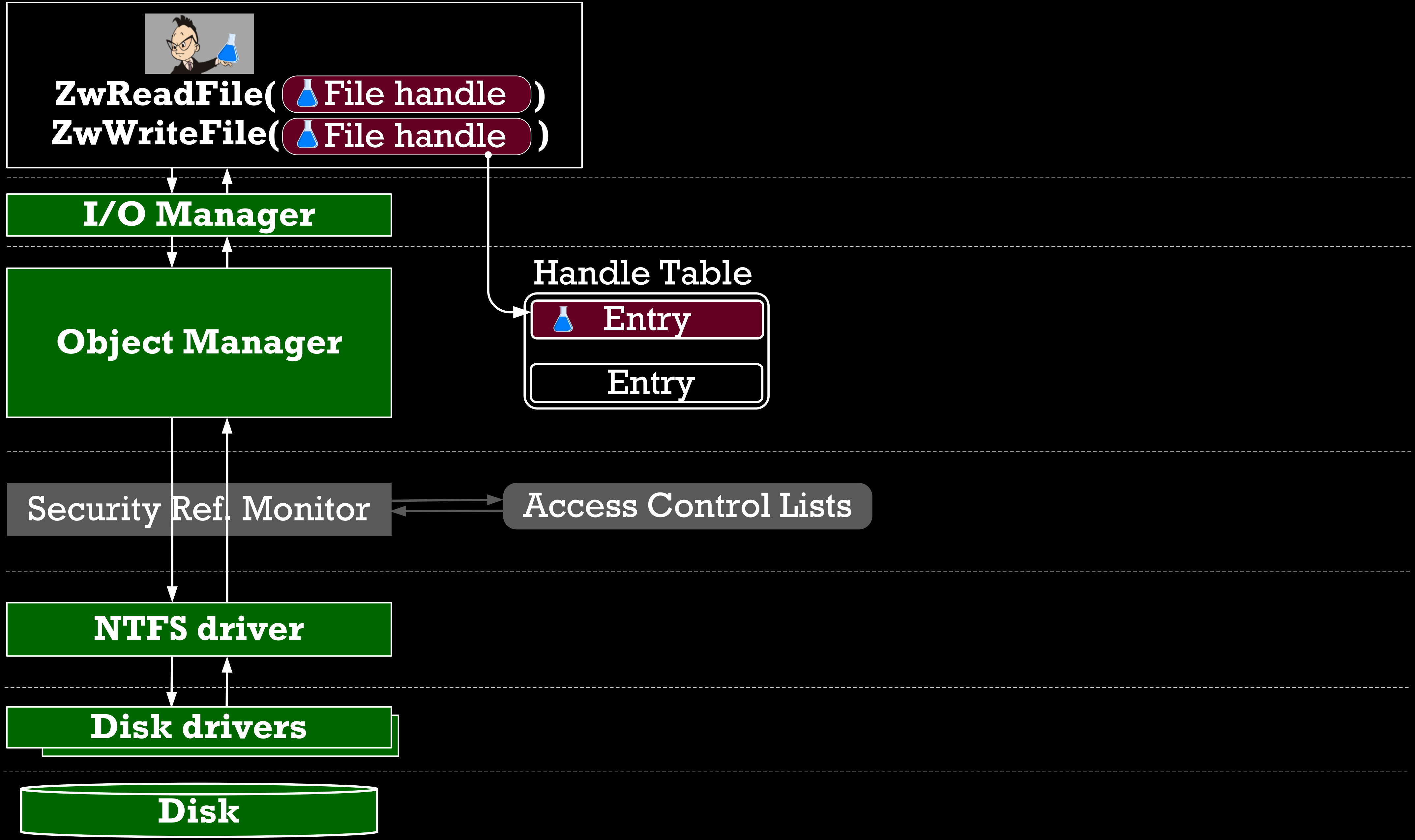

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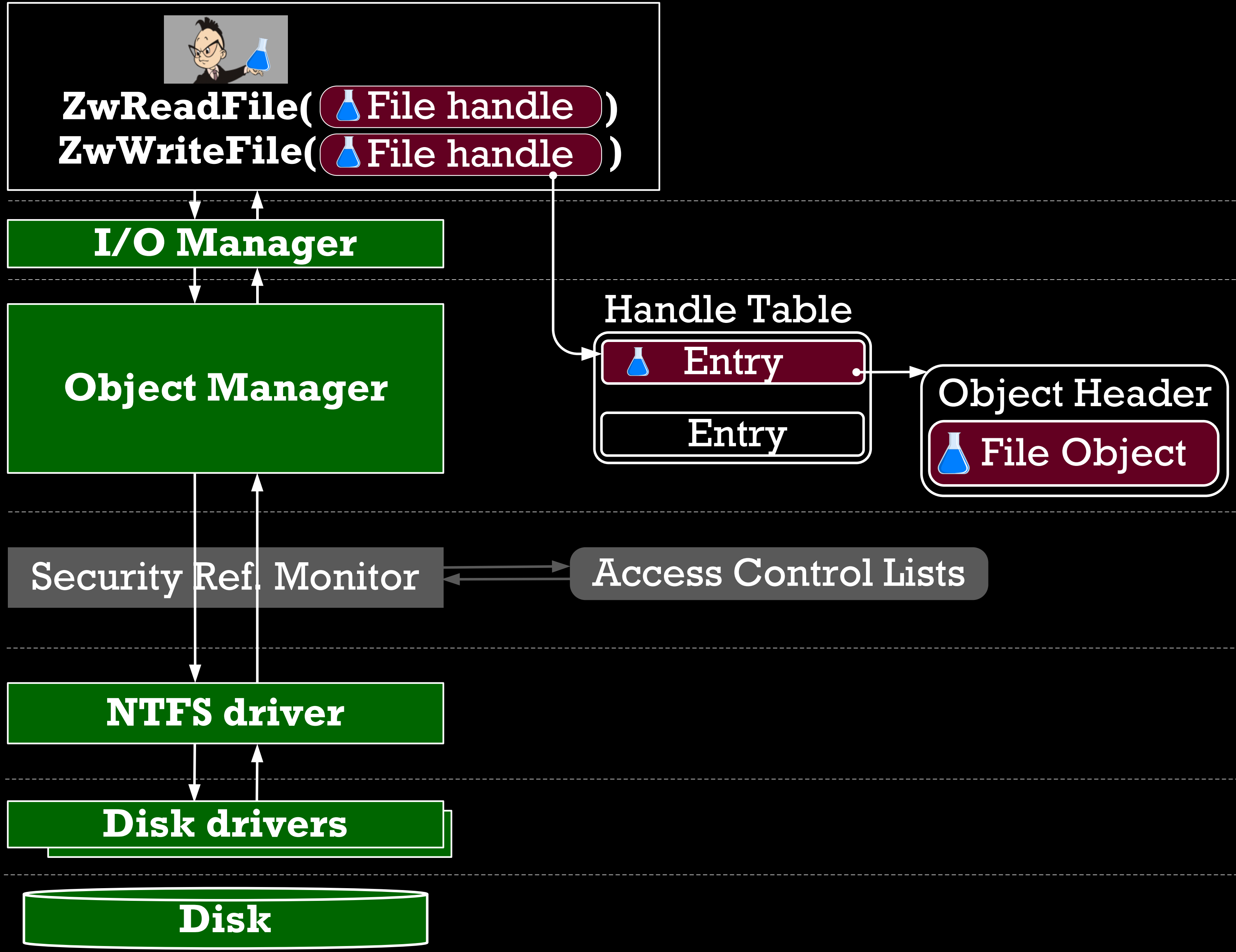
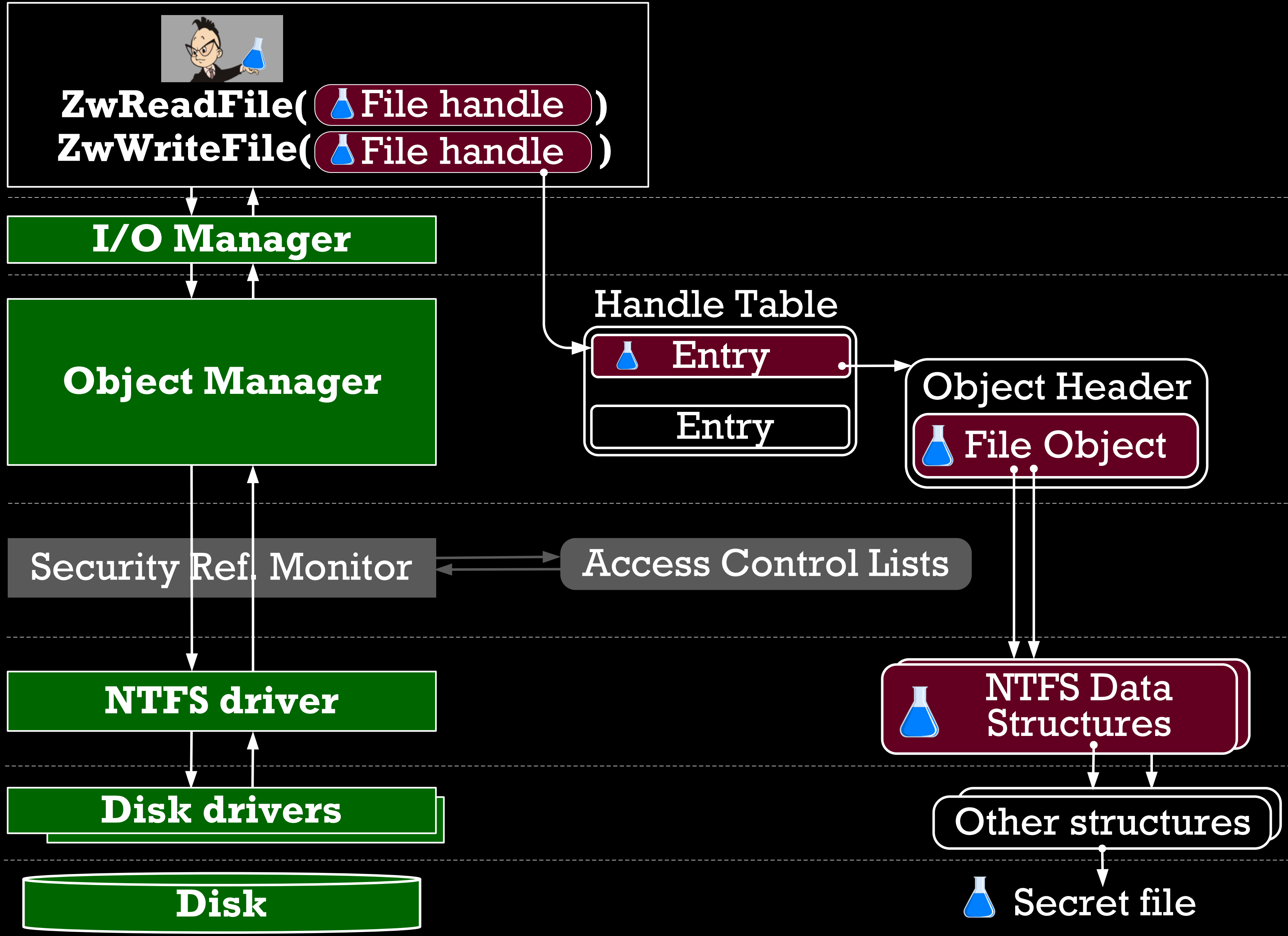


ZwReadFile(File handle)
ZwWriteFile(File handle)

INTERNALS OF ZwReadFile/ZwWriteFile

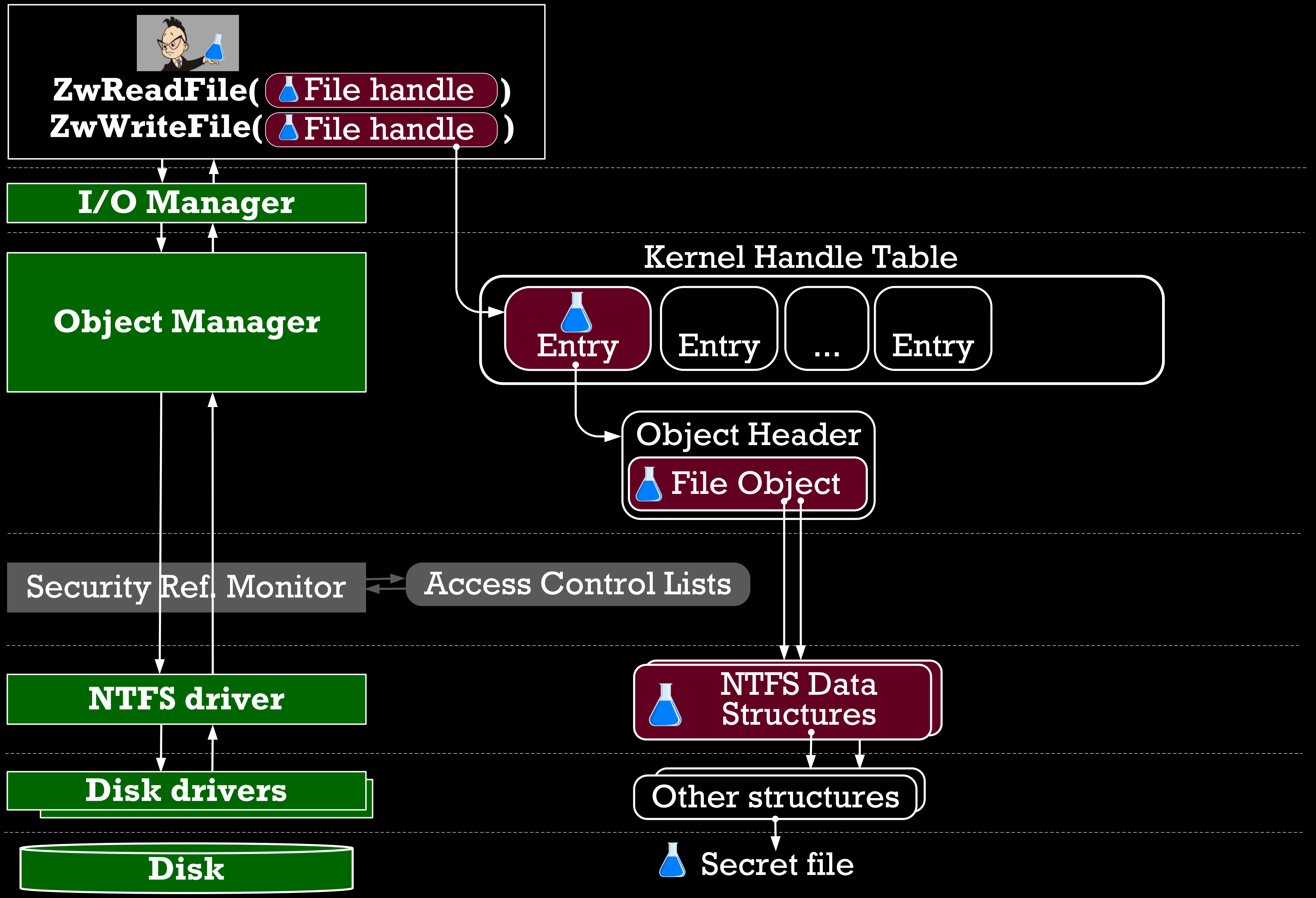


SUMMARY

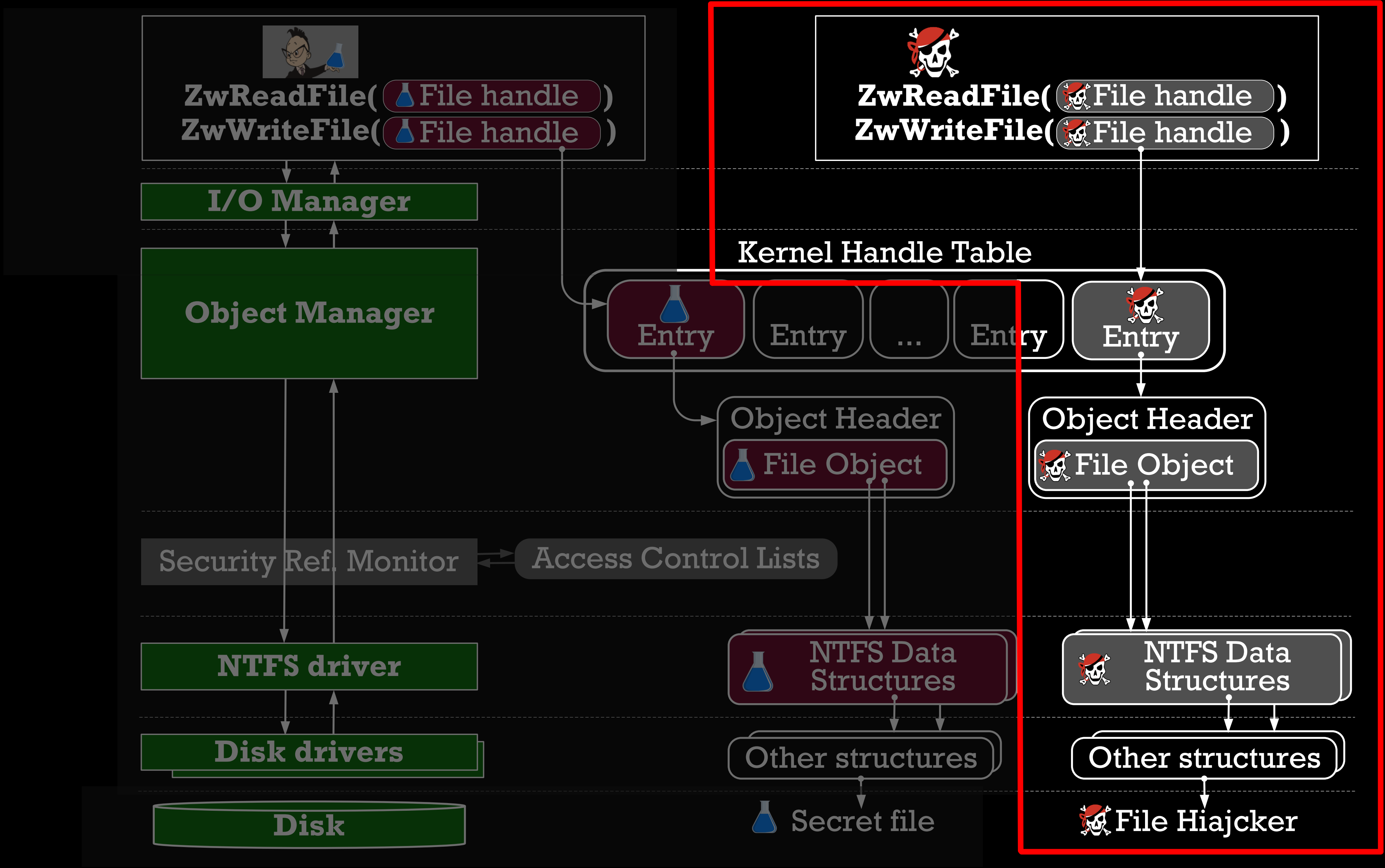
- ZwCreateFile checks shared access permissions

- ZwWriteFile and ZwReadFile do not bother about access permissions

IDEA OF HIJACKING: CREATE A FILE HIAJCKER



IDEA OF HIJACKING: CREATE A FILE HIAJCKER AND COPY STRUCTS



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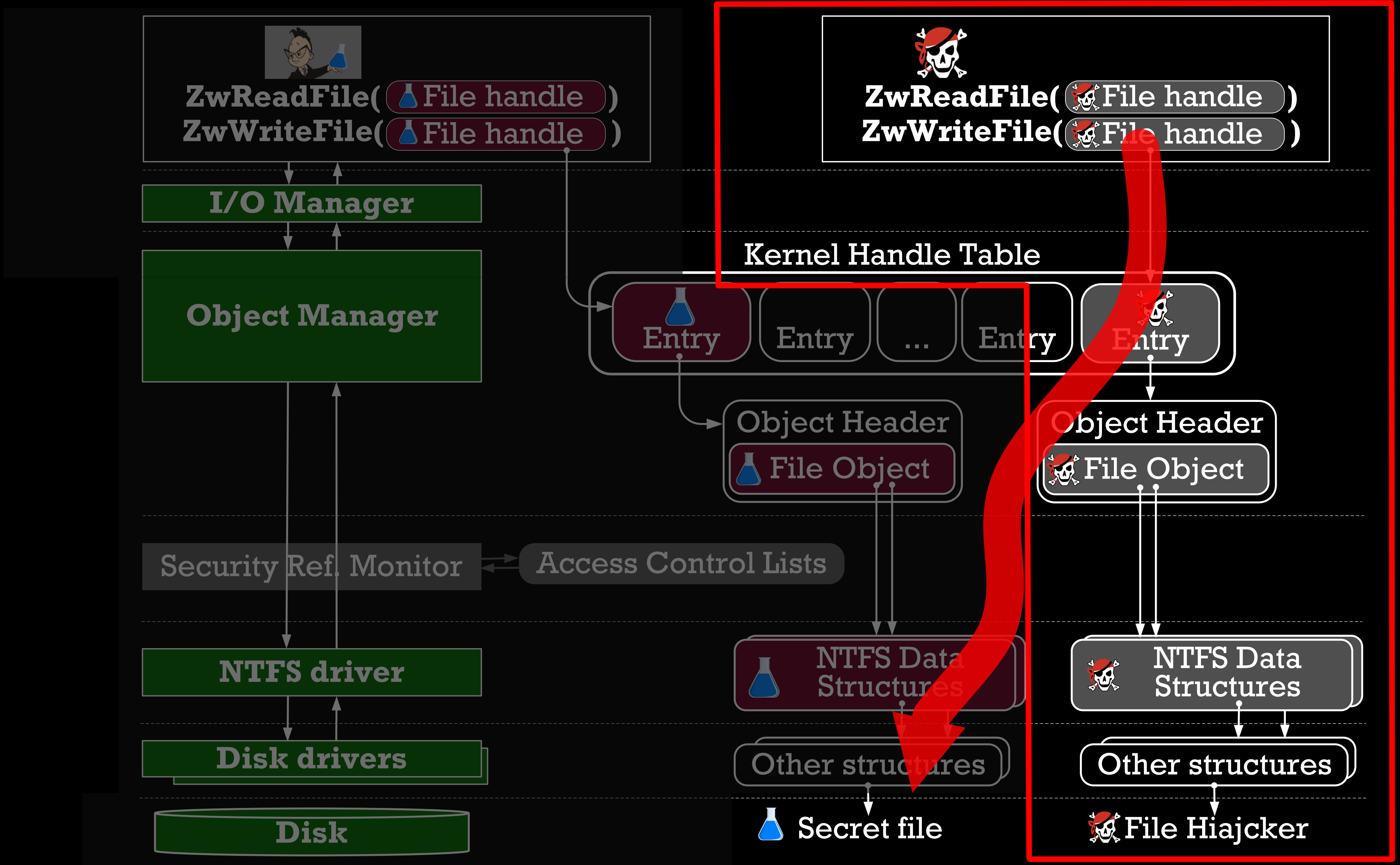
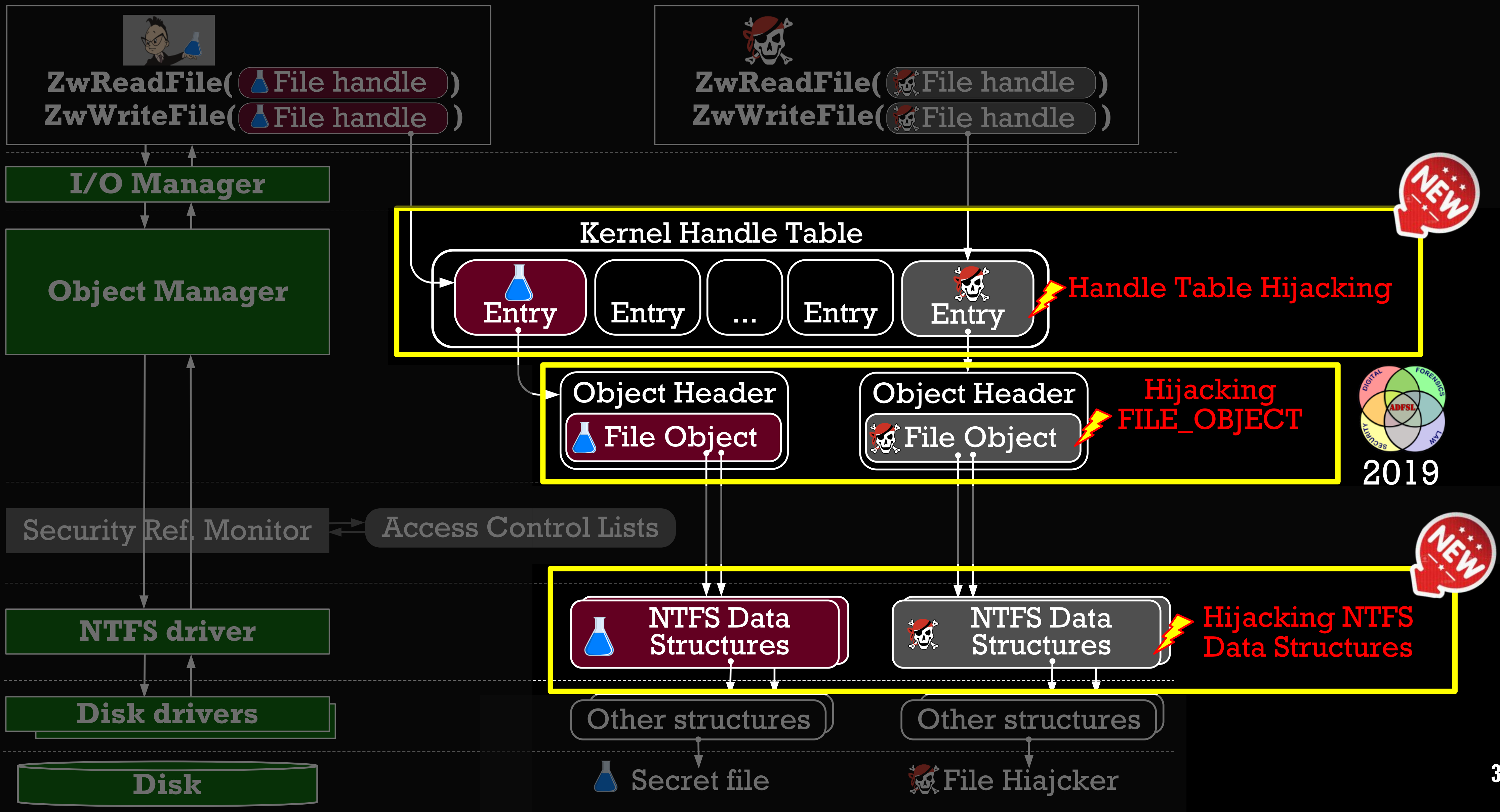


HIJACKING ATTACKS ON FILES STRUCTURES



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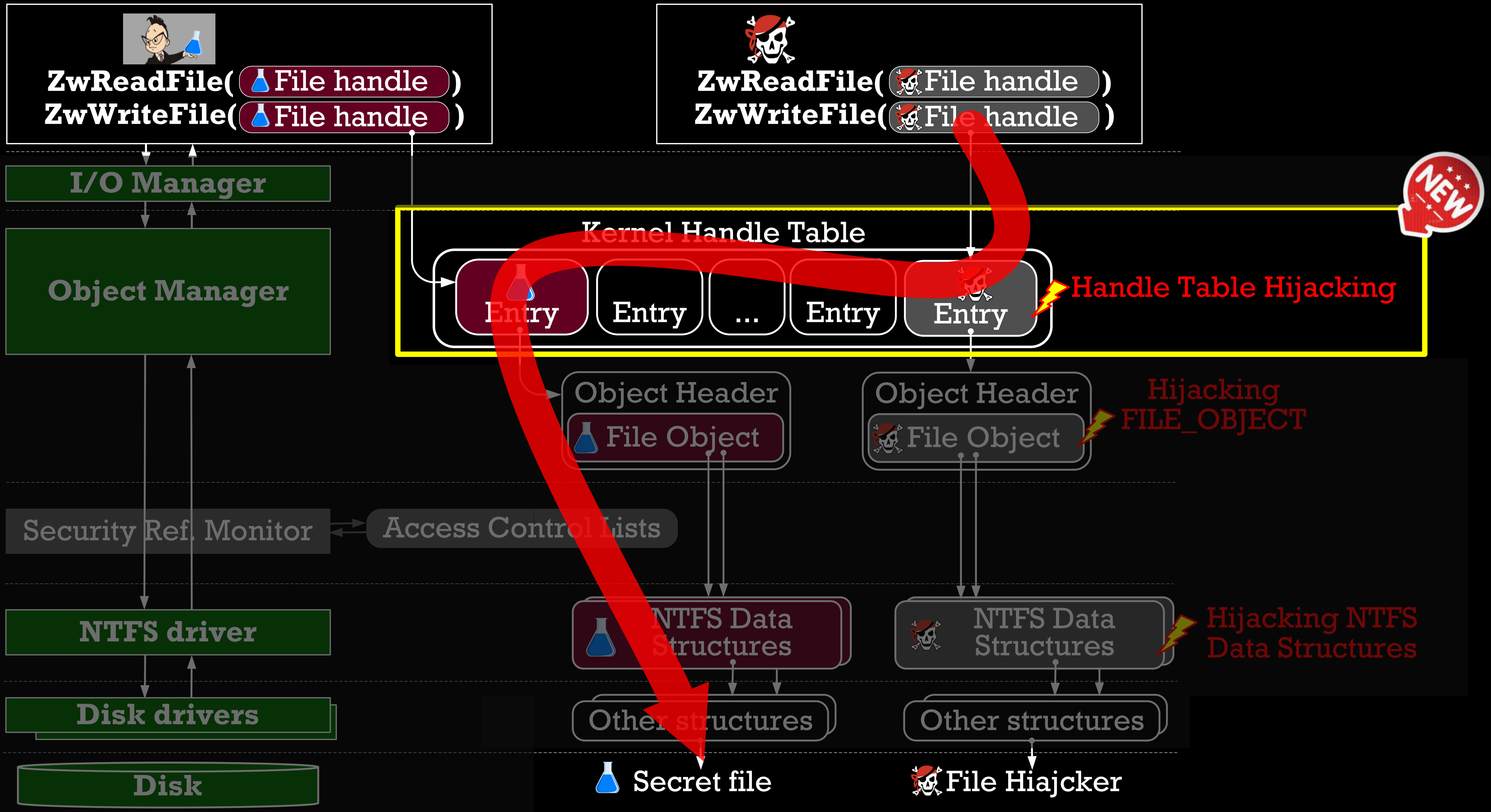

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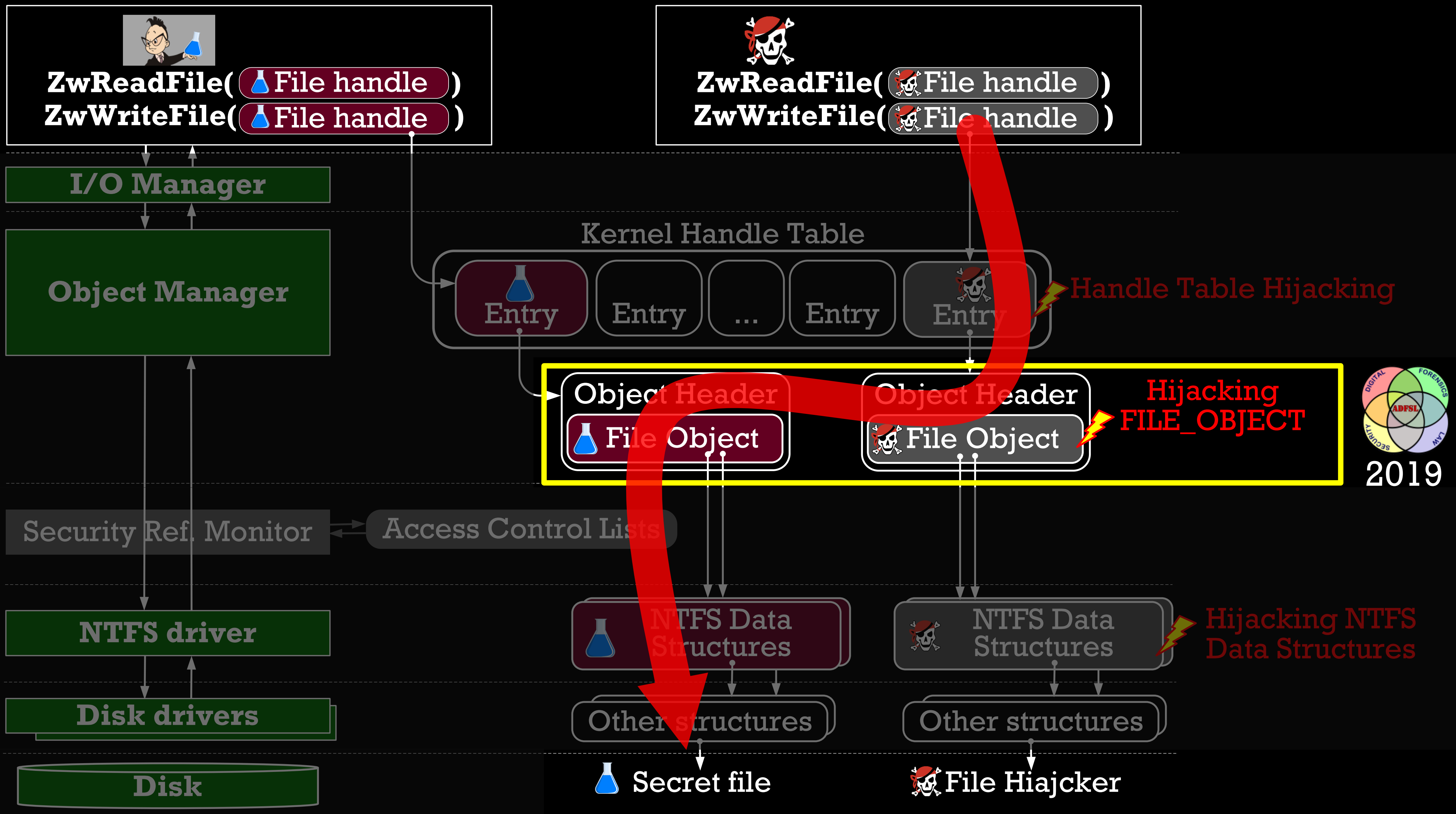

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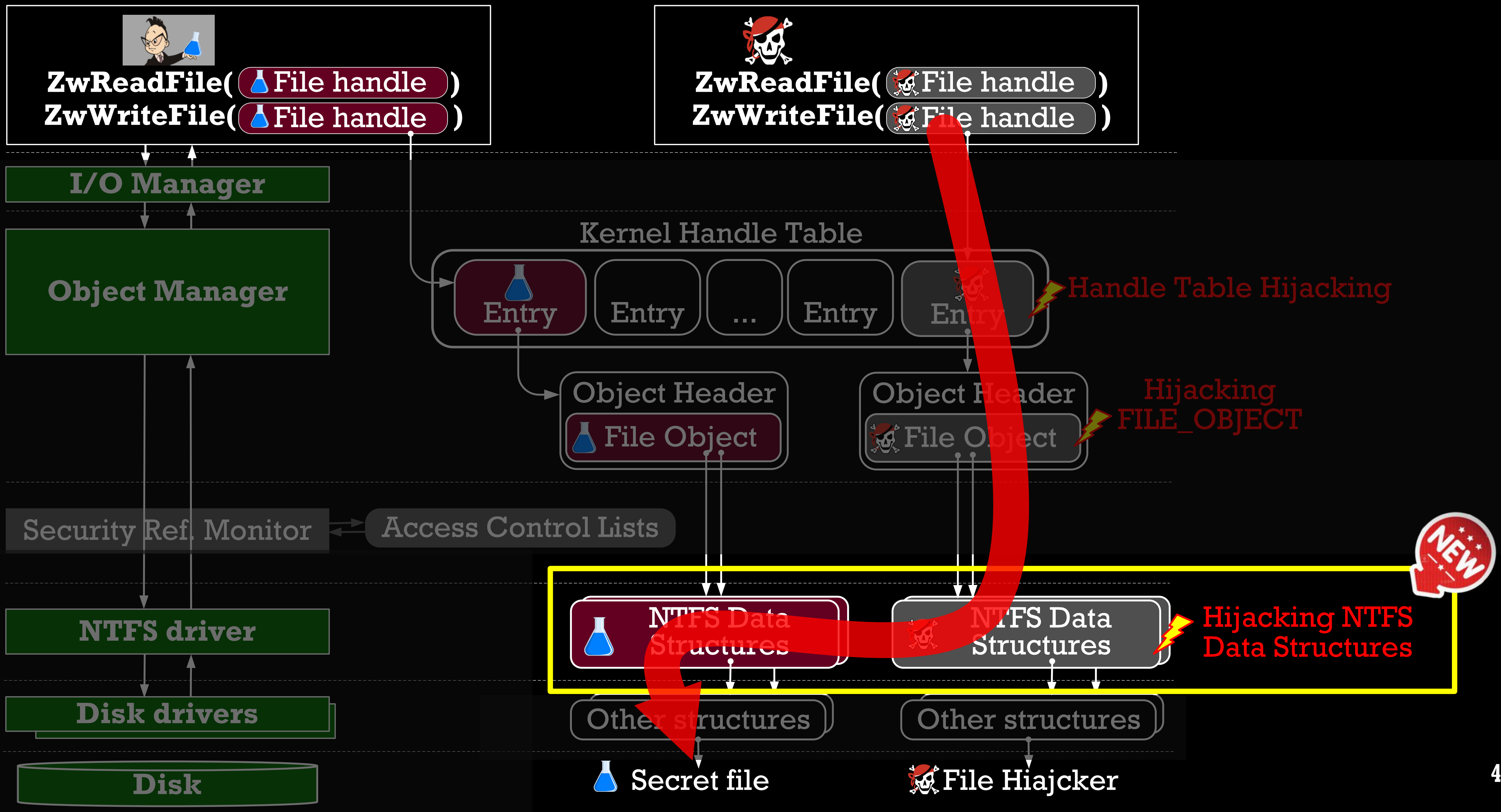


ZwReadFile(File handle)
ZwWriteFile(File handle)

ZwReadFile(File handle)
ZwWriteFile(File handle)

I/O Manager

Object Manager

Kernel Handle Table

Entry | Entry | … | Entry | Entry

Handle Table Hijacking

Object Header
File Object

Object Header
File Object

Hijacking
FILE_OBJECT

Security Ref. Monitor

Access Control Lists

NTFS driver

NTFS Data Structures

NTFS Data Structures

NEW

Hijacking NTFS
Data Structures

Disk drivers

Other structures

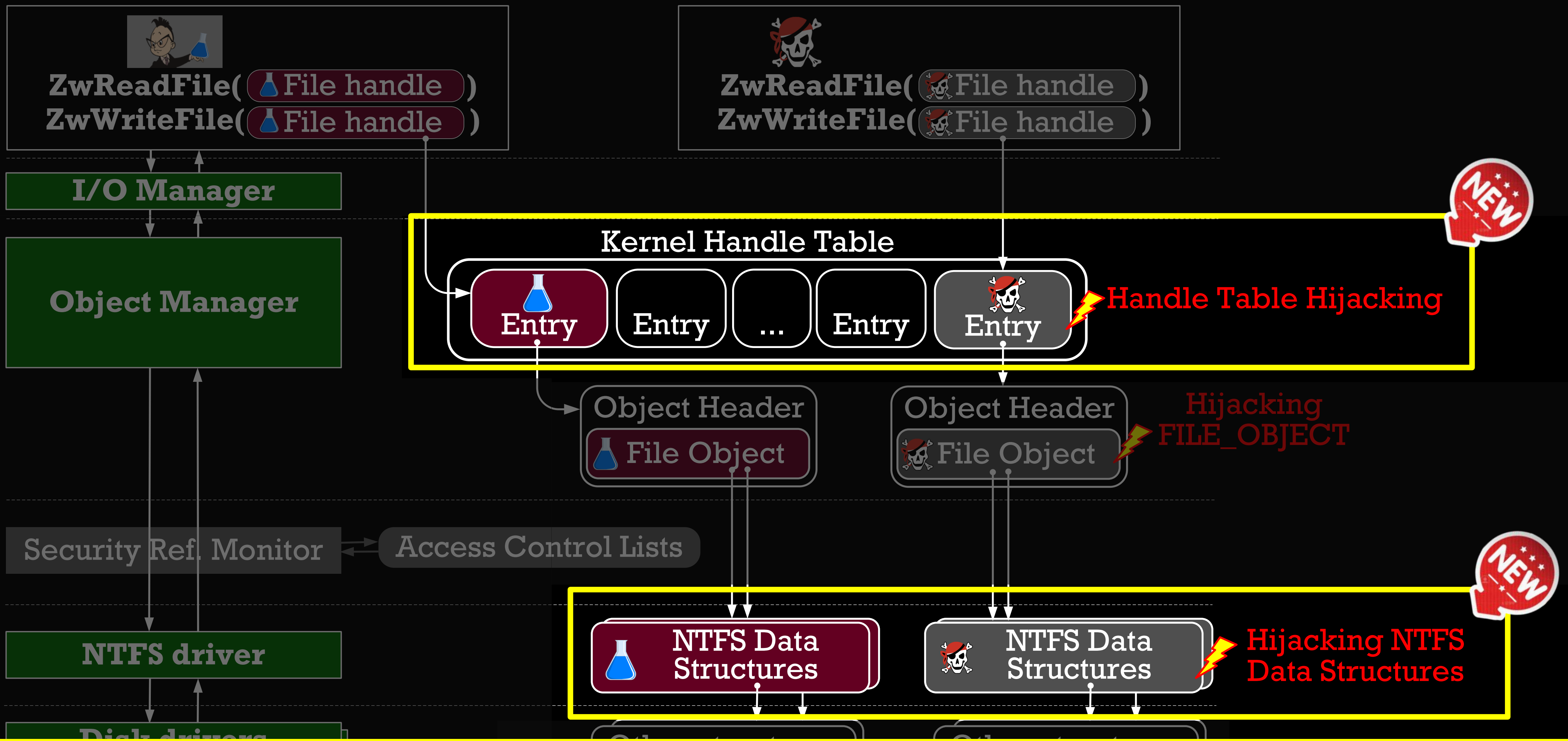
Other structures

Disk

Secret file

File Hiajcker

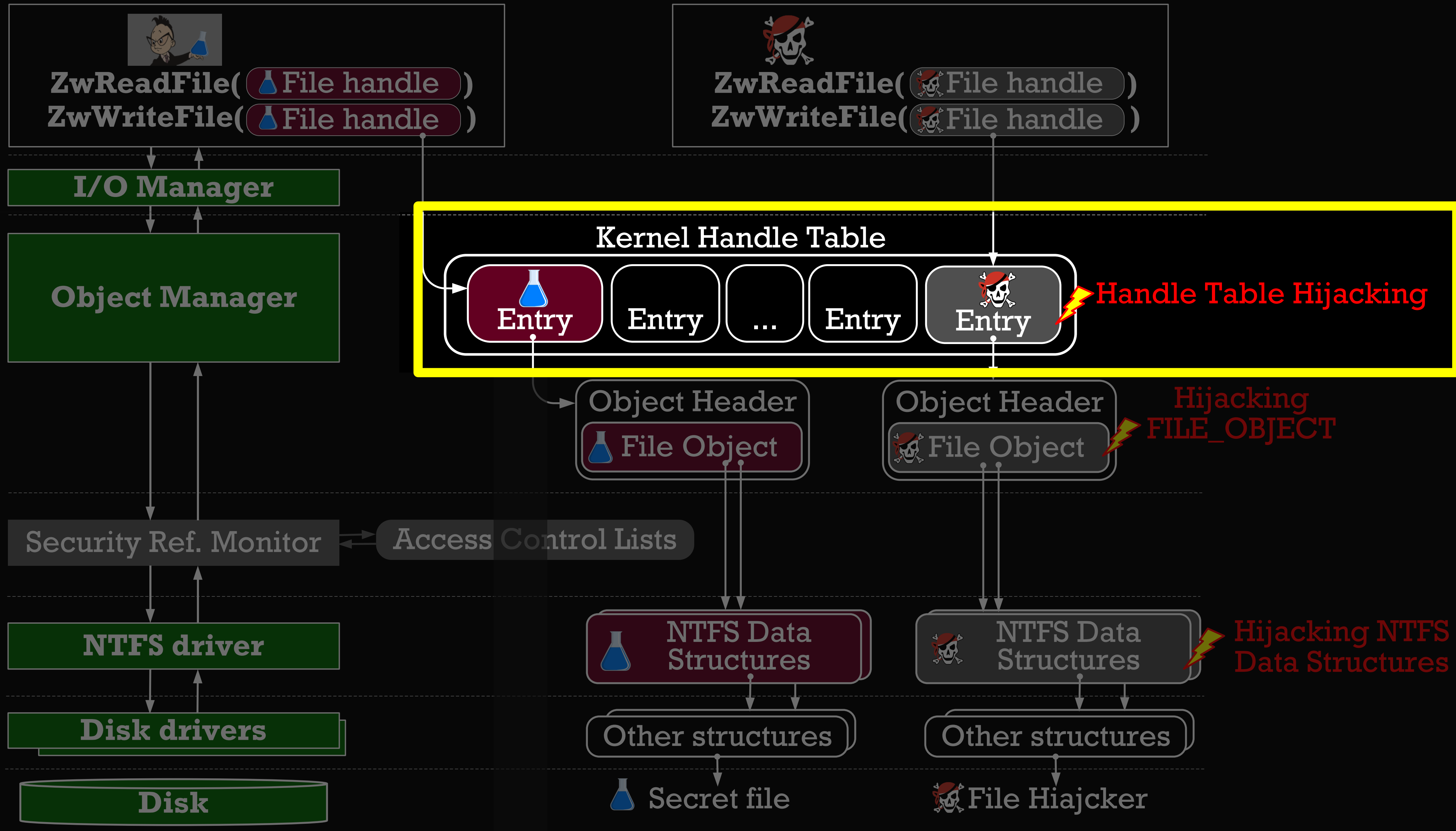
HIJACKING ATTACKS ON FILES STRUCTURES



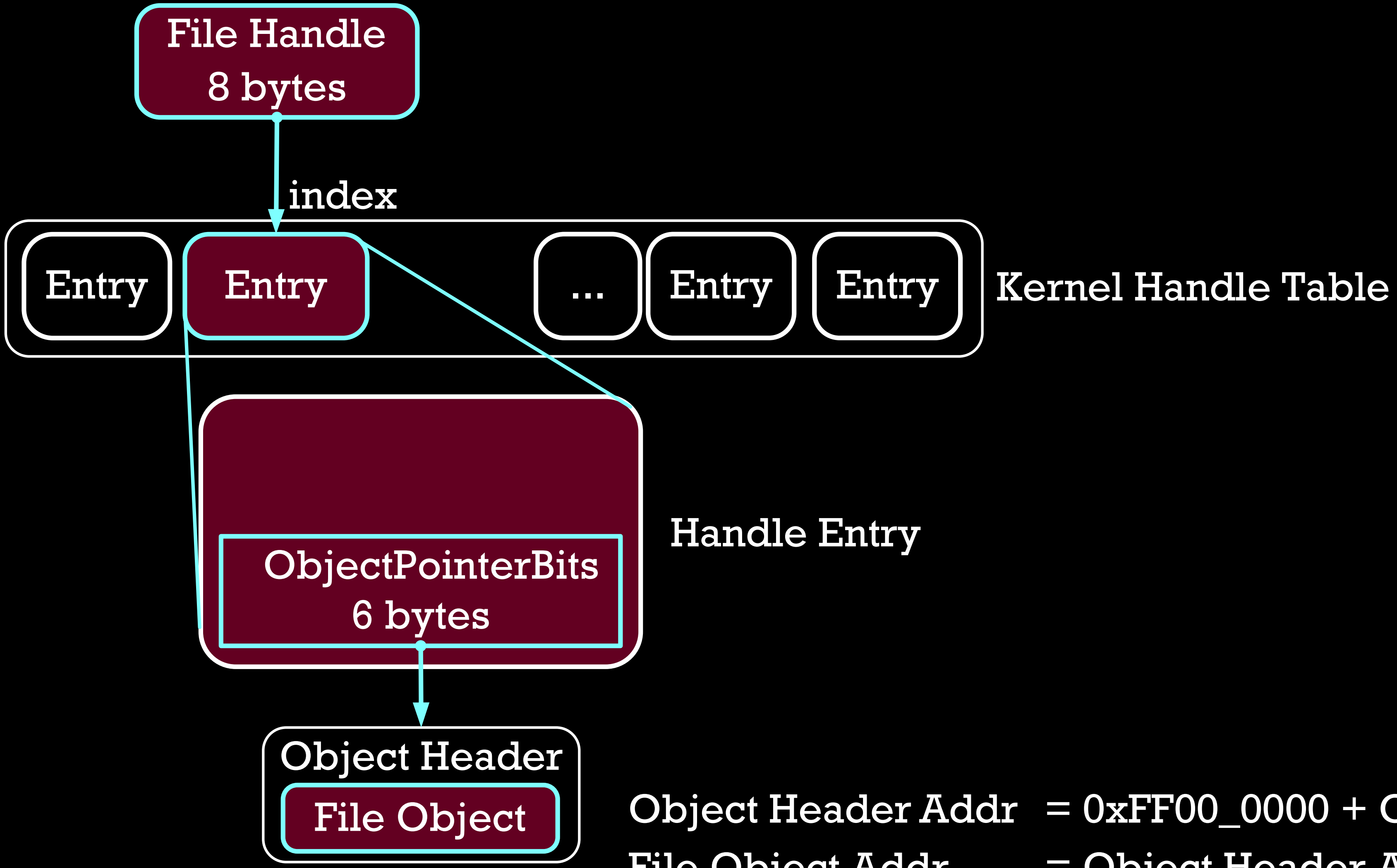
Hijacking FILE_OBJECT → MemoryRanger Prevents Hijacking FILE_OBJECT Structures in Windows Kernel
https://igorkorkin.blogspot.com/2019/04/memoryranger-prevents-hijacking.html

HANDLE HIJACKING ATTACK

HANDLE HIJACKING ATTACK



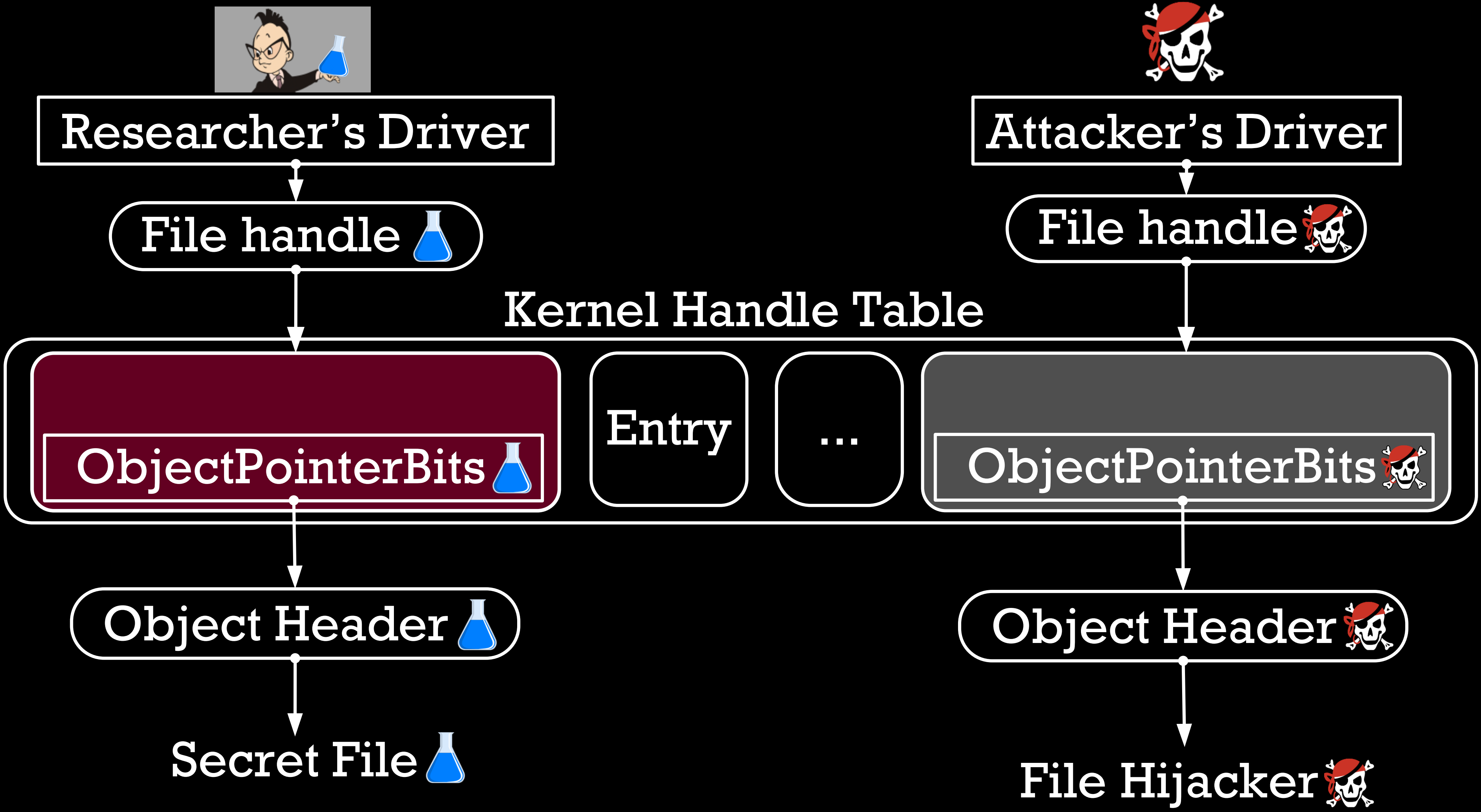
KERNEL HANDLE TABLE



Object Header Addr = 0xFF00_0000 + ObjectPointerBits

File Object Addr = Object Header Addr + 0x18

HANDLE TABLE HIJACKING



Researcher’s Driver

File handle

Kernel Handle Table

ObjectPointerBits

Entry

...

ObjectPointerBits

Object Header

Secret File

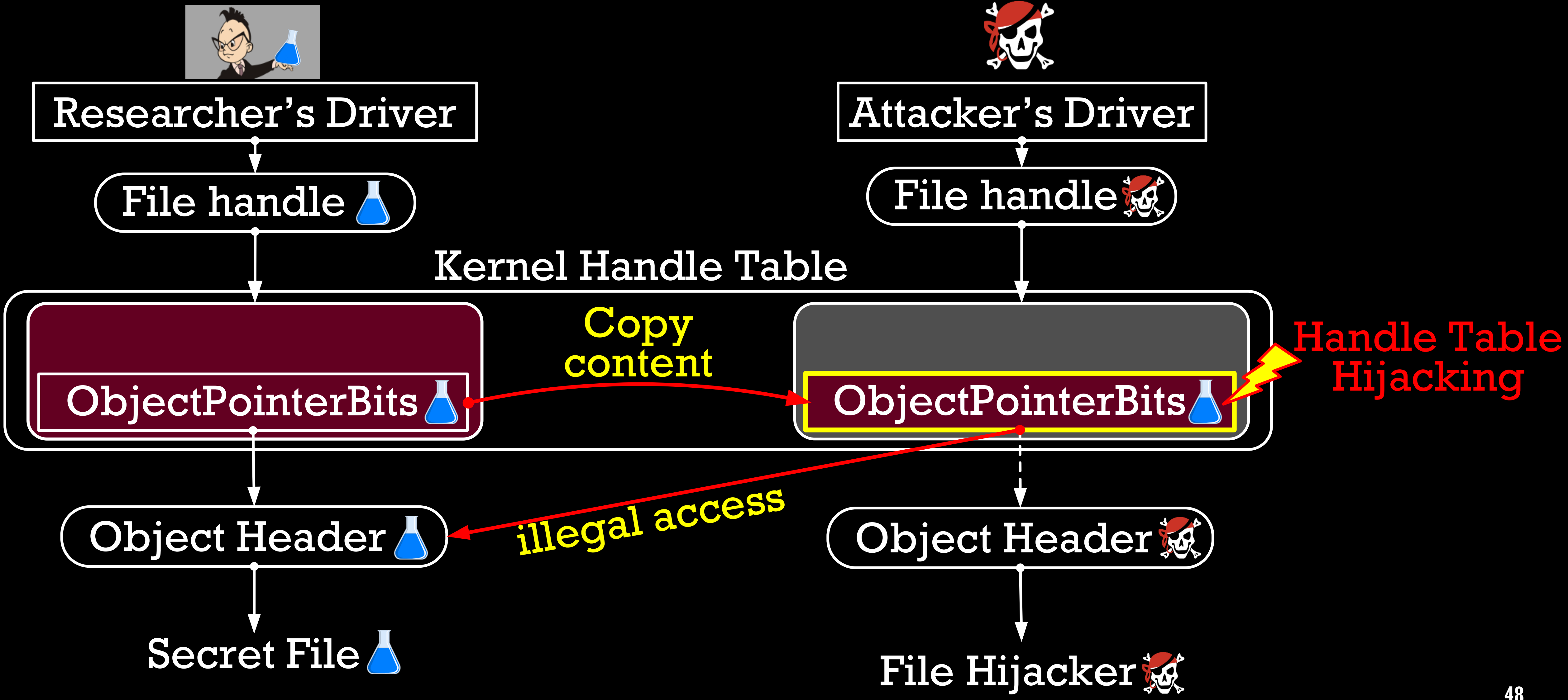
Attacker’s Driver

File handle

Object Header

File Hijacker

HANDLE TABLE HIJACKING



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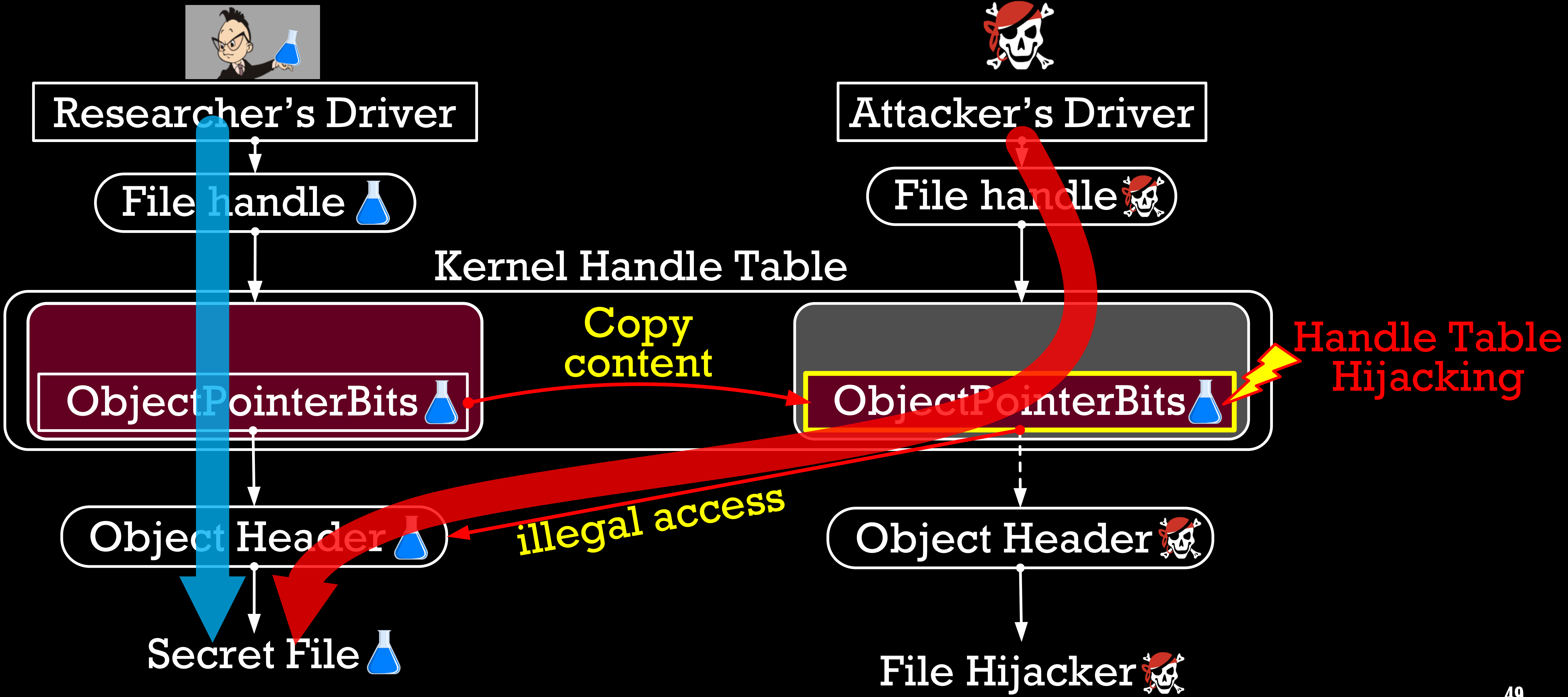
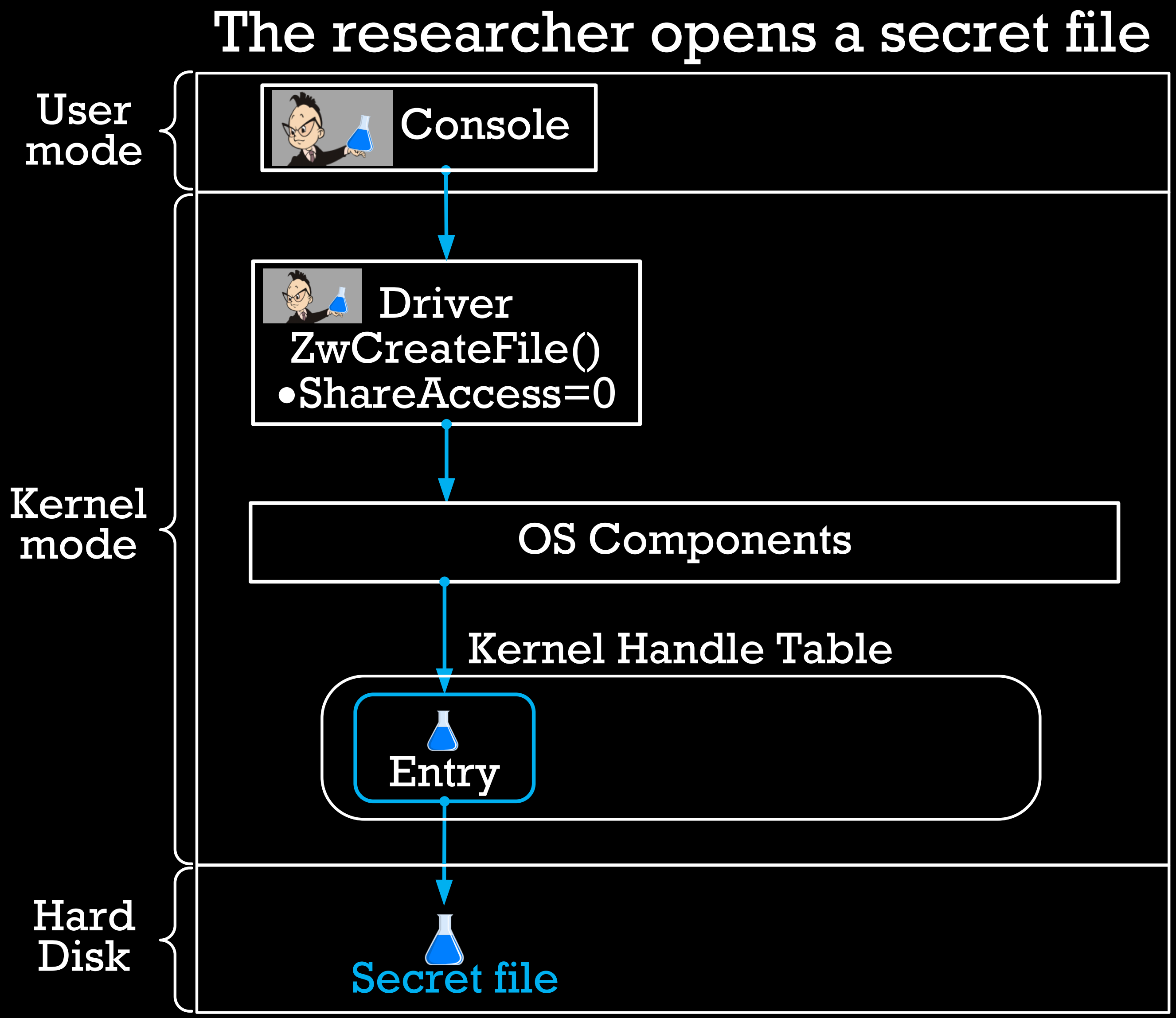
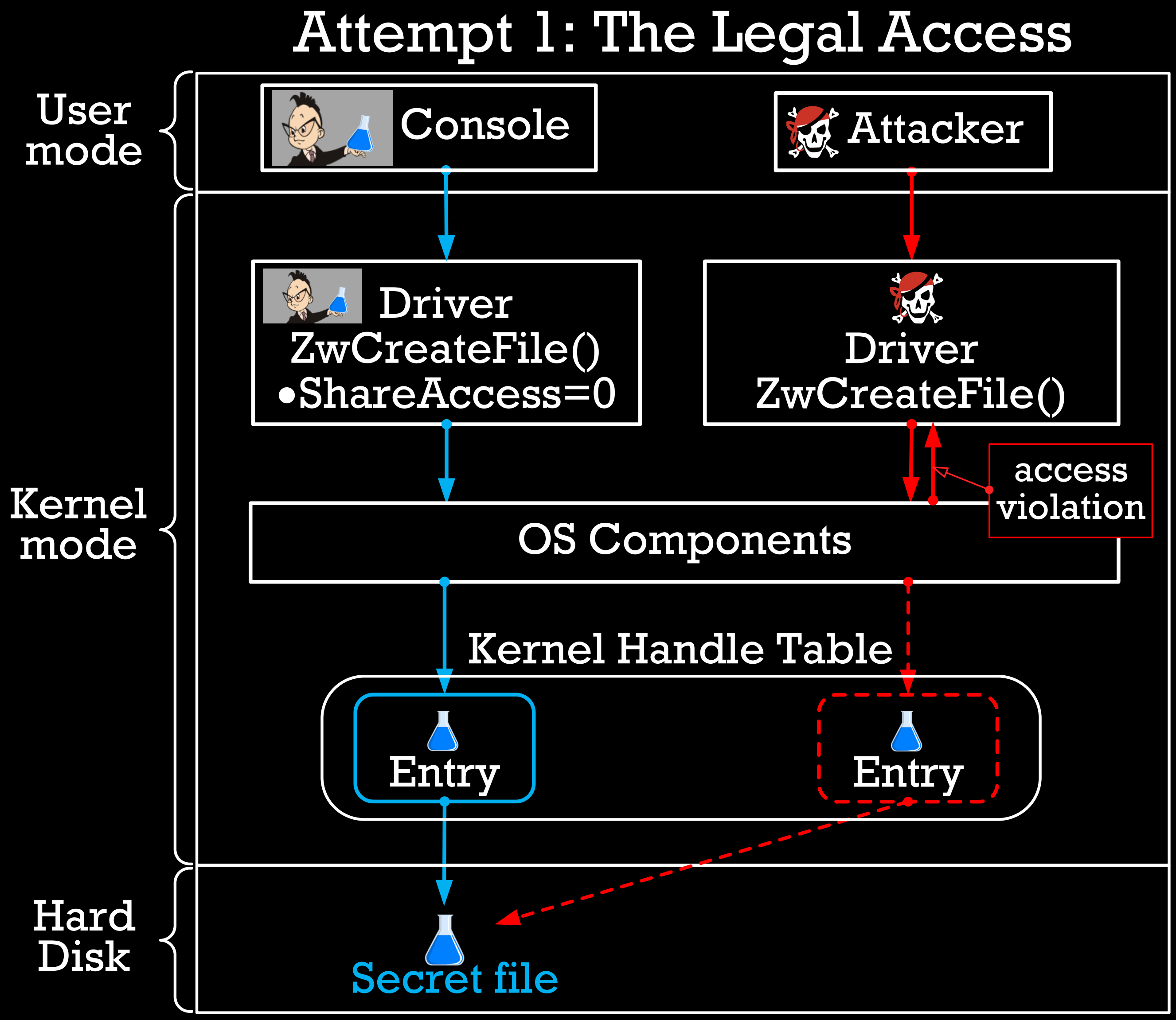


DEMO: HANDLE TABLE HIJACKING



The researcher opens a secret file

DEMO: HANDLE TABLE HIJACKING



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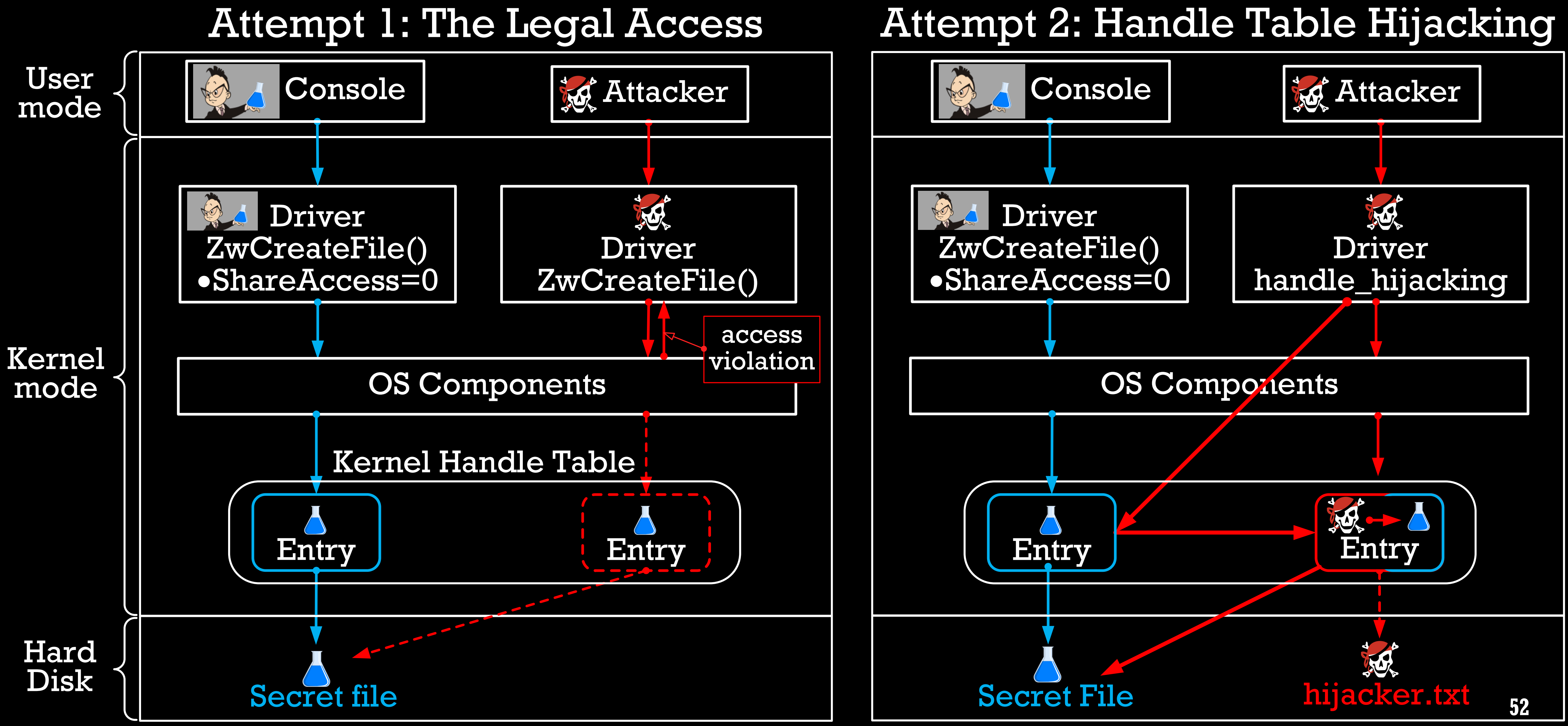
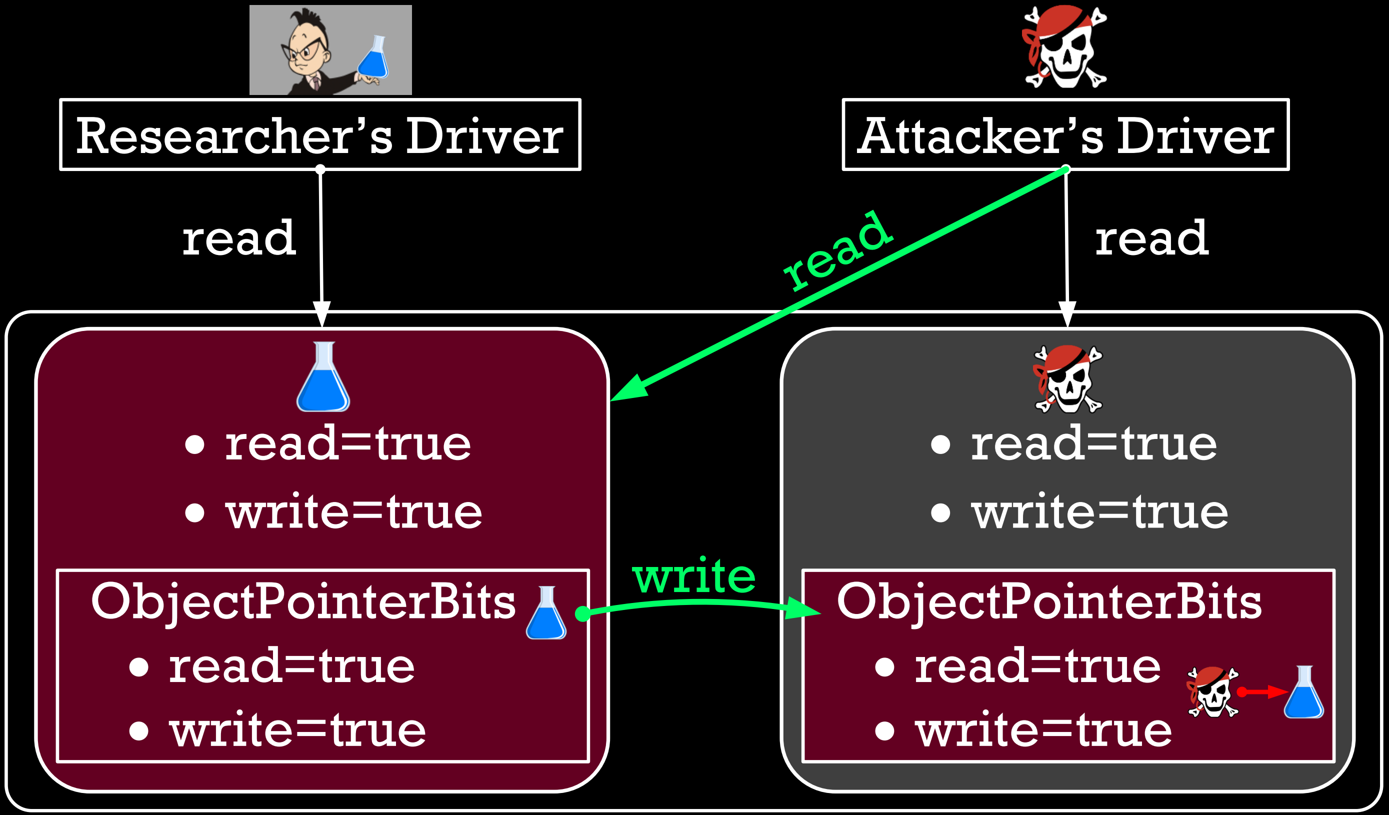


DEMO#1: HANDLE TABLE HIJACKING

The online version is here – https://www.youtube.com/embed/5NNSXfTRtiQ?vq=hd1440

HOW TO PREVENT THE HANDLE HIJACKING?

- We have to block WRITE access to the ObjectPointerBits
- We have to grant READ access to the whole Handle Table for all drivers



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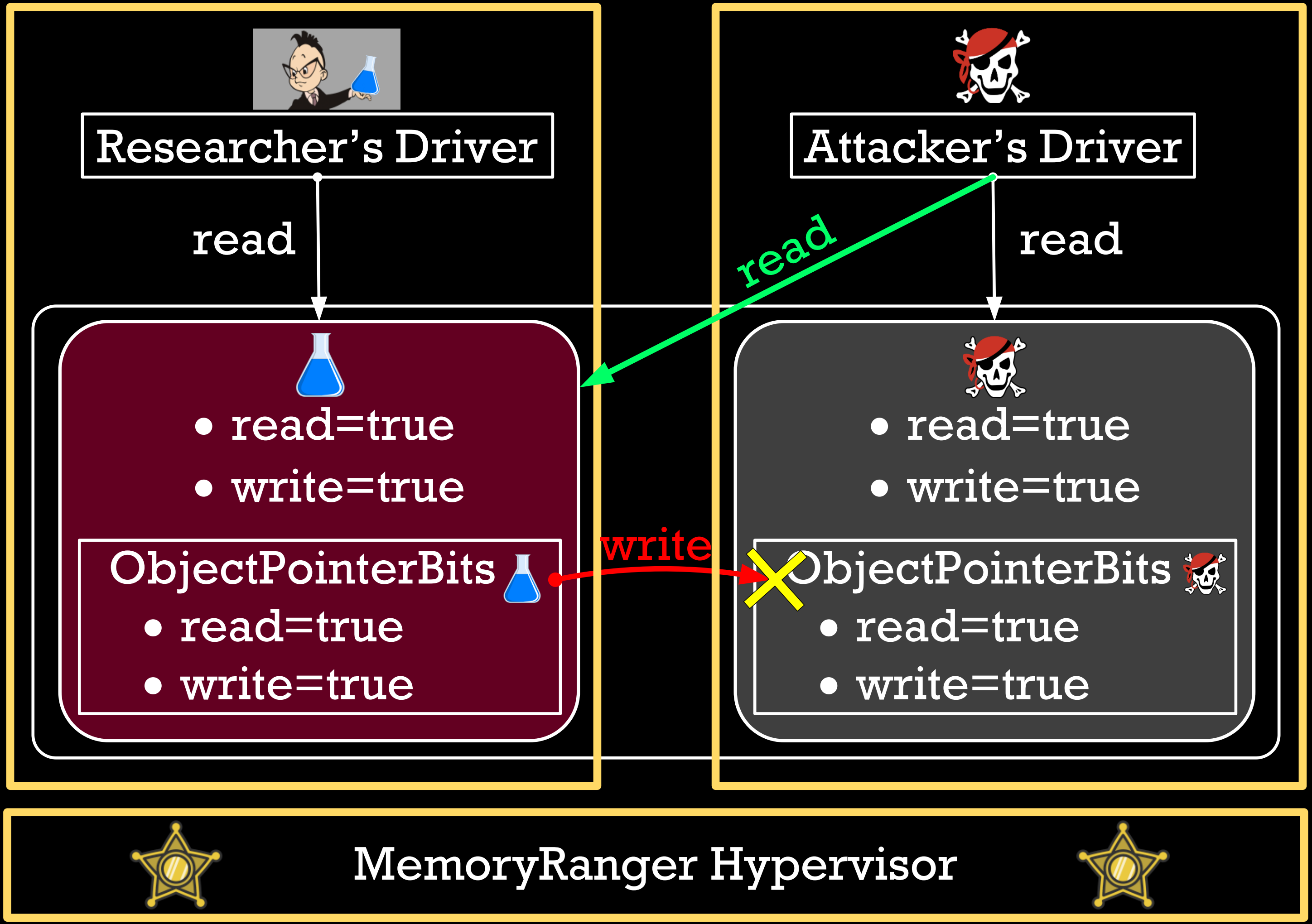
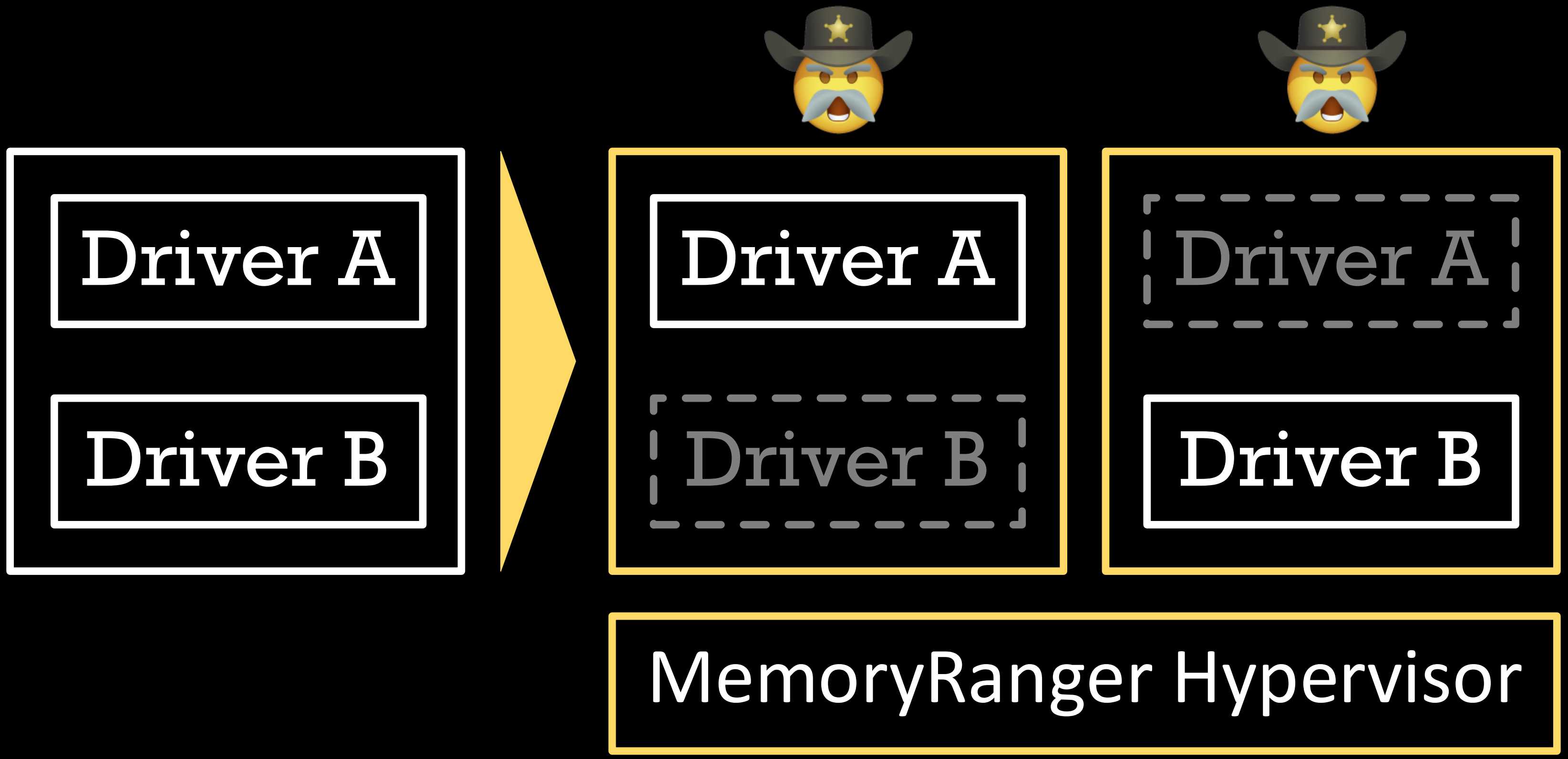


MEMORYRANGER ISOLATES DRIVERS BY RUNNING DRIVERS IN SEPARATE KERNEL SPACES

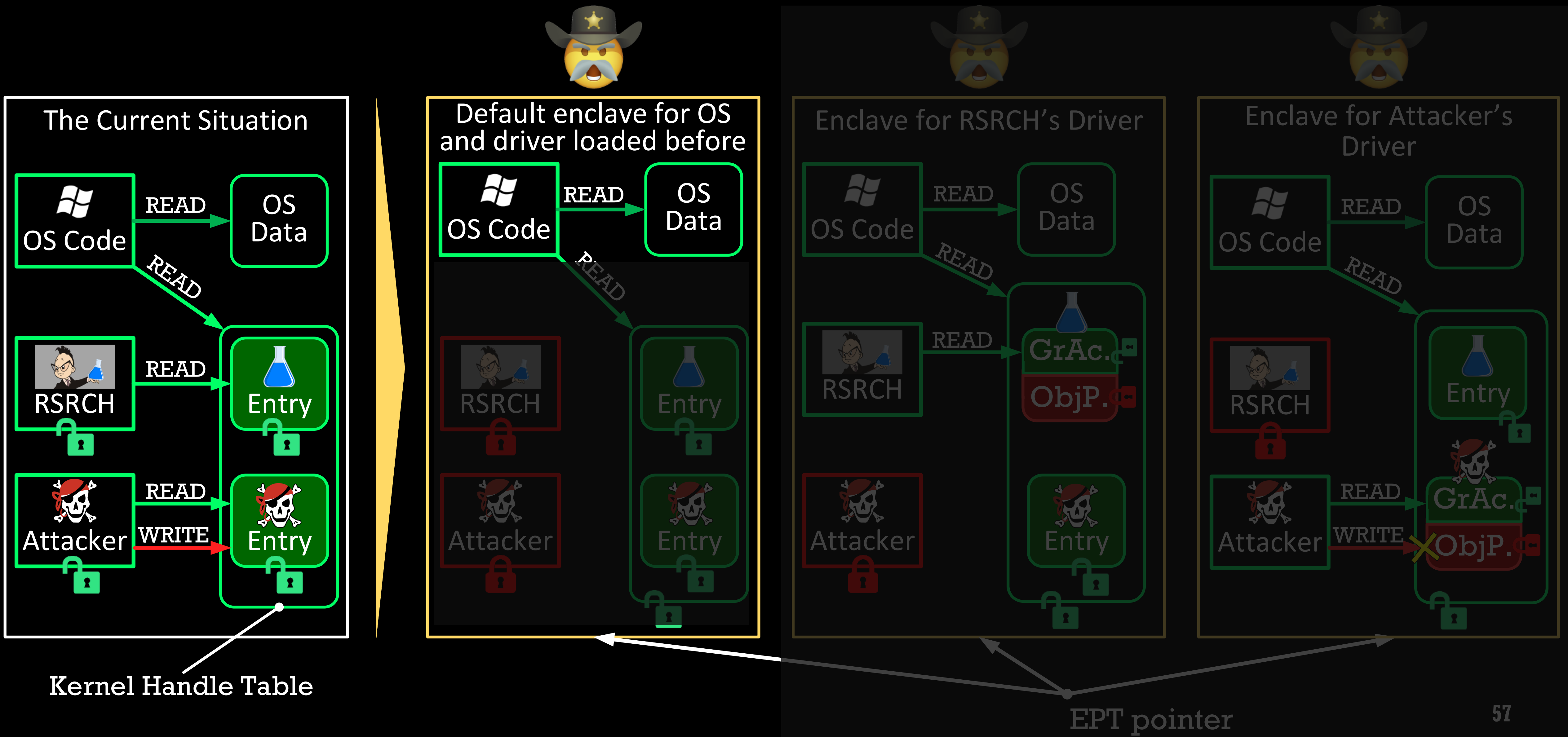


MemoryRanger and Enclaves details are here:

(2019) https://igorkorkin.blogspot.com/2019/04/memoryranger-prevents-hijacking.html

(2018) https://igorkorkin.blogspot.com/2018/12/divide-et-impera-memoryranger-runs.html

MEMORY MAP: MEMORYRANGER PREVENTS HANDLE HIJACKING



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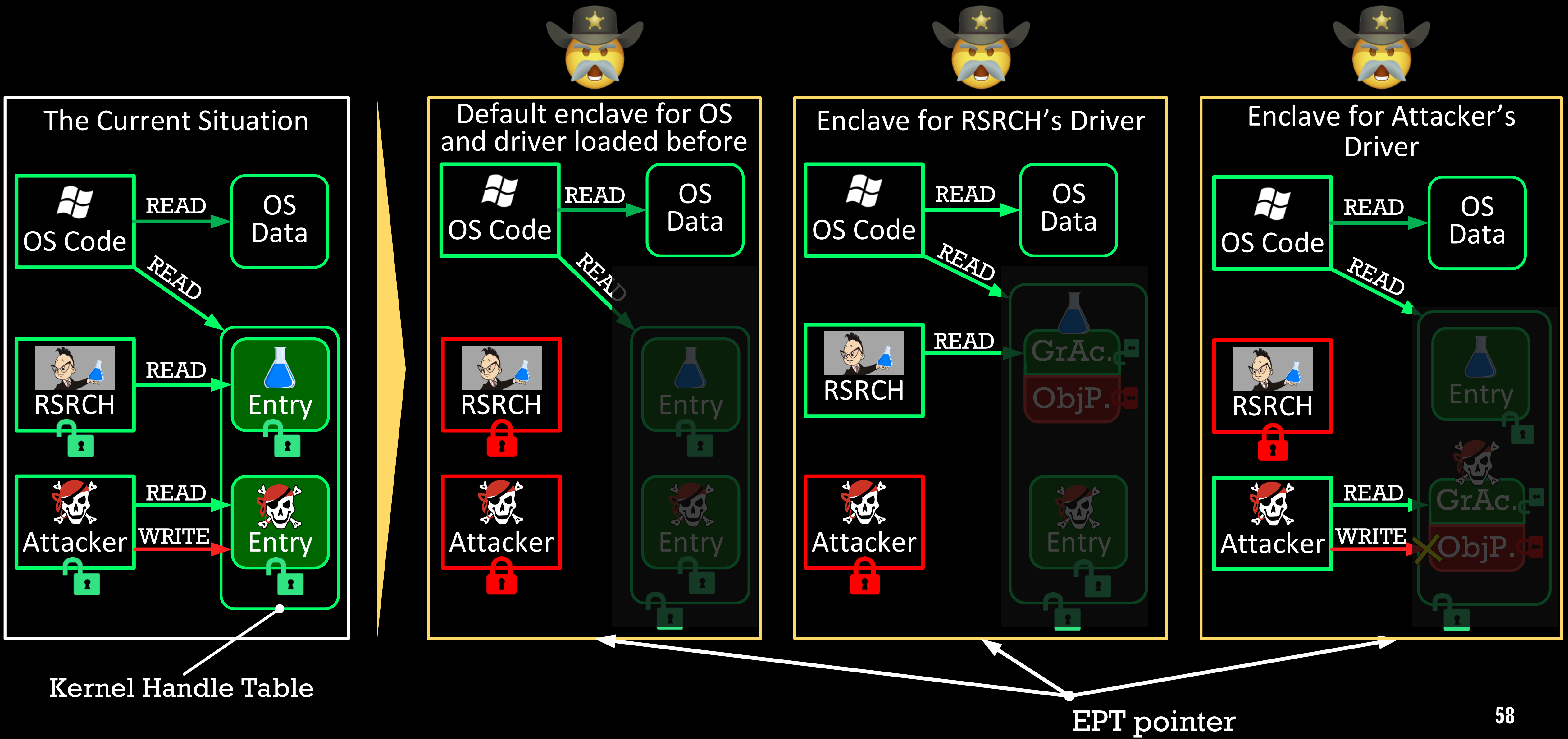

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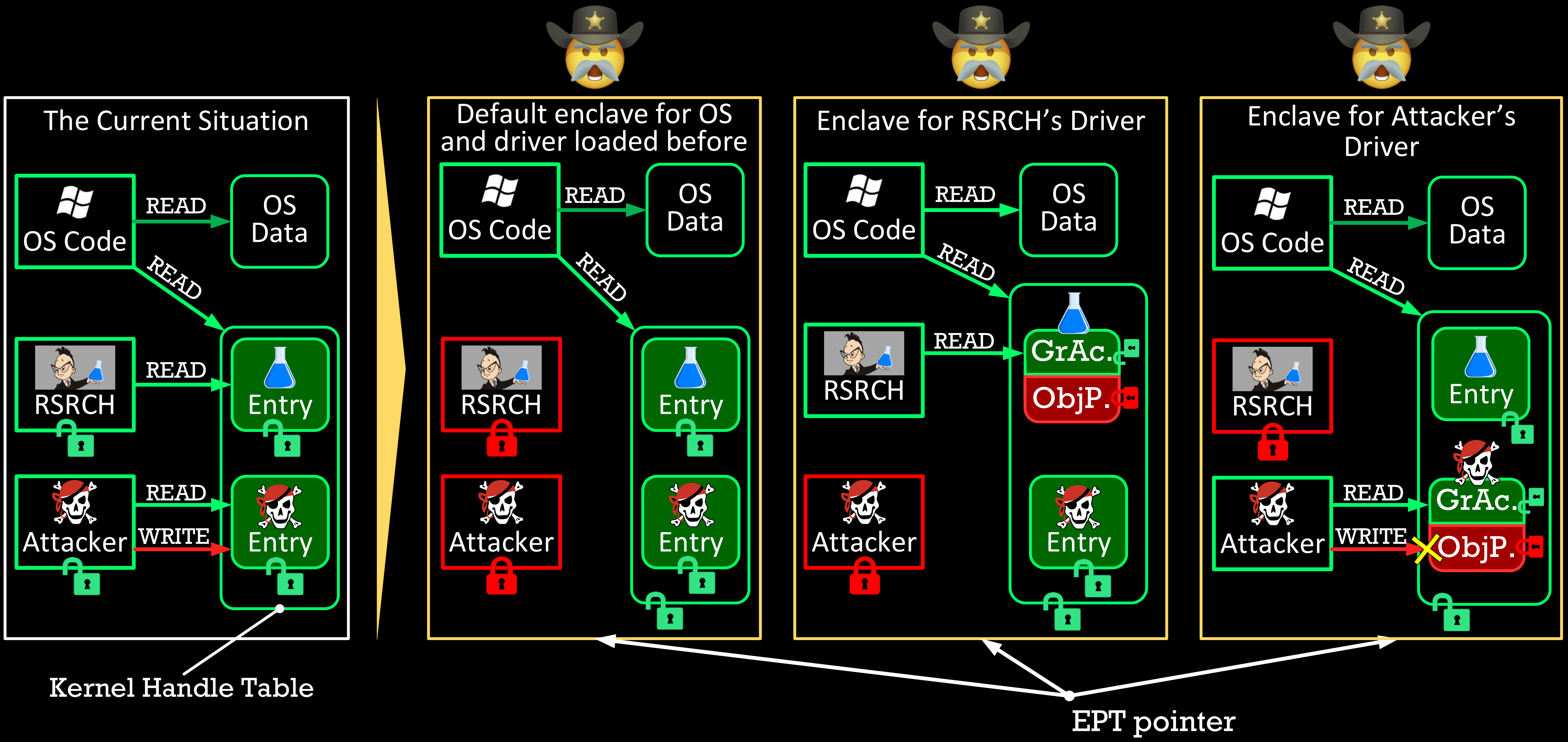
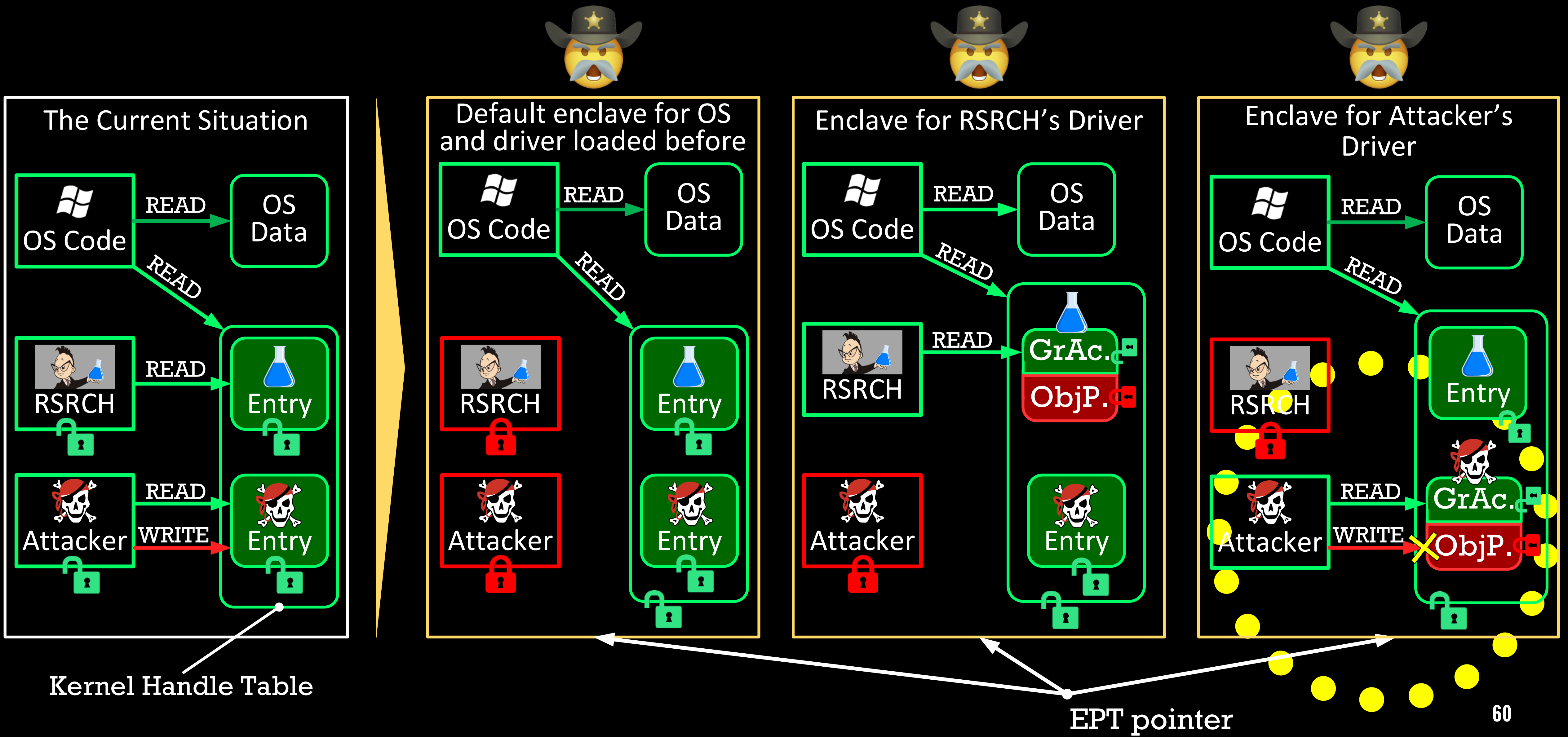


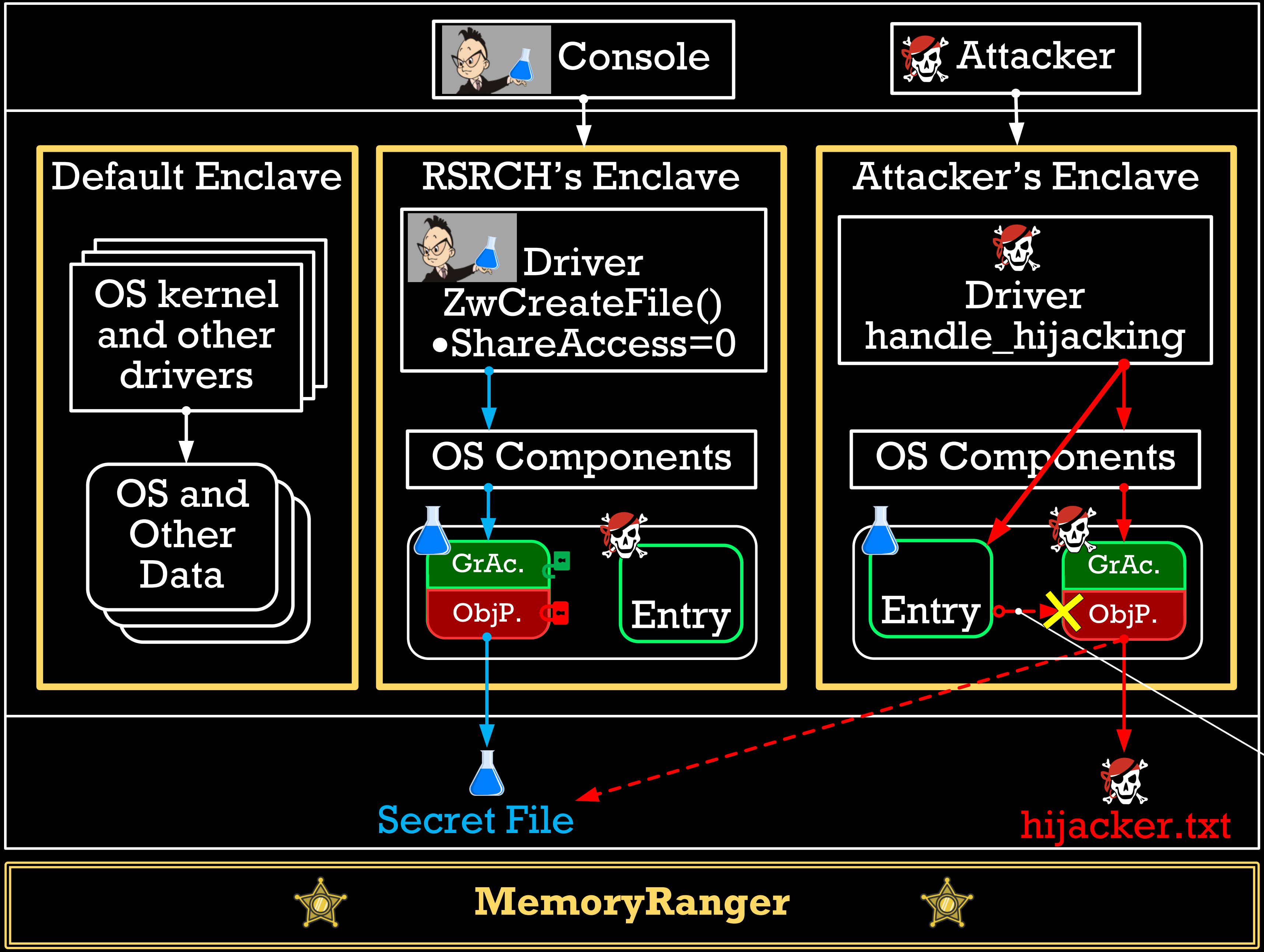
MEMORY MAP: MEMORYRANGER PREVENTS HANDLE HIJACKING



DEMO#2: PREVENTION OF HANDLE TABLE HIJACKING

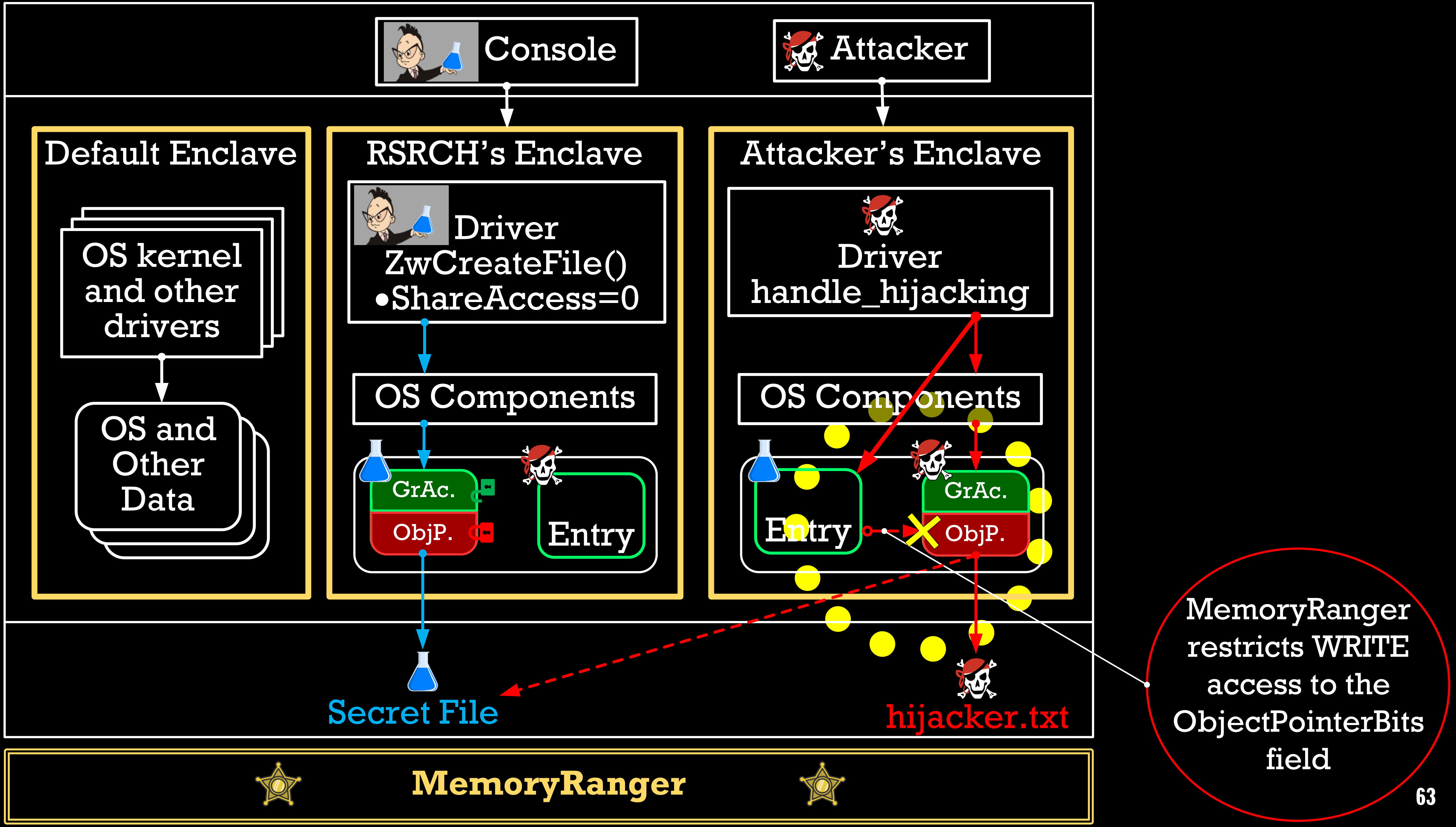
The online version is here – https://www.youtube.com/embed/5Pz-IXvQDiY?vq=hd1440

MemoryRanger Prevents the Handle Hijacking



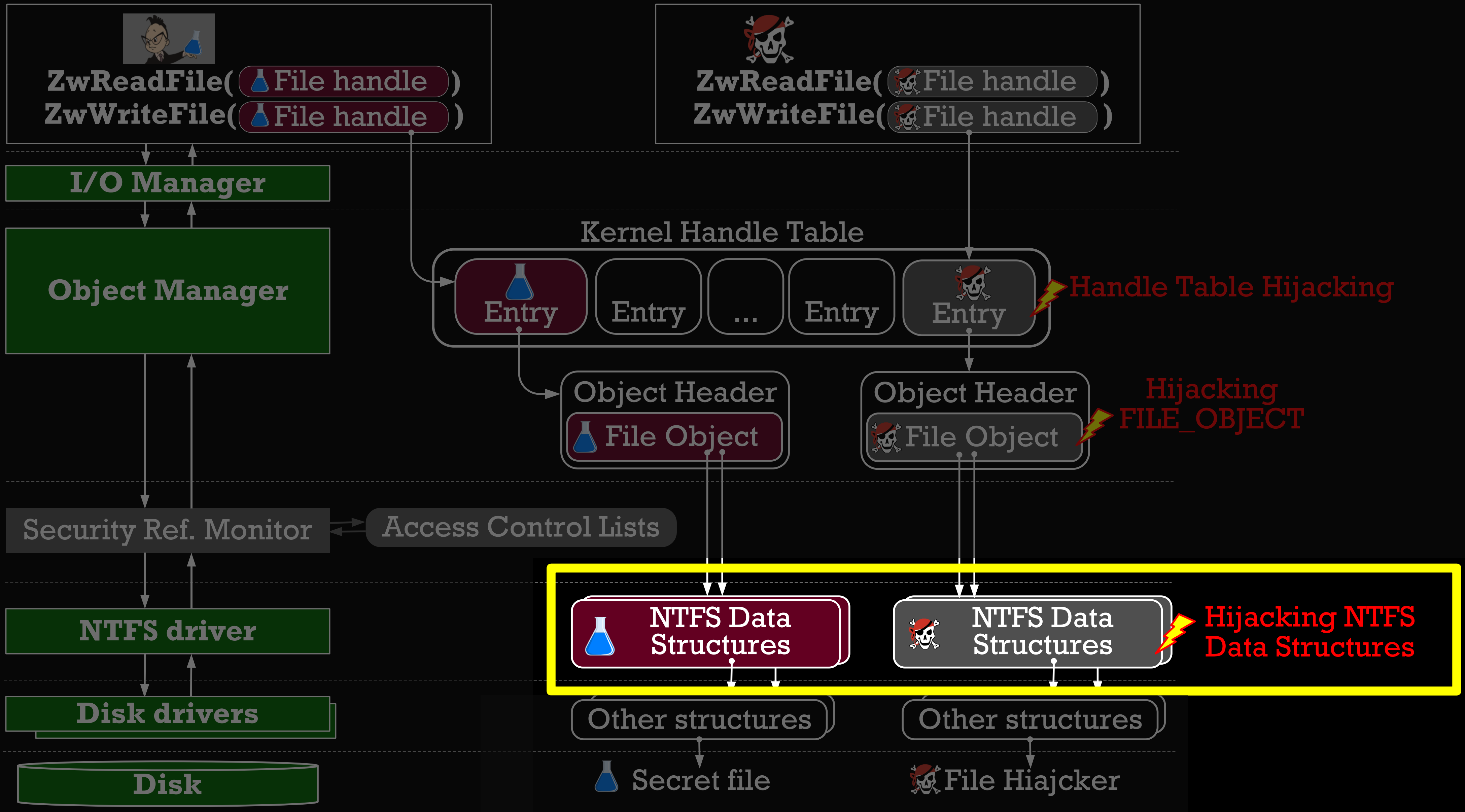
MemoryRanger restricts WRITE access to the ObjectPointerBits field

MemoryRanger Prevents the Handle Hijacking

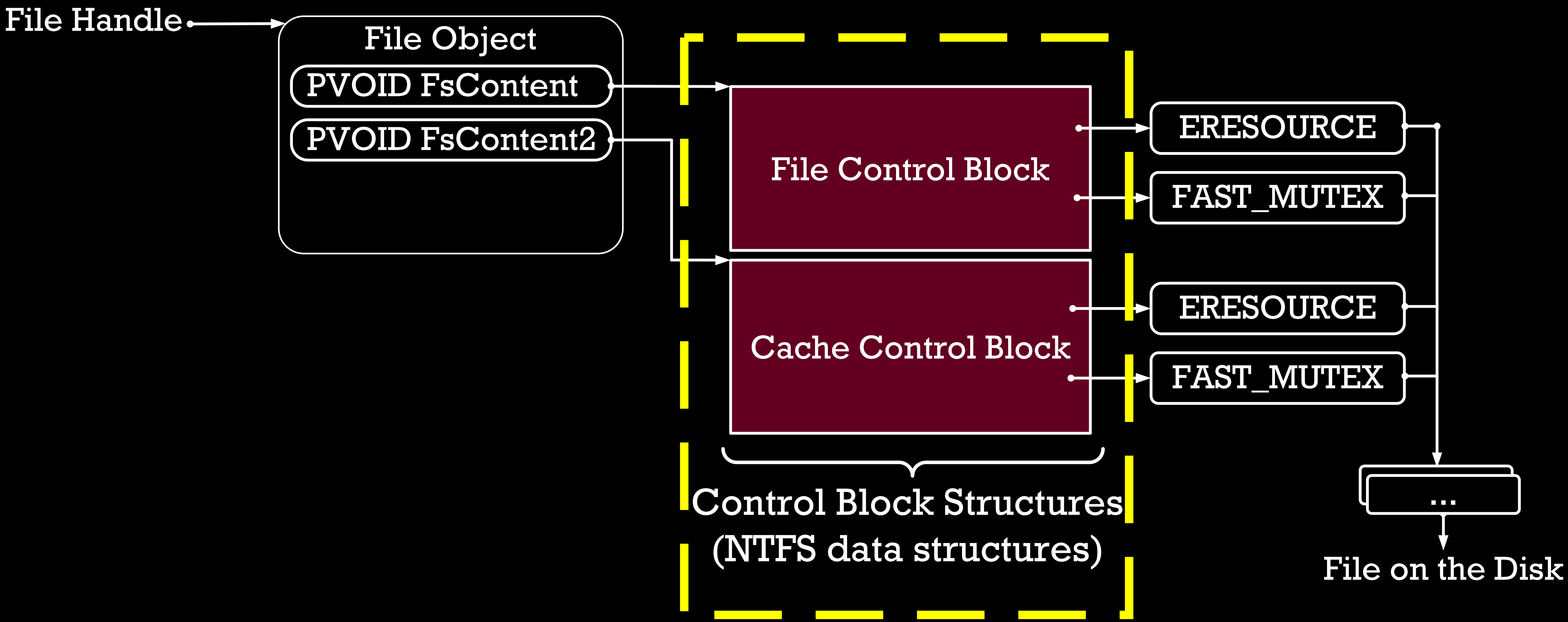


HIJACKING NTFS DATA STRUCTURES

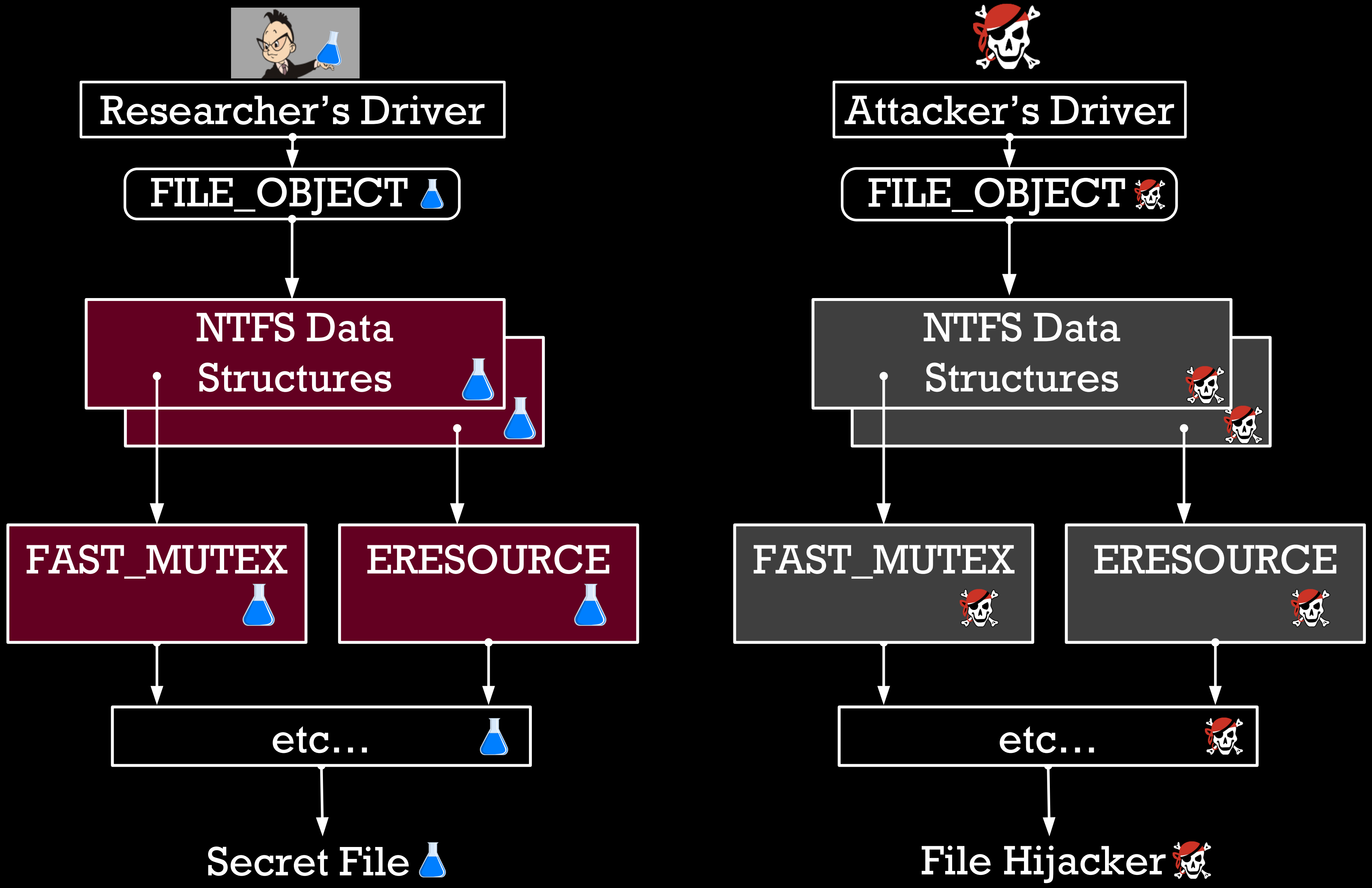
HIJACKING ATTACKS ON FILES STRUCTURES



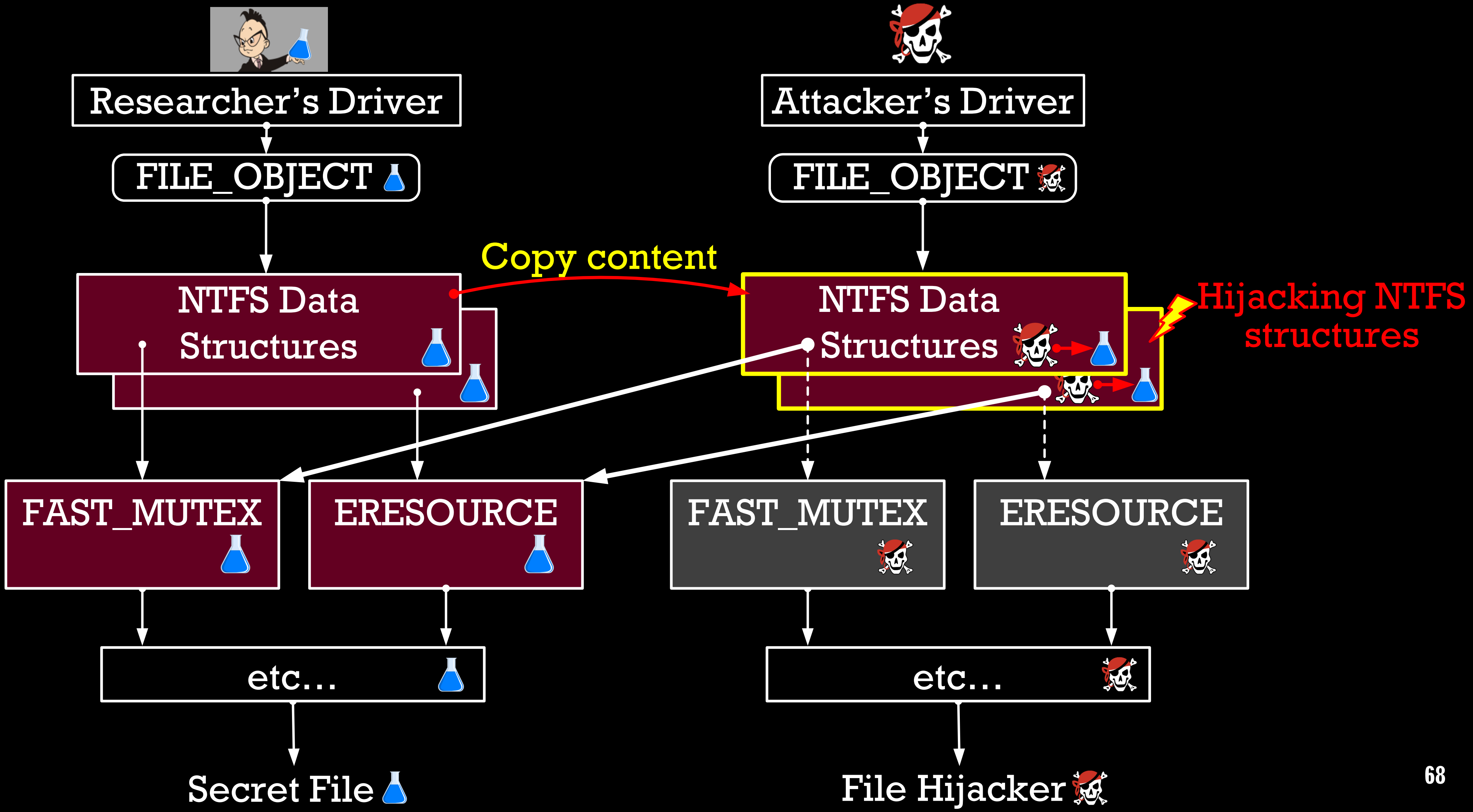
NTFS DATA STRUCTURES



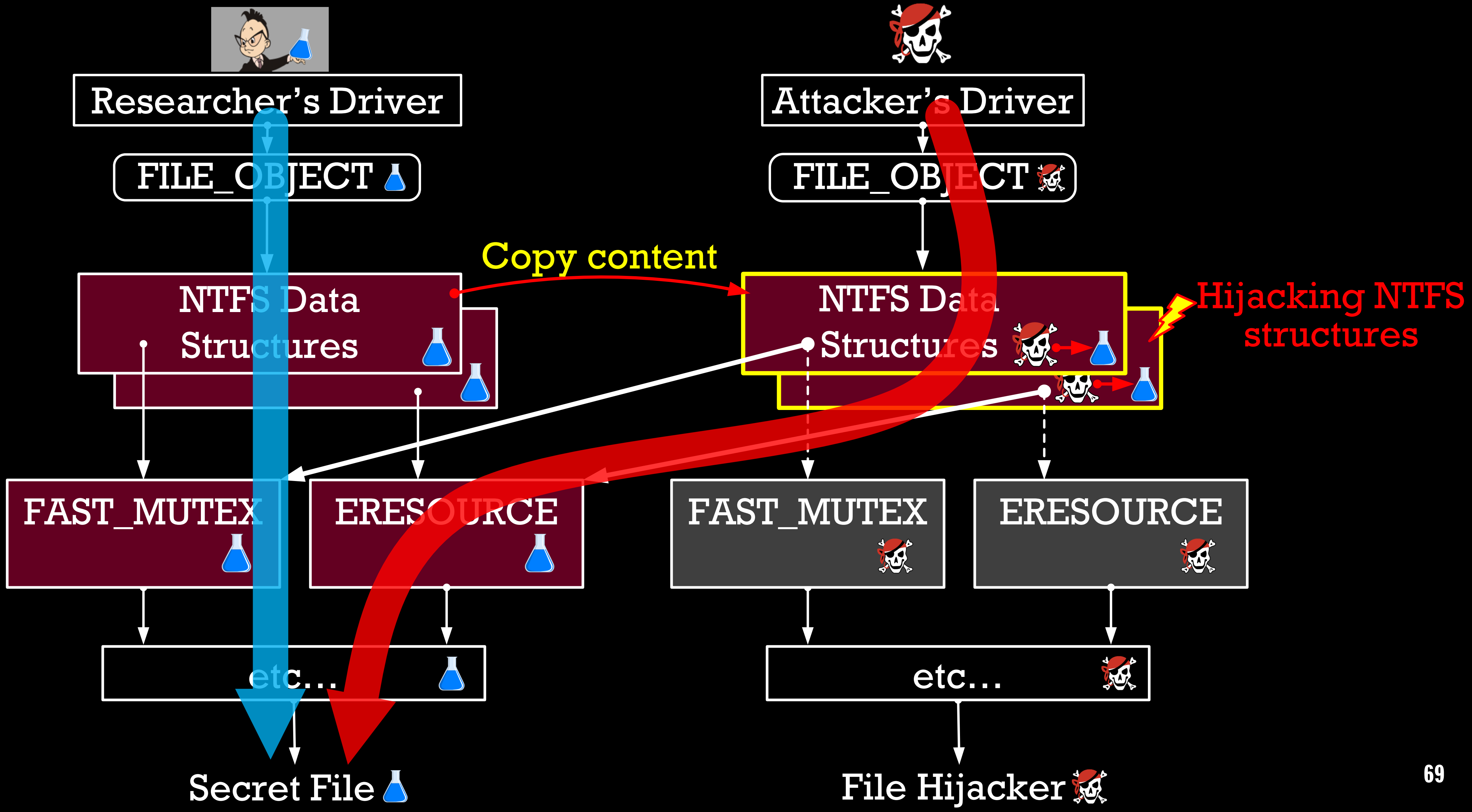
HIJACKING NTFS STRUCTURES



HIJACKING NTFS STRUCTURES



HIJACKING NTFS STRUCTURES



Researcher's Driver

FILE_OBJECT

NTFS Data Structures

FAST_MUTEX

ERESOURCE

etc…

Secret File

Copy content

Attacker's Driver

FILE_OBJECT

NTFS Data Structures

Hijacking NTFS structures

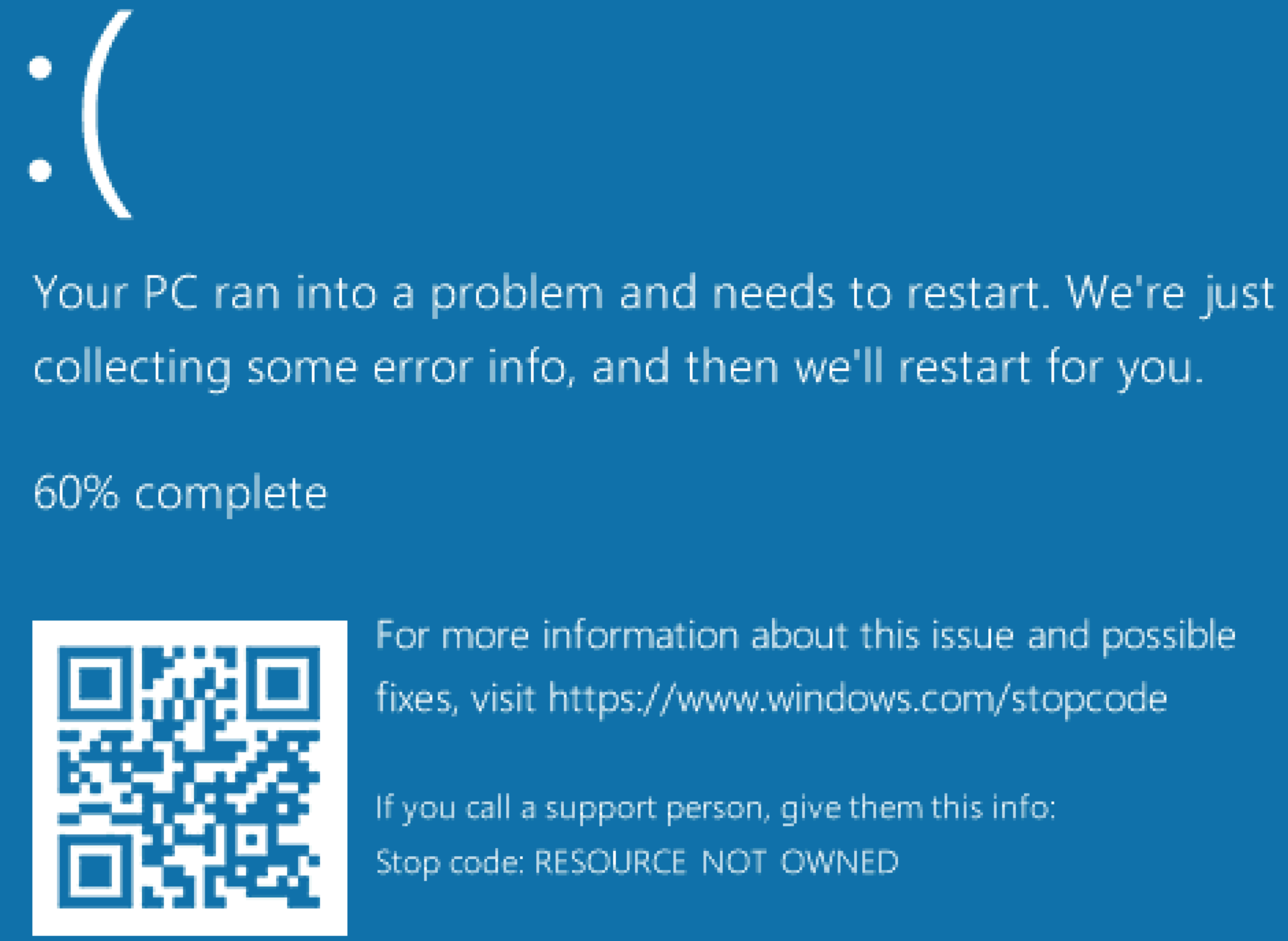
FAST_MUTEX

ERESOURCE

etc…

File Hijacker

BSOD - RESOURCE_NOT_OWNED (0xE3)



:(

Your PC ran into a problem and needs to restart. We're just collecting some error info, and then we'll restart for you.

60% complete

For more information about this issue and possible fixes, visit https://www.windows.com/stopcode

If you call a support person, give them this info:

Stop code: RESOURCE NOT OWNED

BSOD: THE REASON AND THE WAY TO BYPASS

```
void ExReleaseResourceLite(PERESOURCE Resource){
    …
    CurrentThread = KeGetCurrentThread();
    if (IsOwnedExclusive(Resource)) {
        if (Resource->OwnerThreads[0].OwnerThread != CurrentThread) {
            KeBugCheckEx(RESOURCE_NOT_OWNED, … )
        }
    }
}
```

*wrk-v1.2\base\ntos\ex\resource.c

BSOD: THE REASON AND THE WAY TO BYPASS

```
void ExReleaseResourceLite(PERESOURCE Resource){
    …
    CurrentThread = KeGetCurrentThread();
    if (IsOwnedExclusive(Resource)) {
        if (Resource->OwnerThreads[0].OwnerThread != CurrentThread) {
            KeBugCheckEx(RESOURCE_NOT_OWNED, … )
        }
    }
}
```

*wrk-v1.2\base\ntos\ex\resource.c

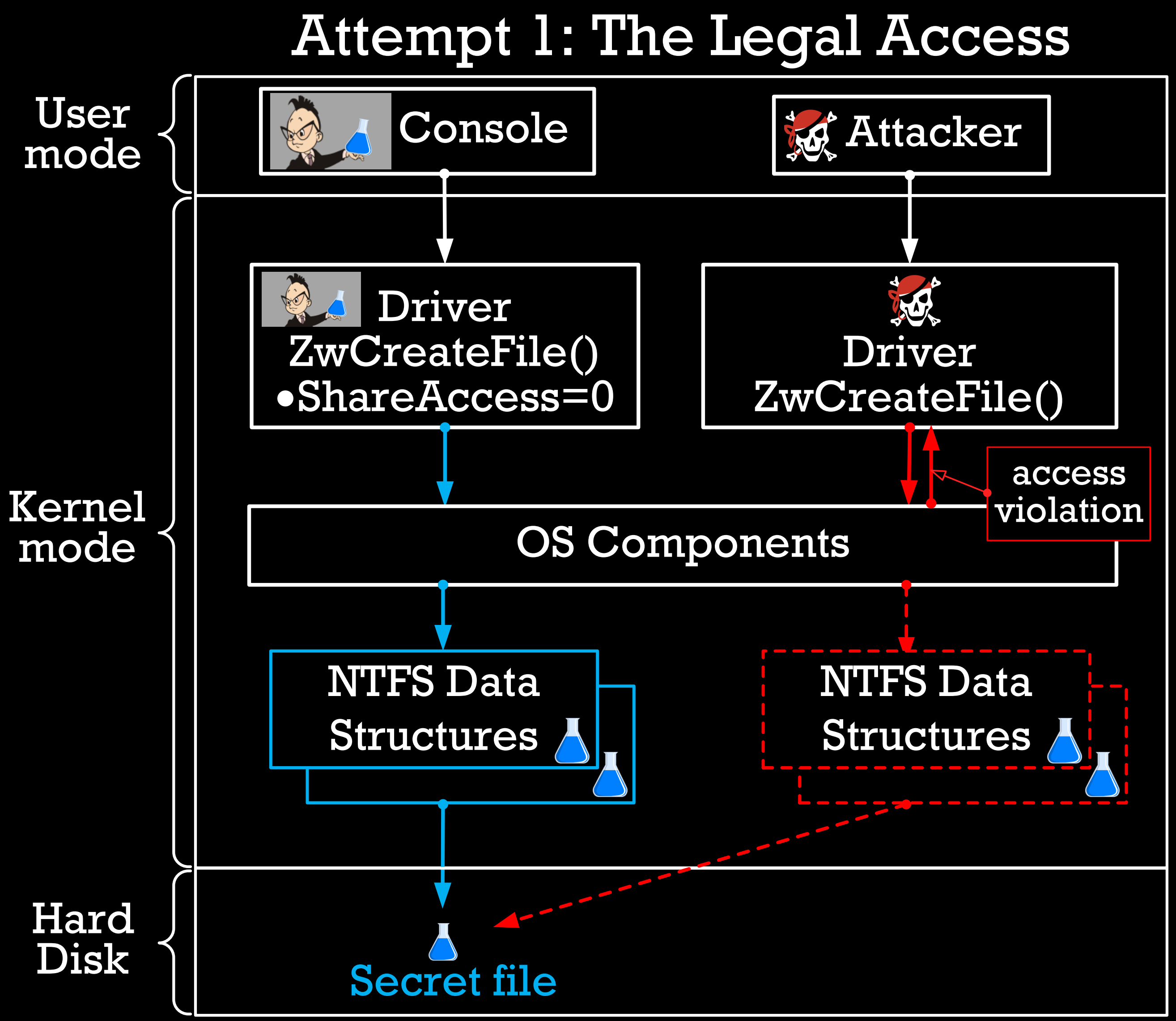
BSOD: THE WAY TO BYPASS (FOR HACKERS ONLY)

1. Overwrite control block structures

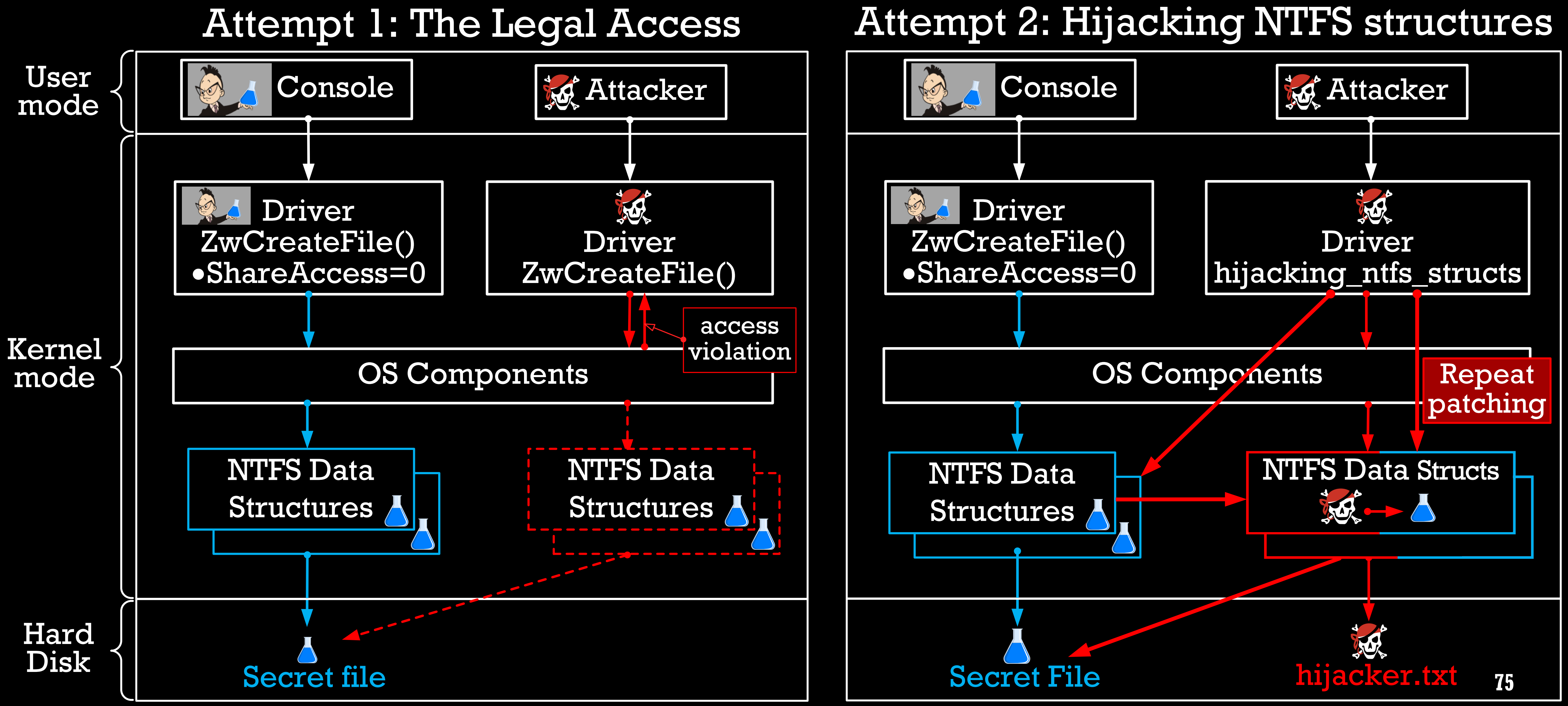
2. Patch ThreadID-related fields using attackers ThreadID:
   - Resource->OwnerEntry.OwnerThread = PsGetCurrentThread();
   - PagingIoResource->OwnerEntry.OwnerThread = PsGetCurrentThread()

3. Repeat steps 1 and 2 before each read and write call

DEMO: HIJACKING NTFS STRUCTURES



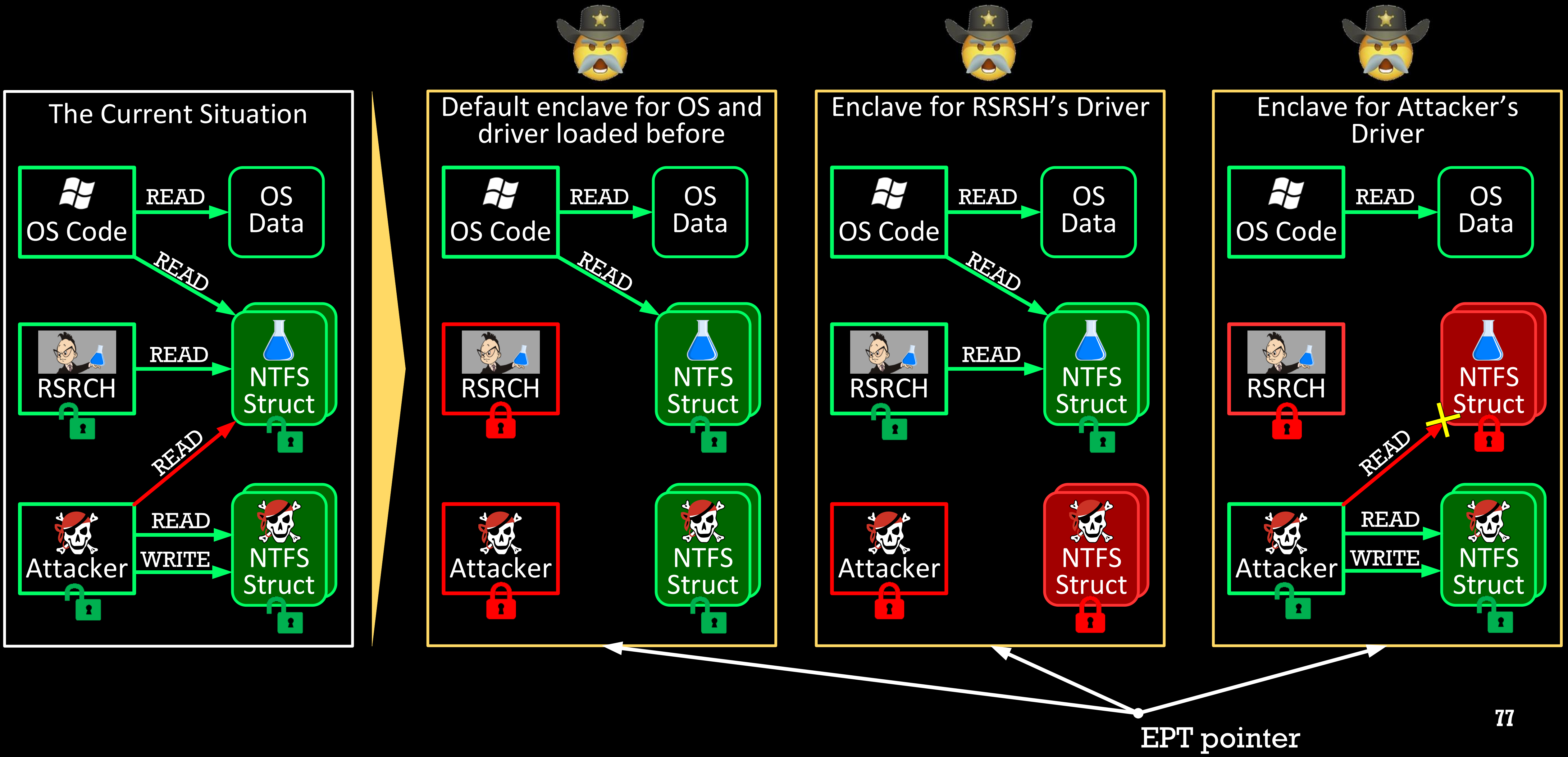
DEMO: HIJACKING NTFS STRUCTURES



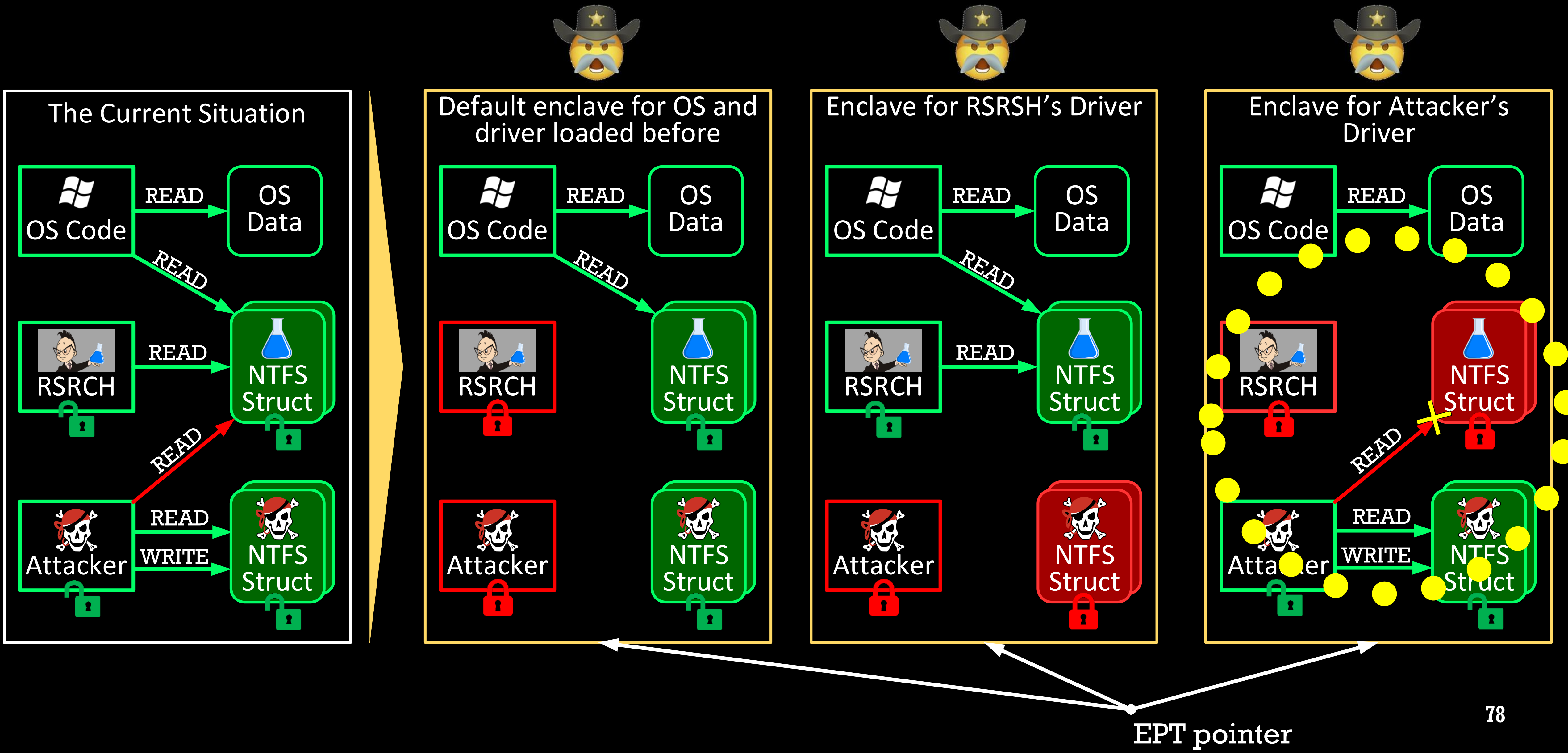
DEMO#3: HIJACKING NTFS STRUCTURES

The online version is here – https://www.youtube.com/embed/bHEf2fNkqbc?vq=hd1440

MEMORYRANGER PREVENTS HIJACKING NTFS STRUCTS



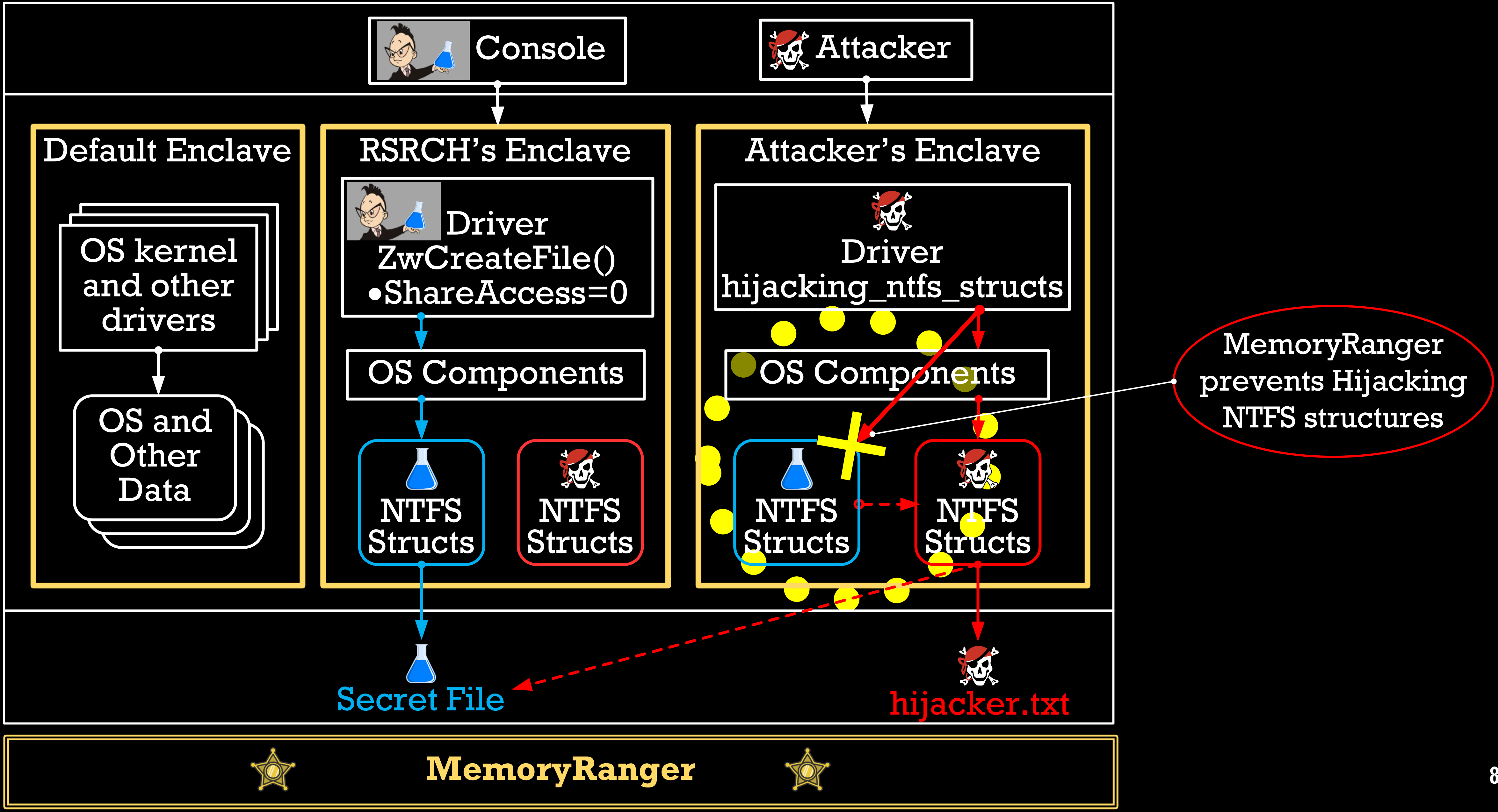
MEMORYRANGER PREVENTS HIJACKING NTFS STRUCTS



DEMO#4: PREVENTION OF HIJACKING NTFS STRUCTS

The online version is here – https://www.youtube.com/embed/CSvq-VyxFH4?vq=hd1440

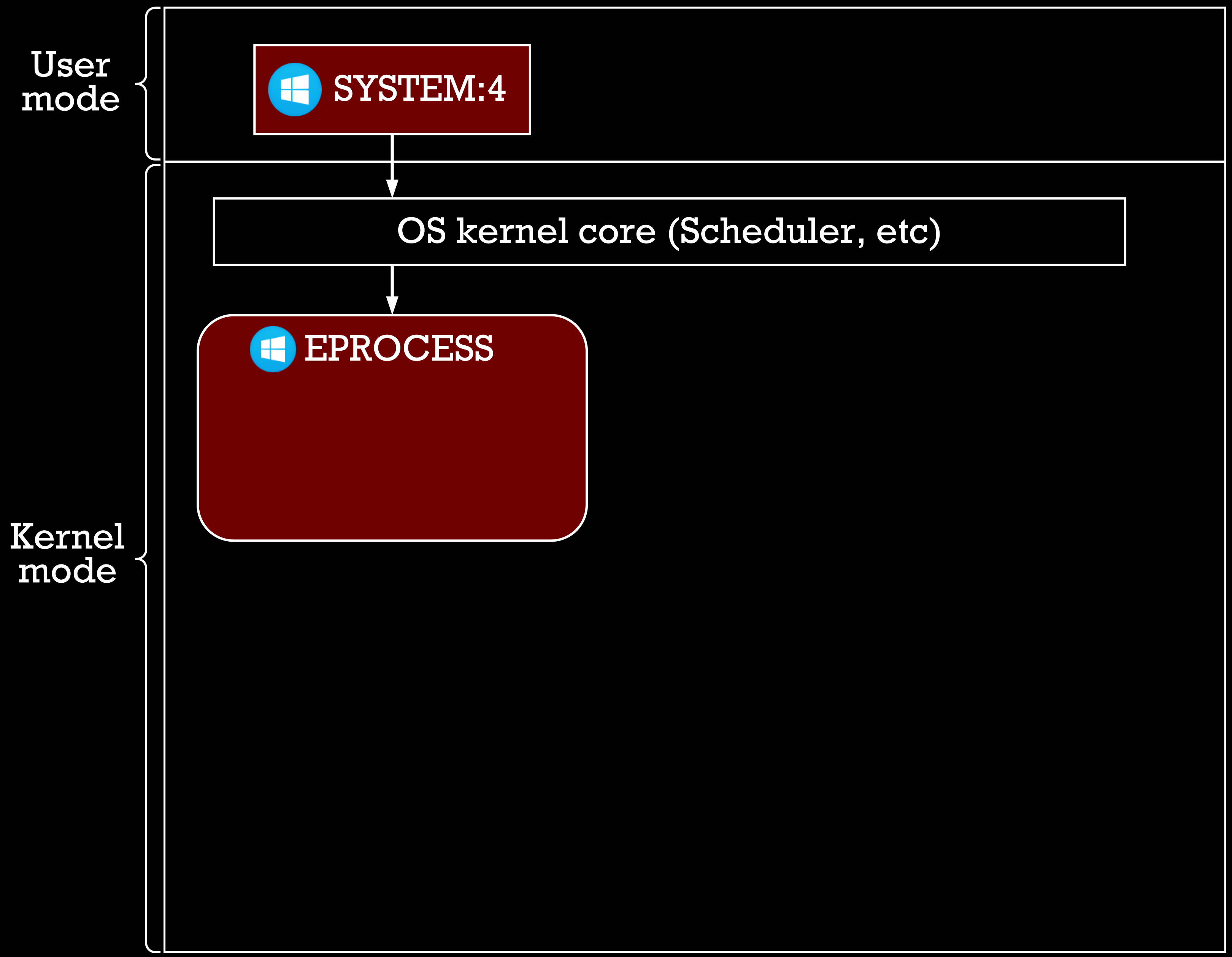
Preventing the Hijacking NTFS structures



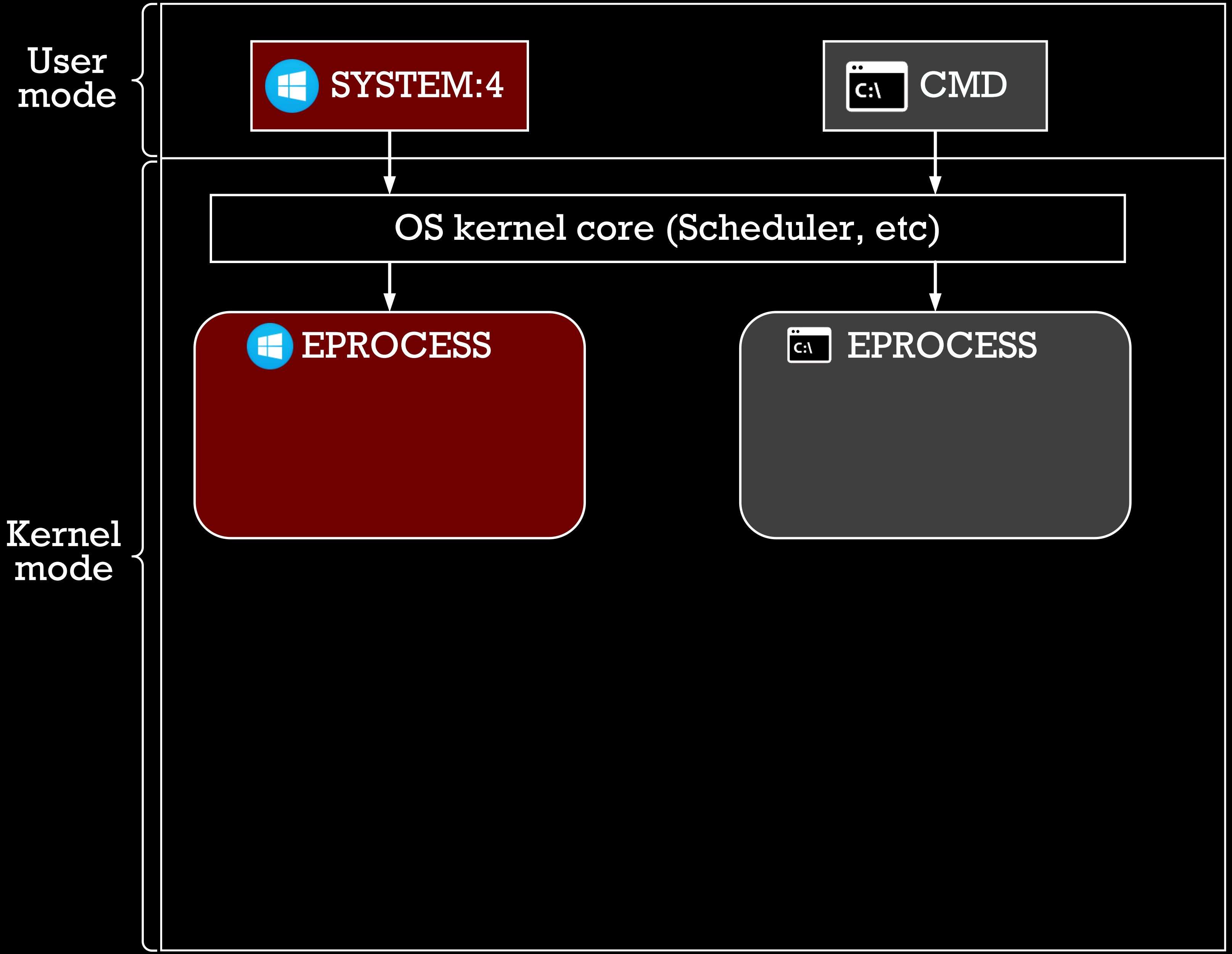
Episode 2

Privilege Escalation via Token Hijacking

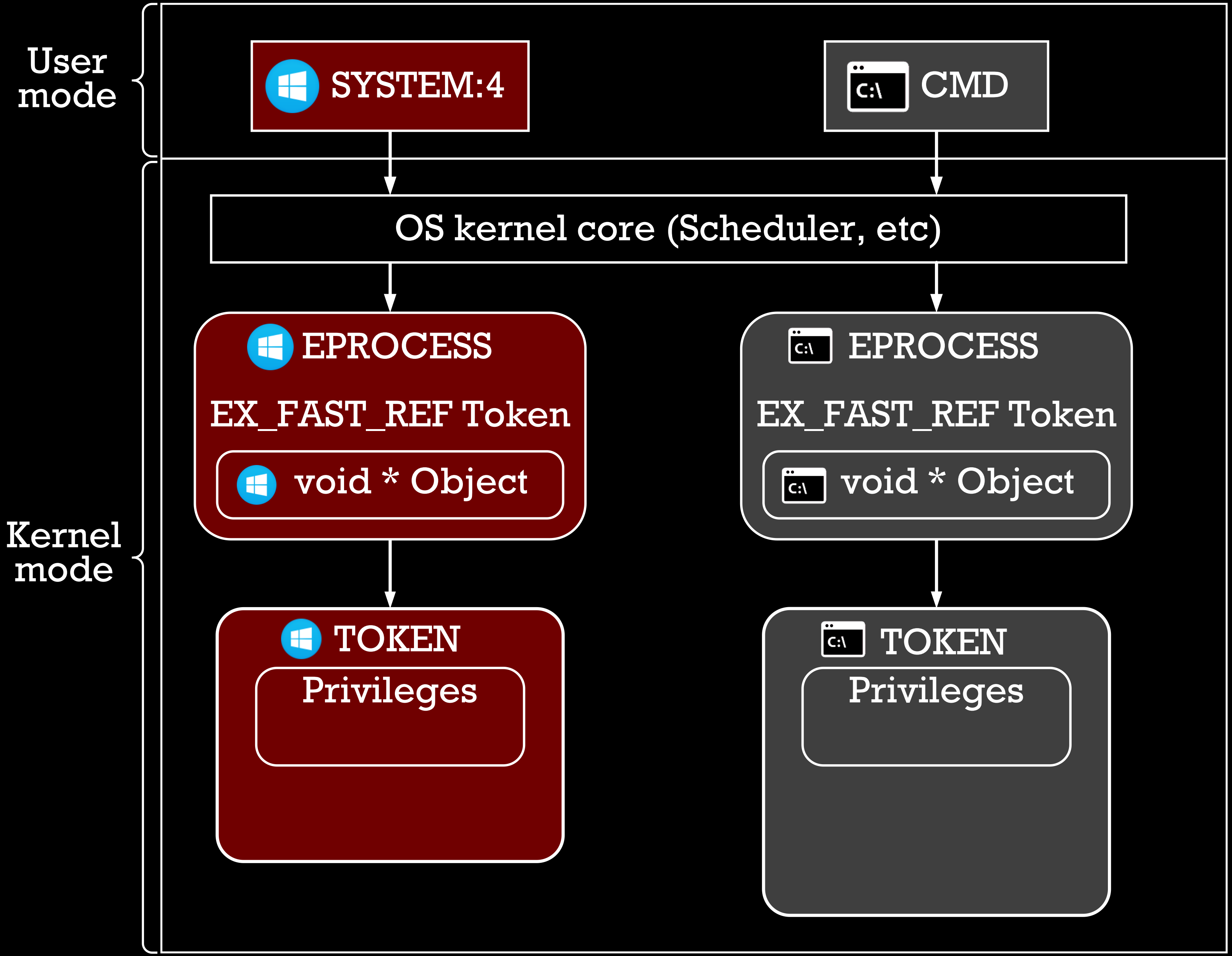
EPROCESS AND TOKEN IN WINDOWS



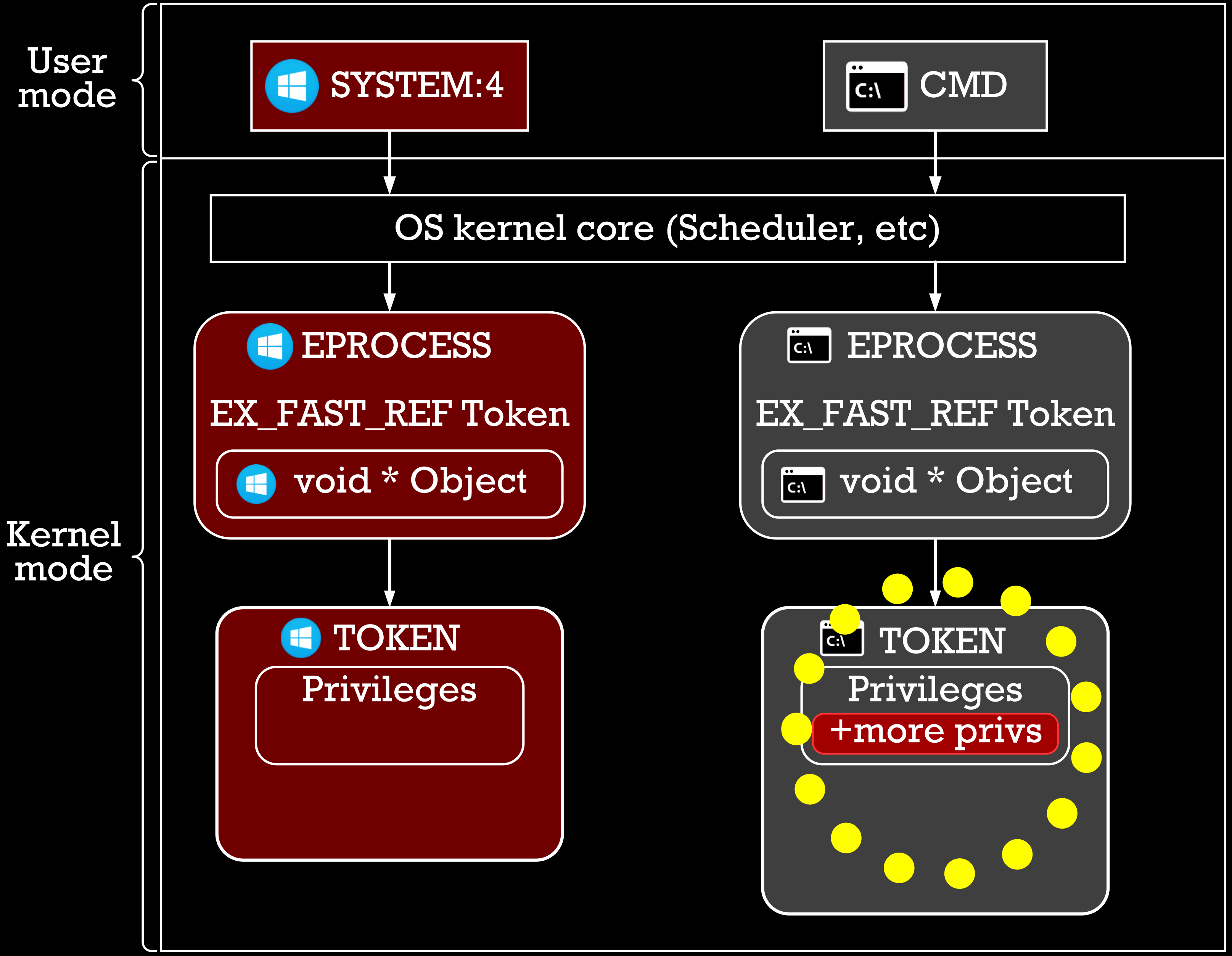
EPROCESS AND TOKEN IN WINDOWS



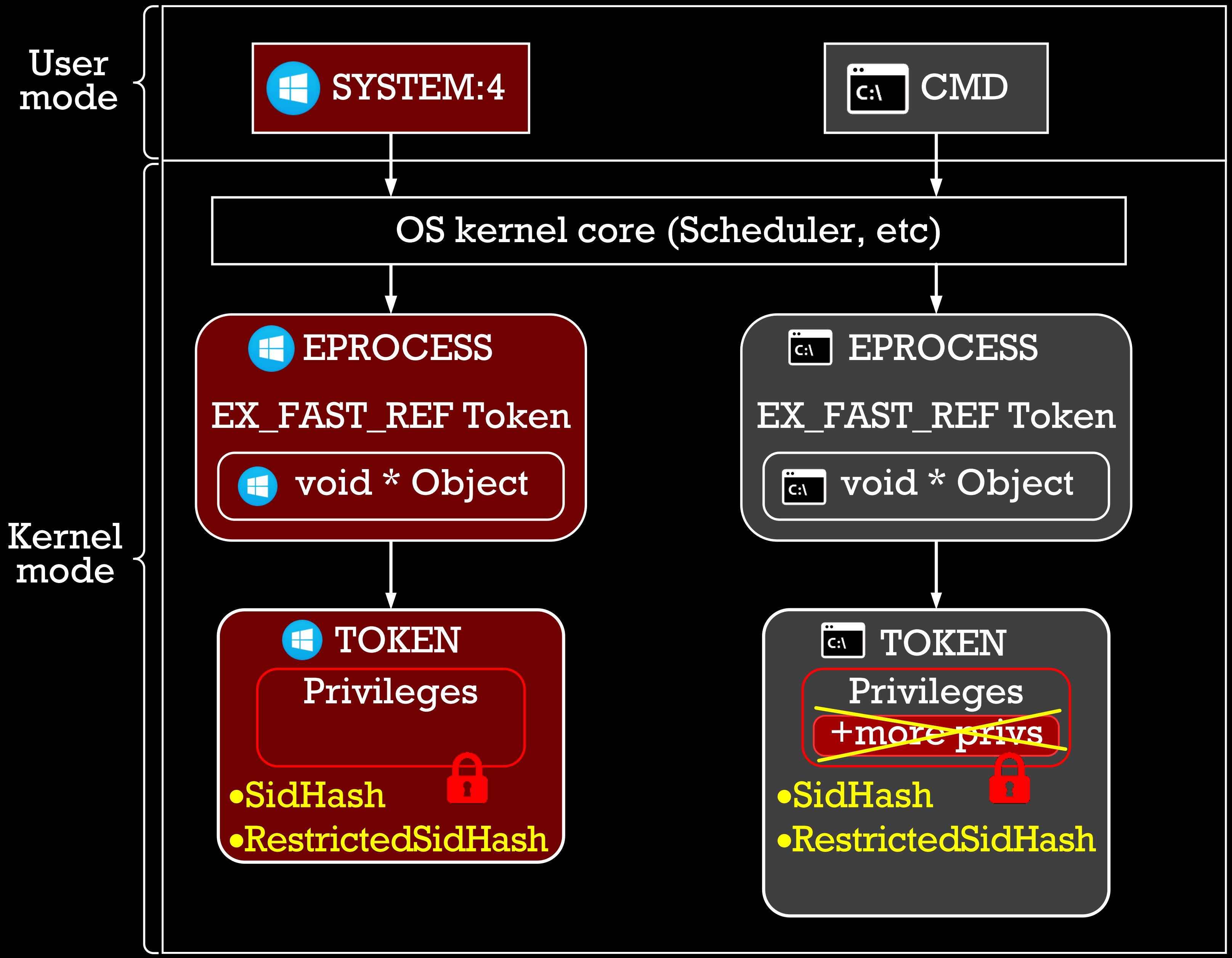
EPROCESS AND TOKEN IN WINDOWS



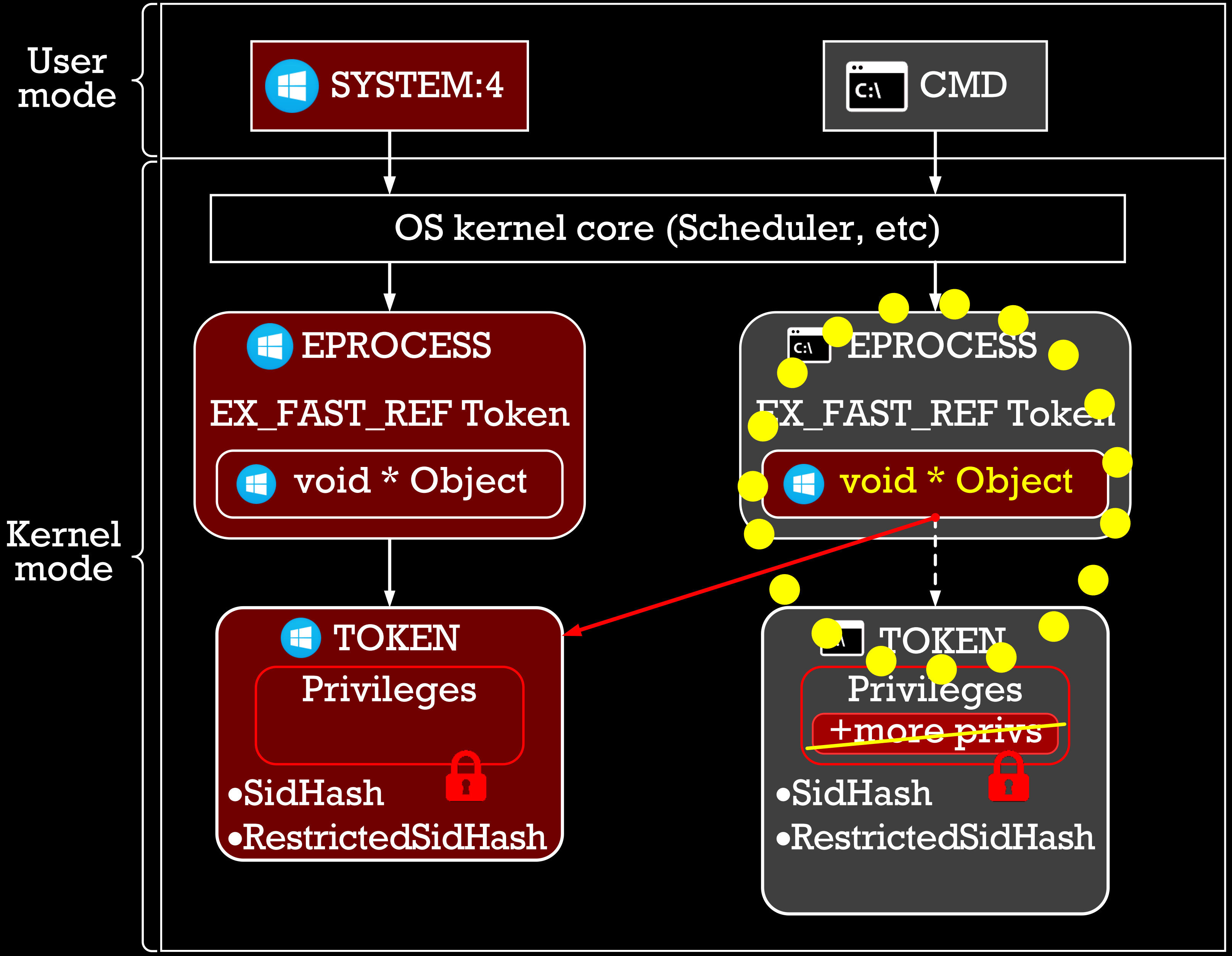
EPROCESS AND TOKEN IN WINDOWS: ADD MORE PRIVILEGES



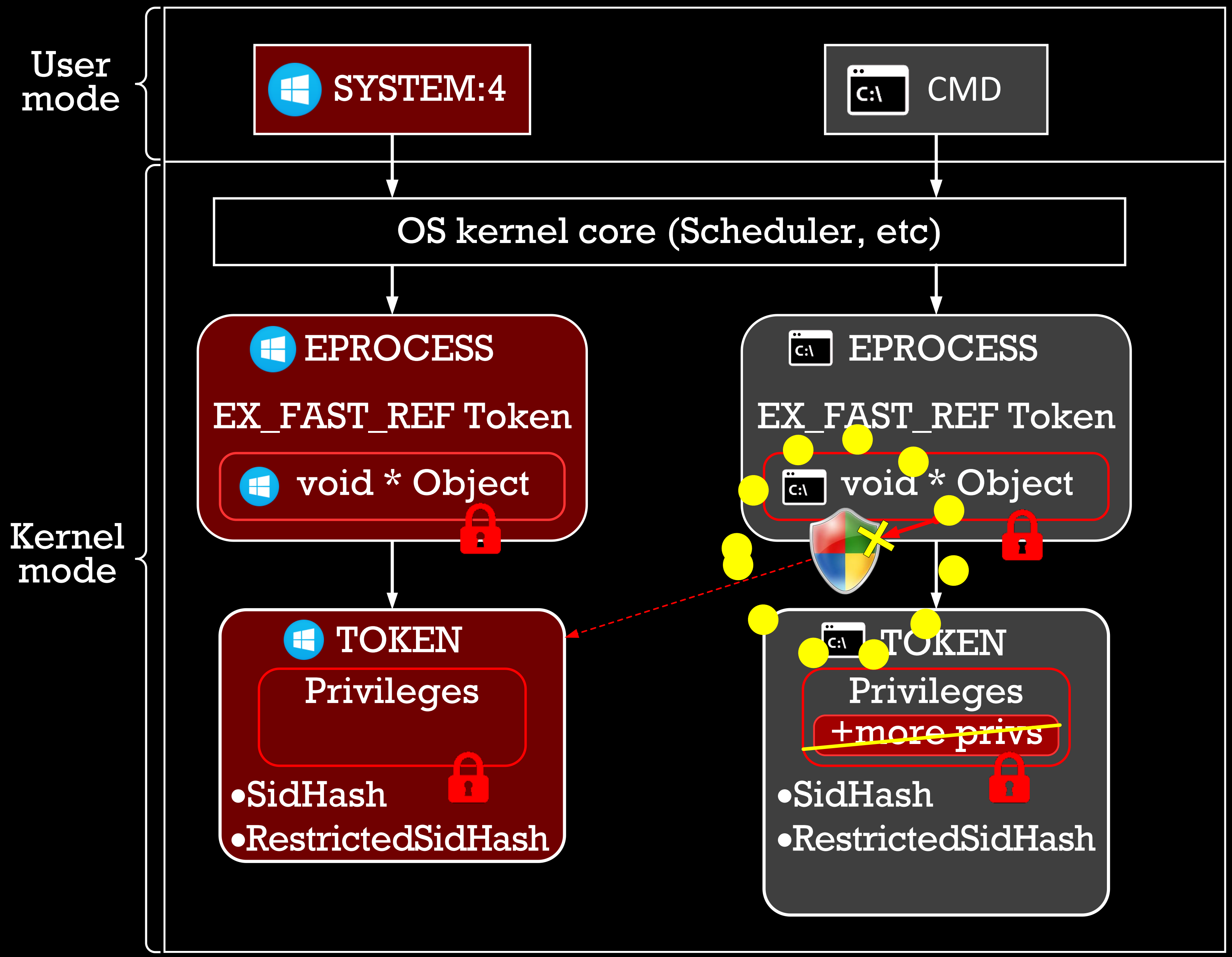
EPROCESS AND TOKEN IN WINDOWS: SidHash field



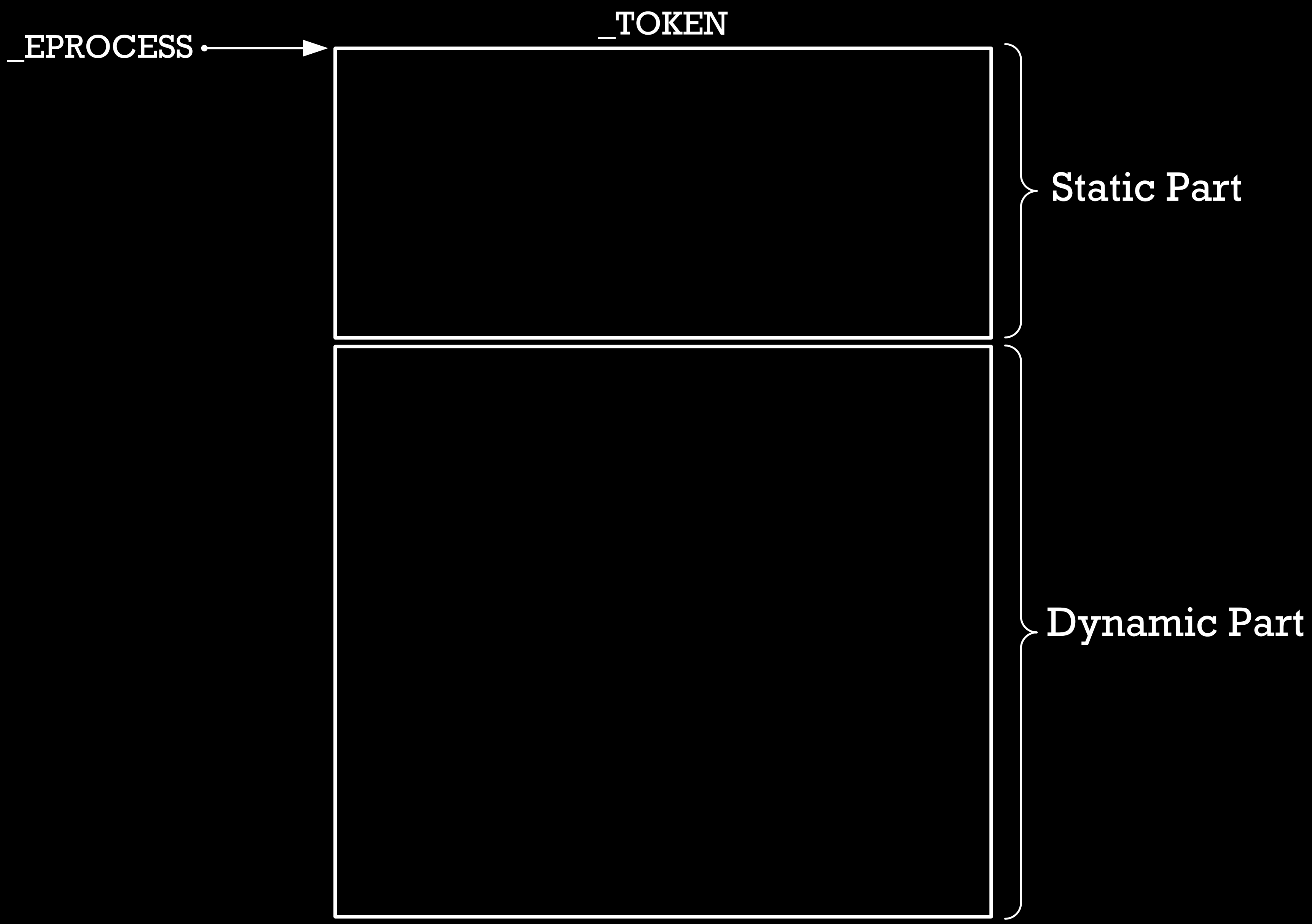
EPROCESS AND TOKEN IN WINDOWS: TOKEN SWAPPING



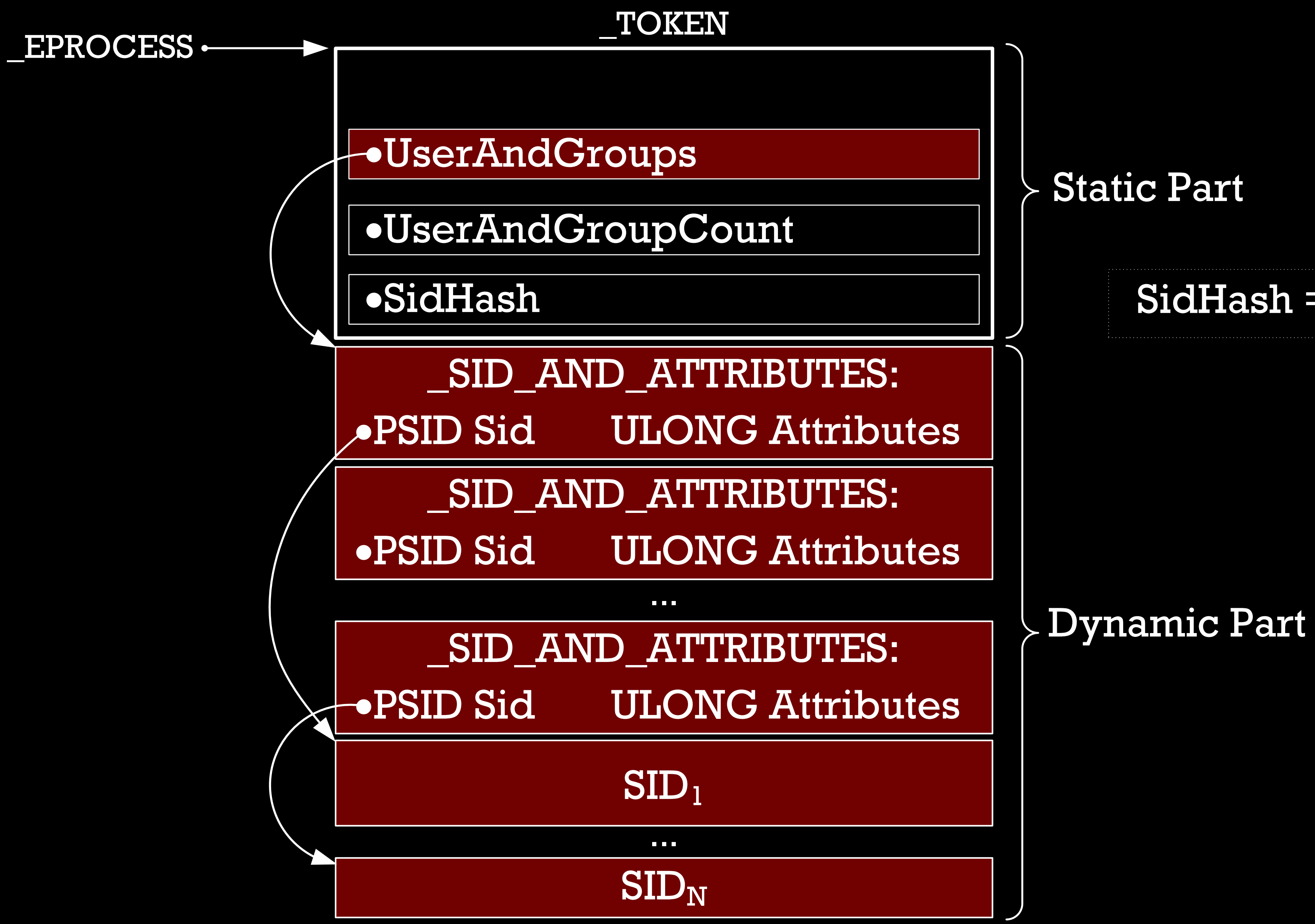
EPROCESS AND TOKEN IN WINDOWS: MSFT Defender



TOKEN INTERNALS

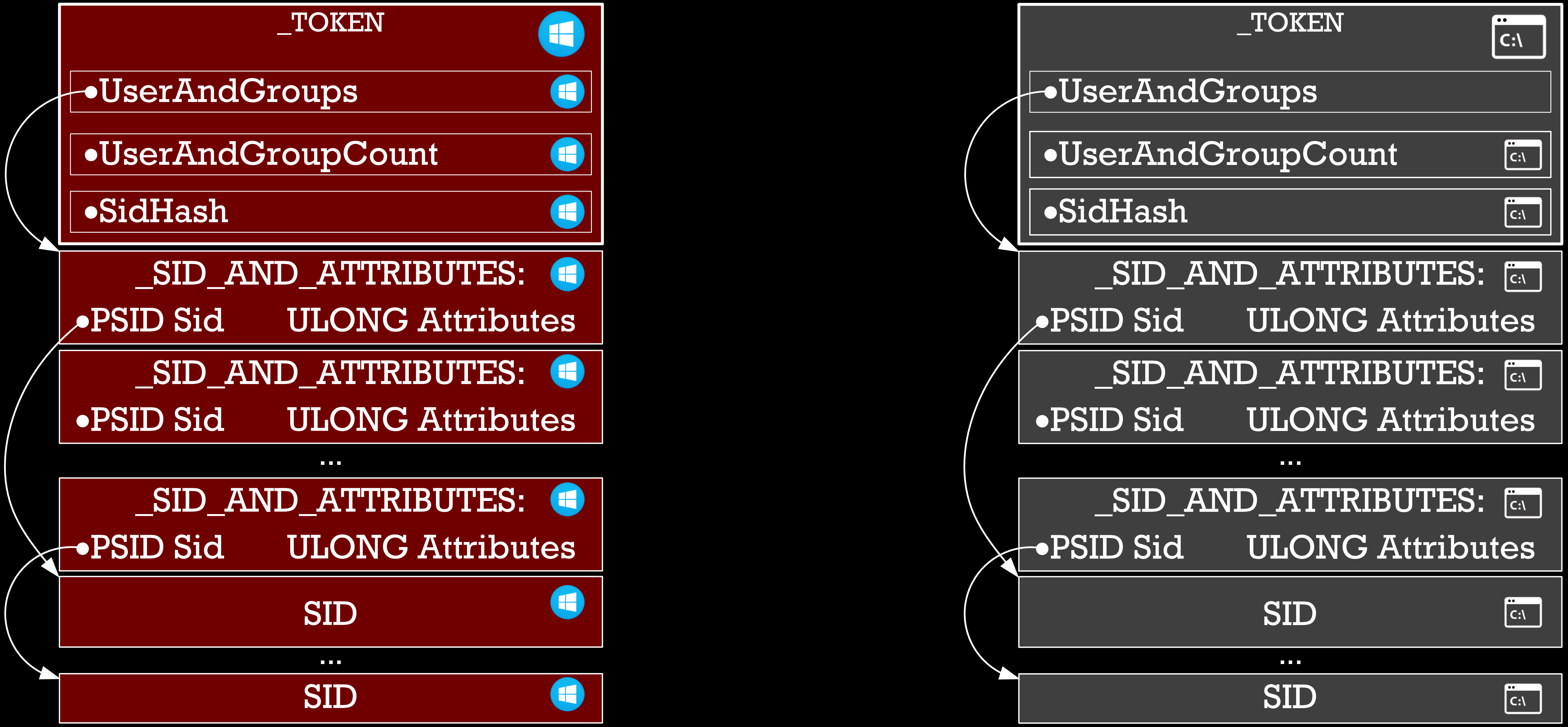


TOKEN INTERNALS



$SidHash = hash(SID_1+..+SID_N)$

AN IDEA OF TOKEN HIJACKING ATACK



_TOKEN

- UserAndGroups
- UserAndGroupCount
- SidHash

_SID_AND_ATTRIBUTES:

- PSID Sid ULONG Attributes

_SID_AND_ATTRIBUTES:

- PSID Sid ULONG Attributes

...

_SID_AND_ATTRIBUTES:

- PSID Sid ULONG Attributes

SID

...

SID

_TOKEN

- UserAndGroups
- UserAndGroupCount
- SidHash

_SID_AND_ATTRIBUTES:

- PSID Sid ULONG Attributes

_SID_AND_ATTRIBUTES:

- PSID Sid ULONG Attributes

...

_SID_AND_ATTRIBUTES:

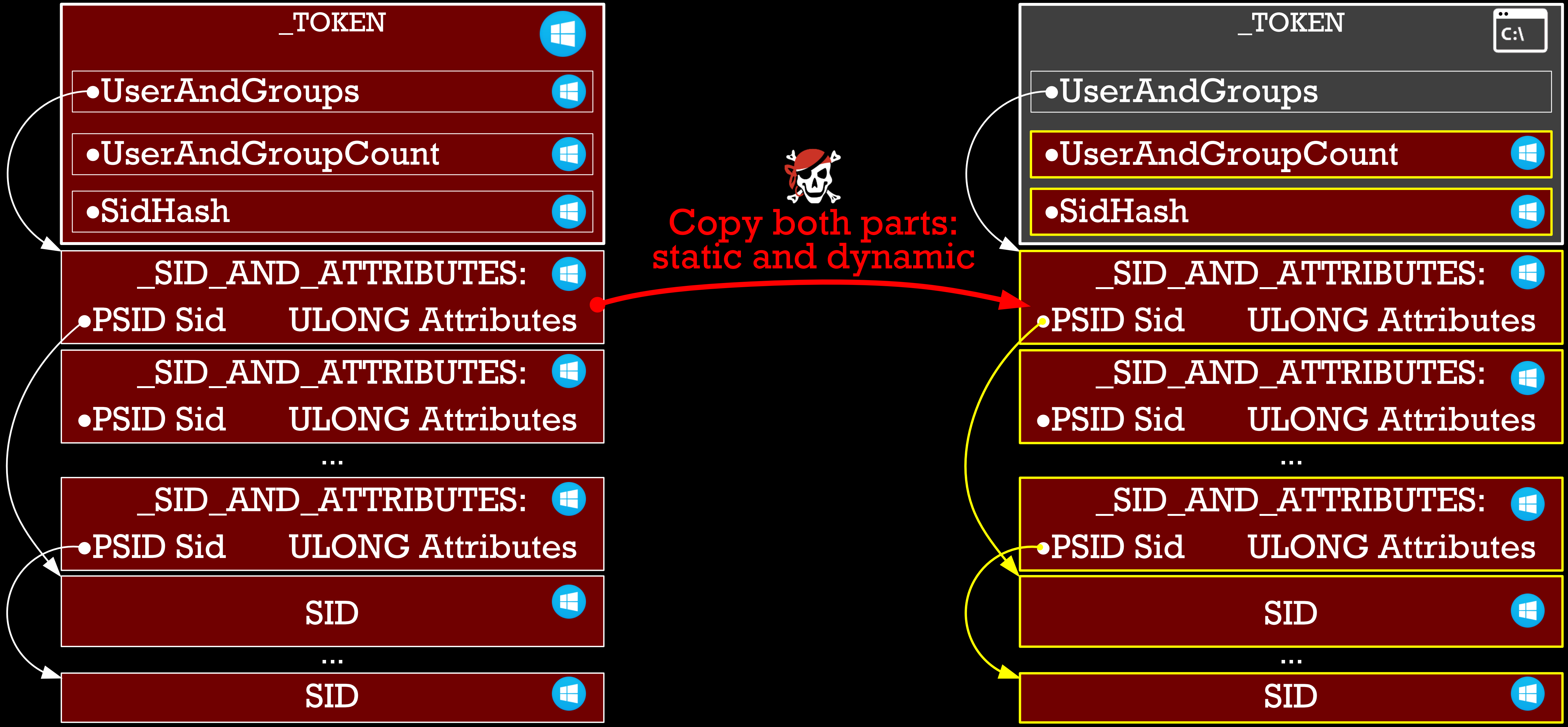
- PSID Sid ULONG Attributes

SID

...

SID

AN IDEA OF TOKEN HIJACKING ATACK



_TOKEN

•UserAndGroups

•UserAndGroupCount

•SidHash

_SID_AND_ATTRIBUTES:

•PSID Sid ULONG Attributes

_SID_AND_ATTRIBUTES:

•PSID Sid ULONG Attributes

...

_SID_AND_ATTRIBUTES:

•PSID Sid ULONG Attributes

SID

...

SID

Copy both parts: static and dynamic

_TOKEN

•UserAndGroups

•UserAndGroupCount

•SidHash

_SID_AND_ATTRIBUTES:

•PSID Sid ULONG Attributes

_SID_AND_ATTRIBUTES:

•PSID Sid ULONG Attributes

...

_SID_AND_ATTRIBUTES:

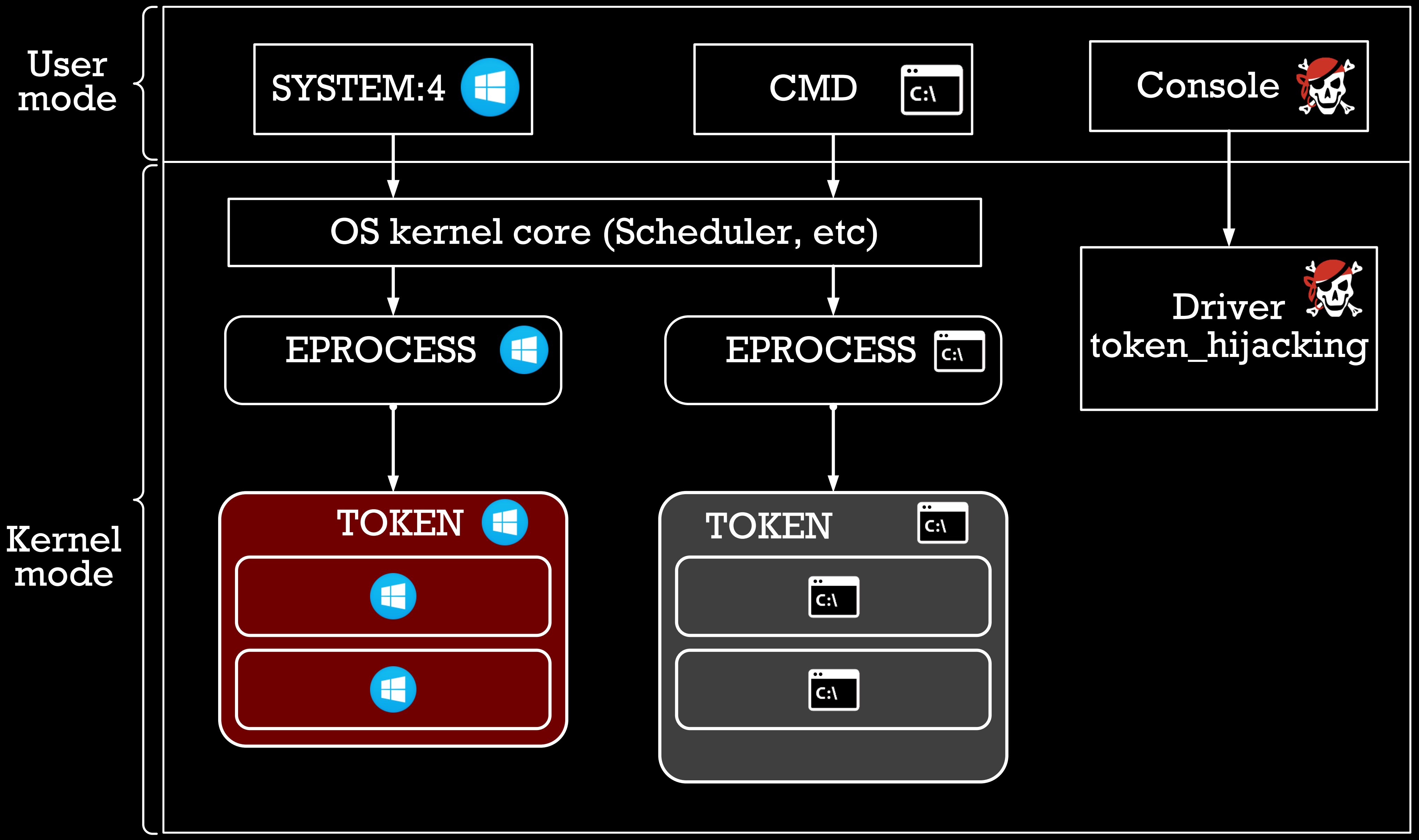
•PSID Sid ULONG Attributes

SID

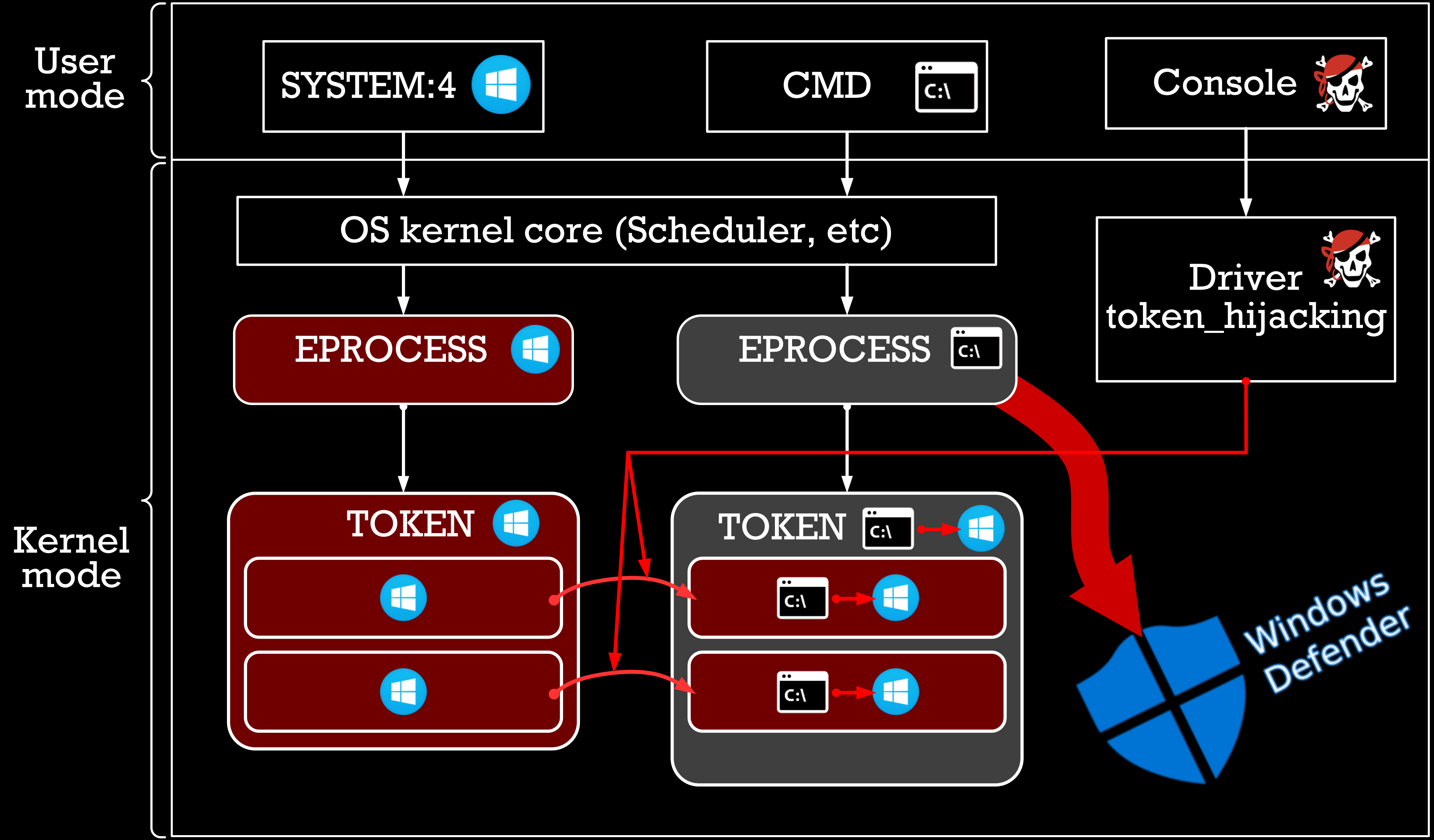
...

SID

TOKEN HIJACKING ATTACK



TOKEN HIJACKING ATTACK



User mode

SYSTEM:4

CMD

Console

Kernel mode

OS kernel core (Scheduler, etc)

Driver token_hijacking

EPROCESS

EPROCESS

TOKEN

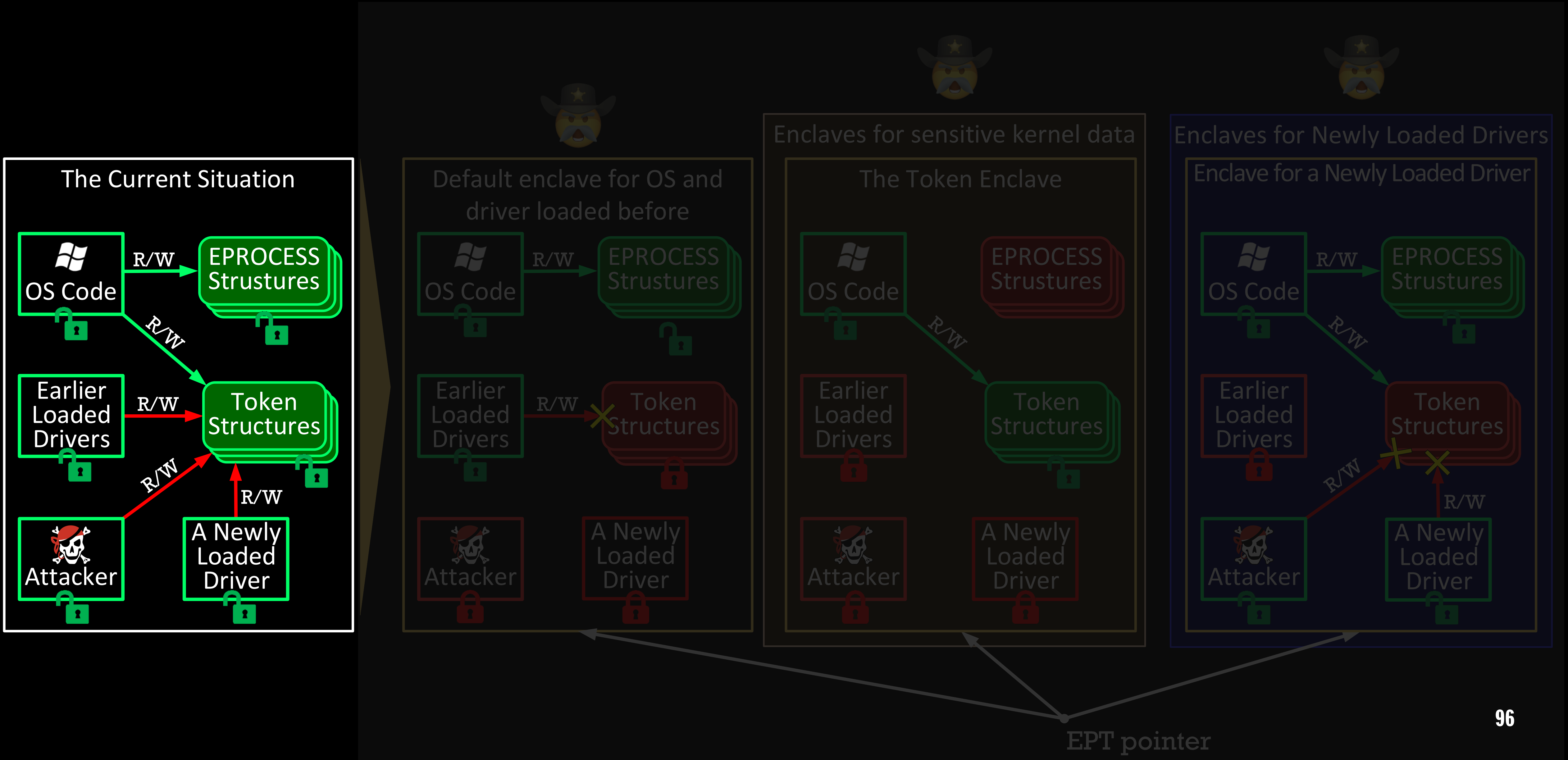
TOKEN

Commands to stop and disable Windows Defender — https://www.carbonblack.com/2019/08/16/cb-tau-threat-intelligence-notification-trickbot-banking-trojan-continues-to-evolve/

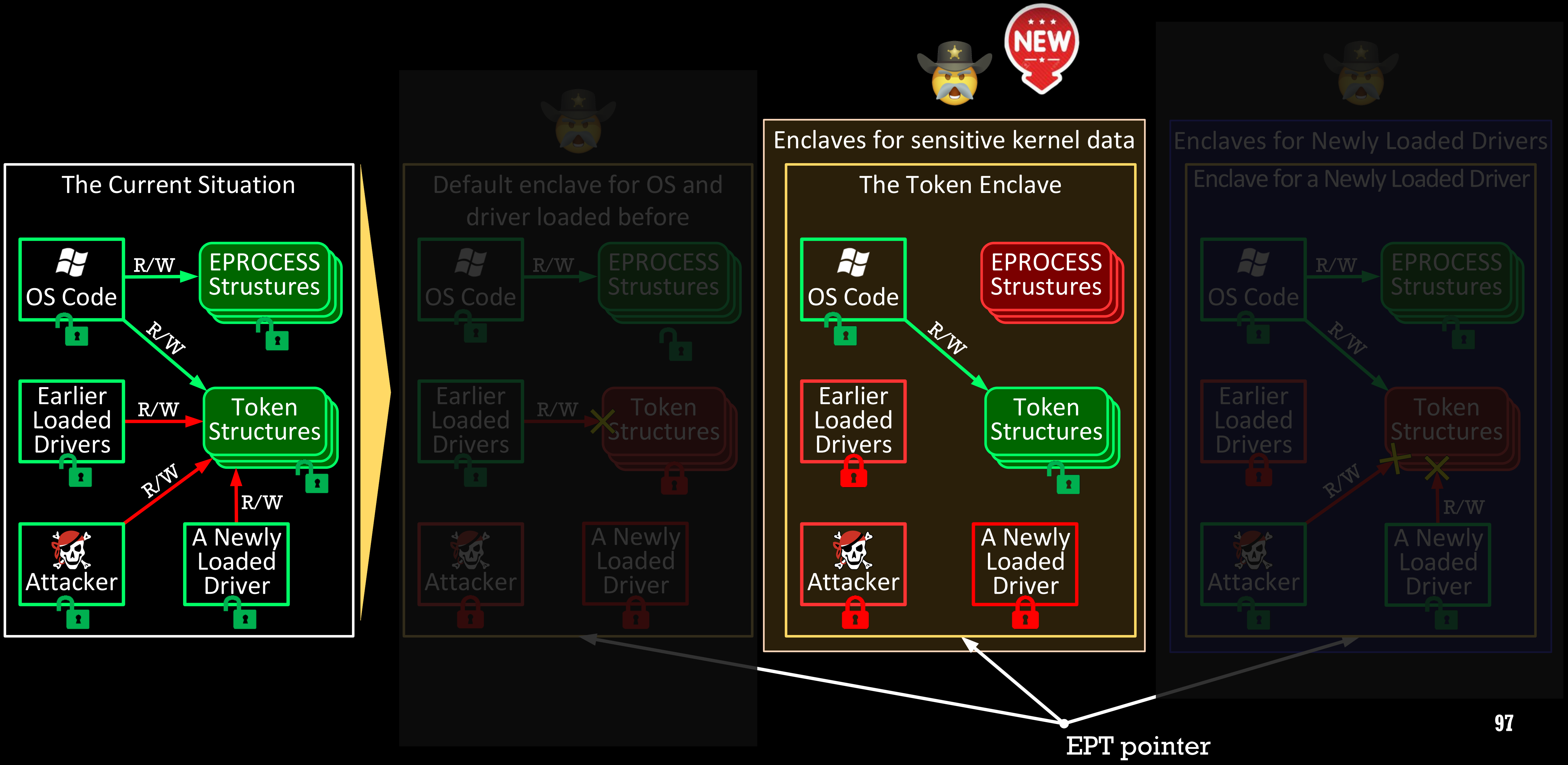
DEMO#5: TOKEN HIJACKING

The online version is here – https://www.youtube.com/embed/7Dgtz_2oGJg?vq=hd1440

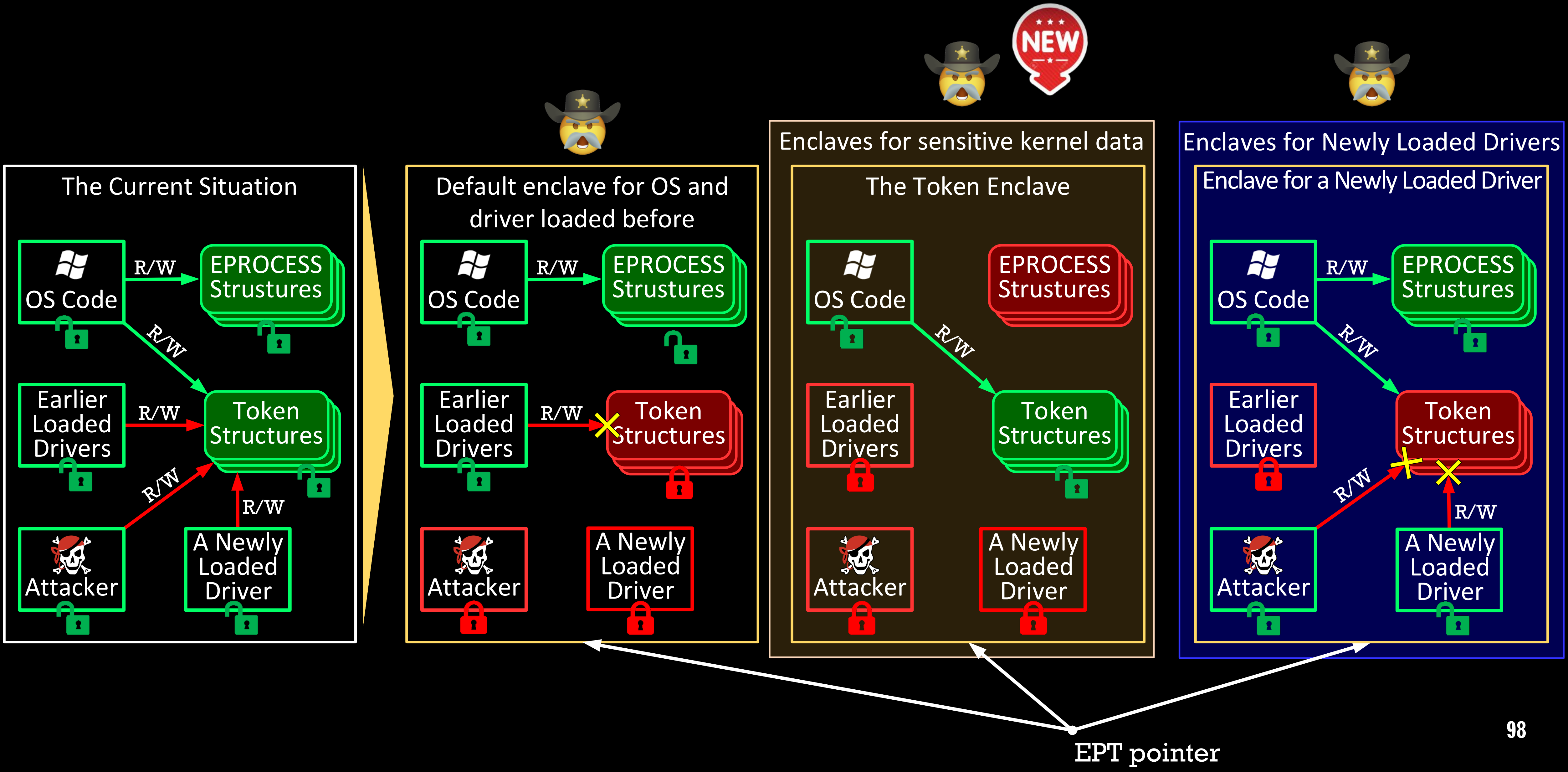
MEMORY MAP: MEMORYRANGER PREVENTS TOKEN HIAJCKING



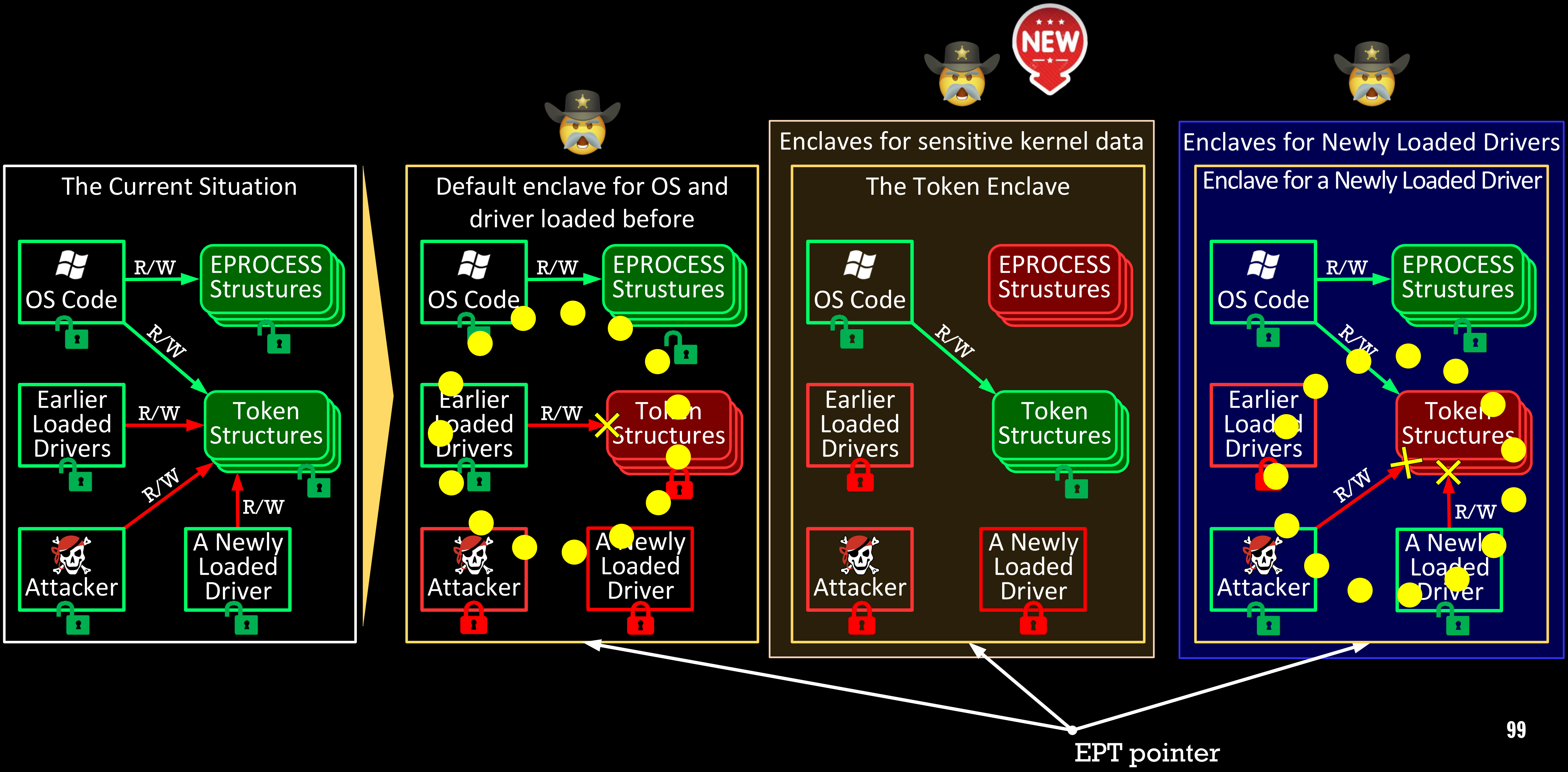
MEMORY MAP: MEMORYRANGER PREVENTS TOKEN HIAJCKING



MEMORY MAP: MEMORYRANGER PREVENTS TOKEN HIAJCKING



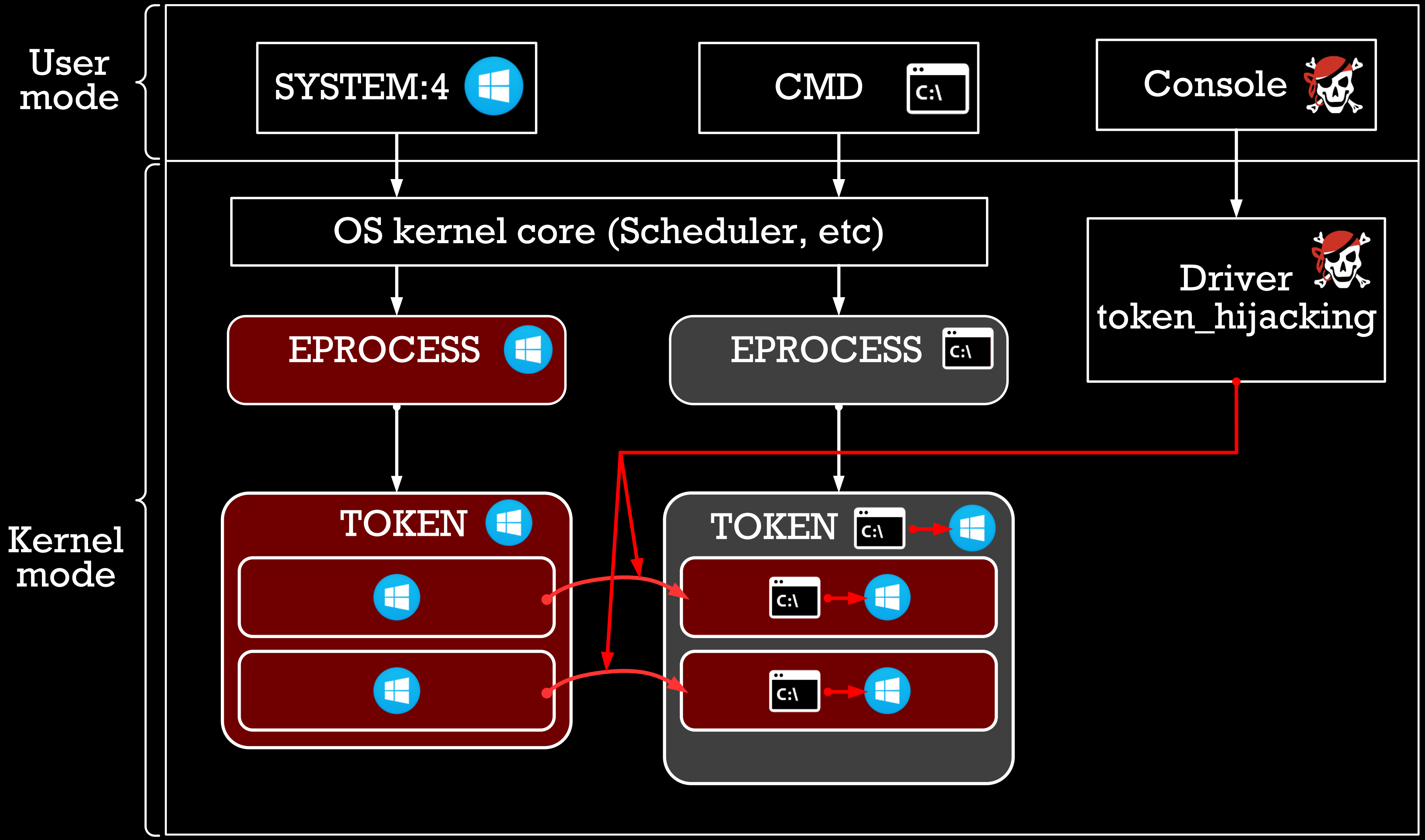
MEMORY MAP: MEMORYRANGER PREVENTS TOKEN HIAJCKING



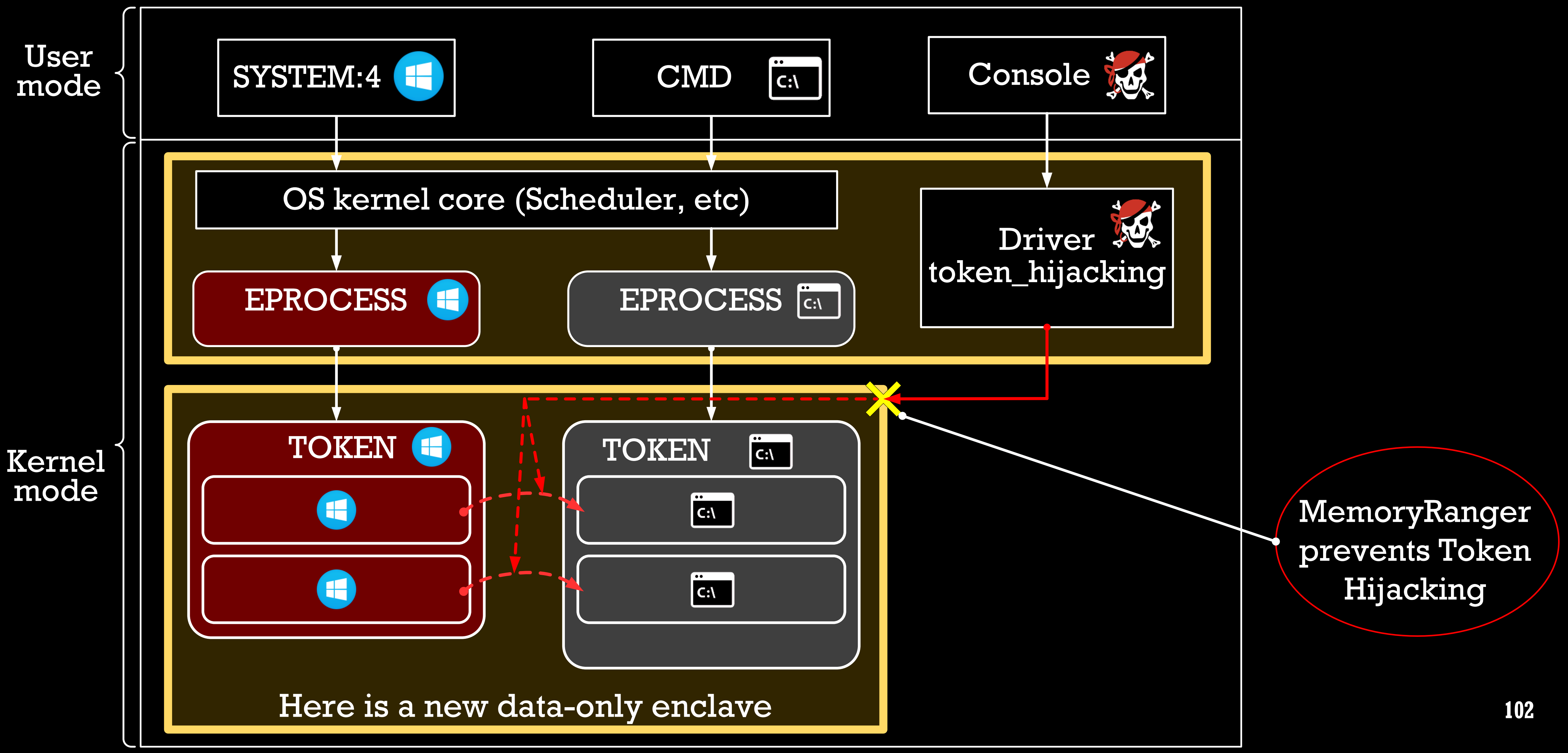
DEMO#6: PREVENTION OF TOKEN HIJACKING

The online version is here –
https://www.youtube.com/embed/_zGAR7wvM4g?vq=hd1440

TOKEN HIJACKING ATTACK



TOKEN HIJACKING IS BLOCKED BY A NEW DATA-ONLY ENCLAVE

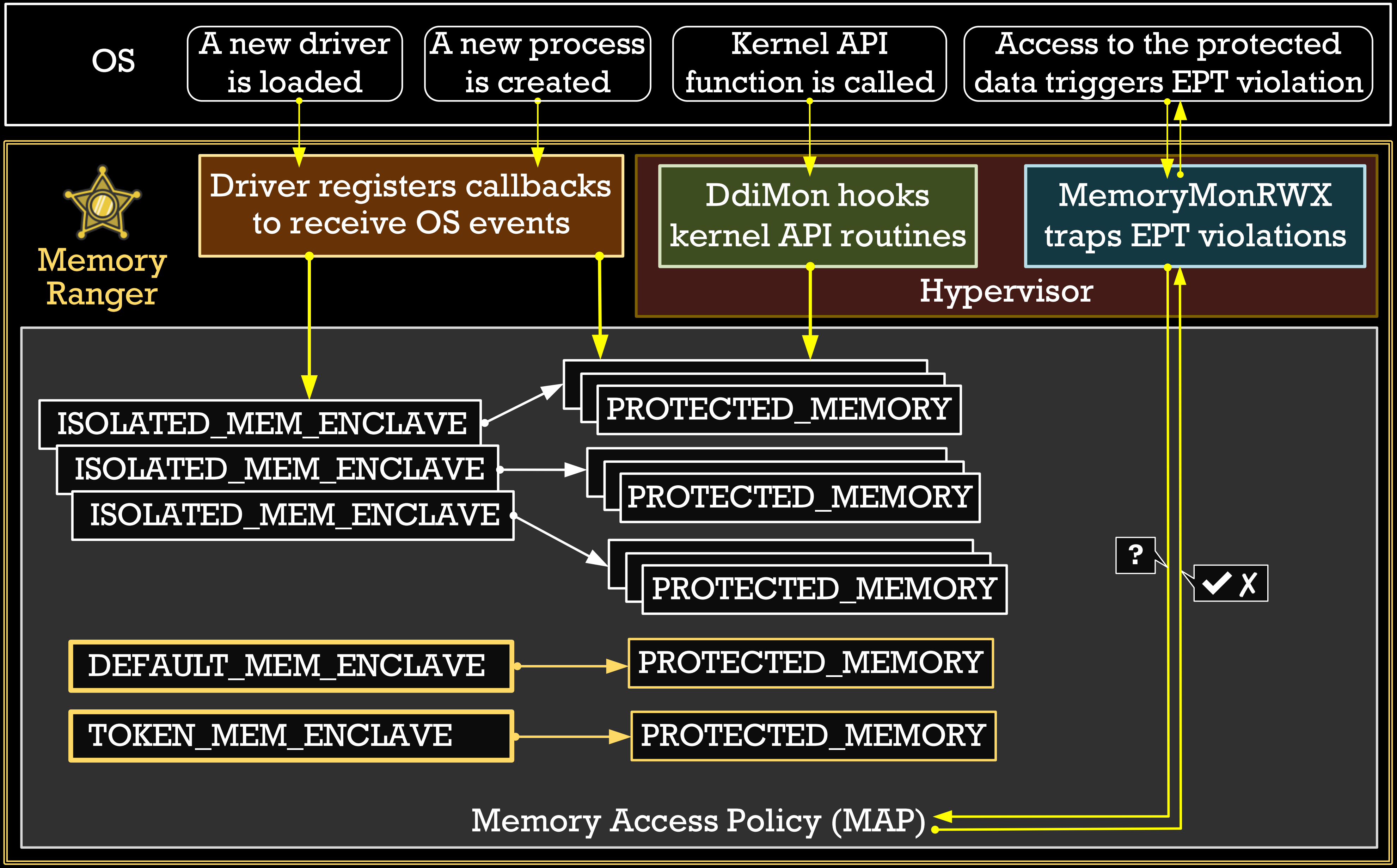


MemoryRanger prevents Token Hijacking

Episode 3

MemoryRanger

MEMORY RANGER ARCHITECTURE

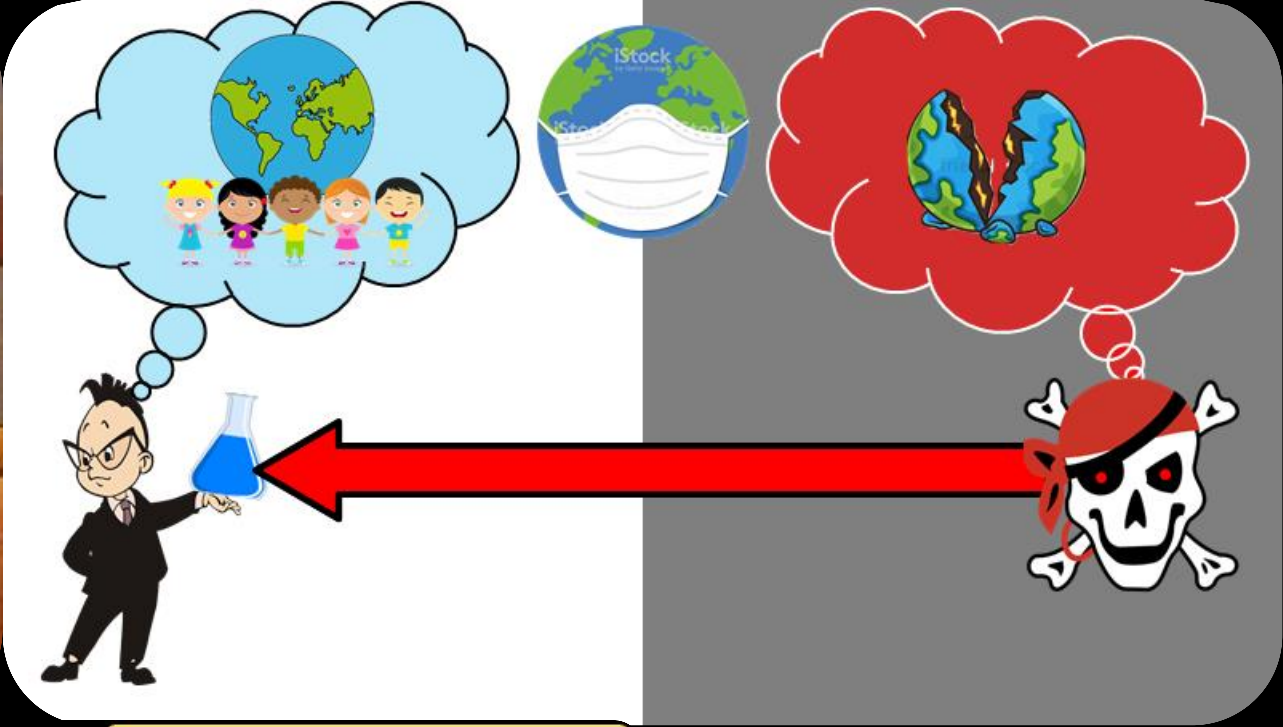


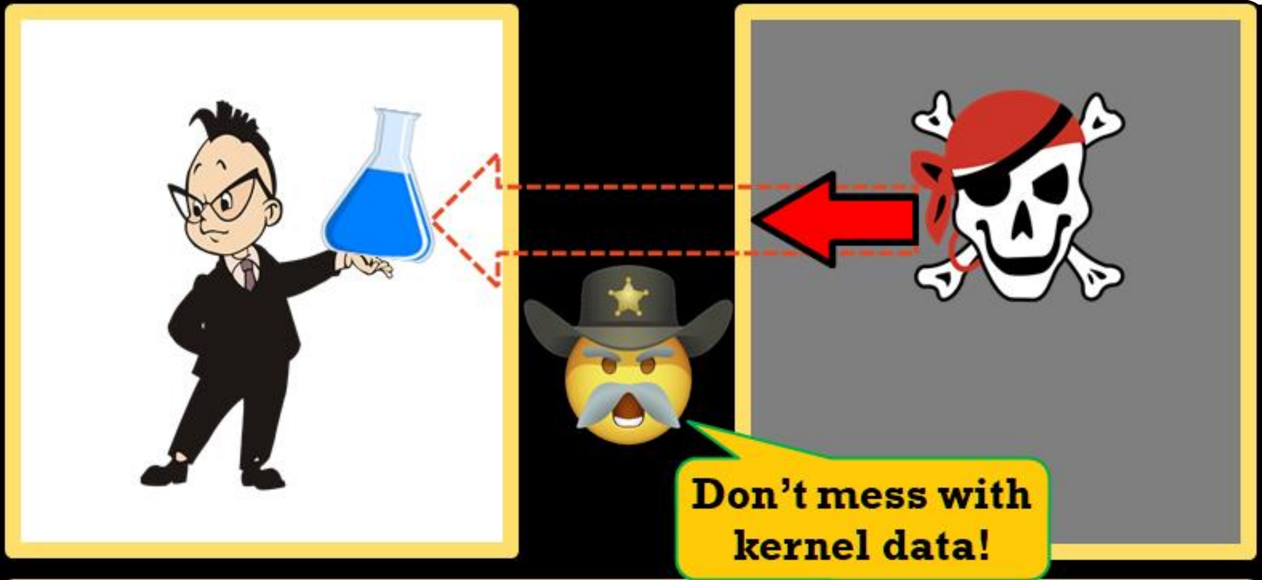
(Further details in the paper)

https://github.com/IgorKorkin/MemoryRanger

CONCLUSION

1. Windows OS security features provide limited kernel memory protection
2. Handle Hijacking = copy 6 bytes of structure
3. Hijacking NTFS = copy data structures & Thread ID
4. Token Hijacking = copy structures & their interconnections
5. Updated MemoryRanger
   - protects new data structures
   - includes a new data-only enclave to isolate the secret data from all drivers
   - works well on the recent Windows 1903





MemoryRanger

MemoryRanger protects the OS!

HITB

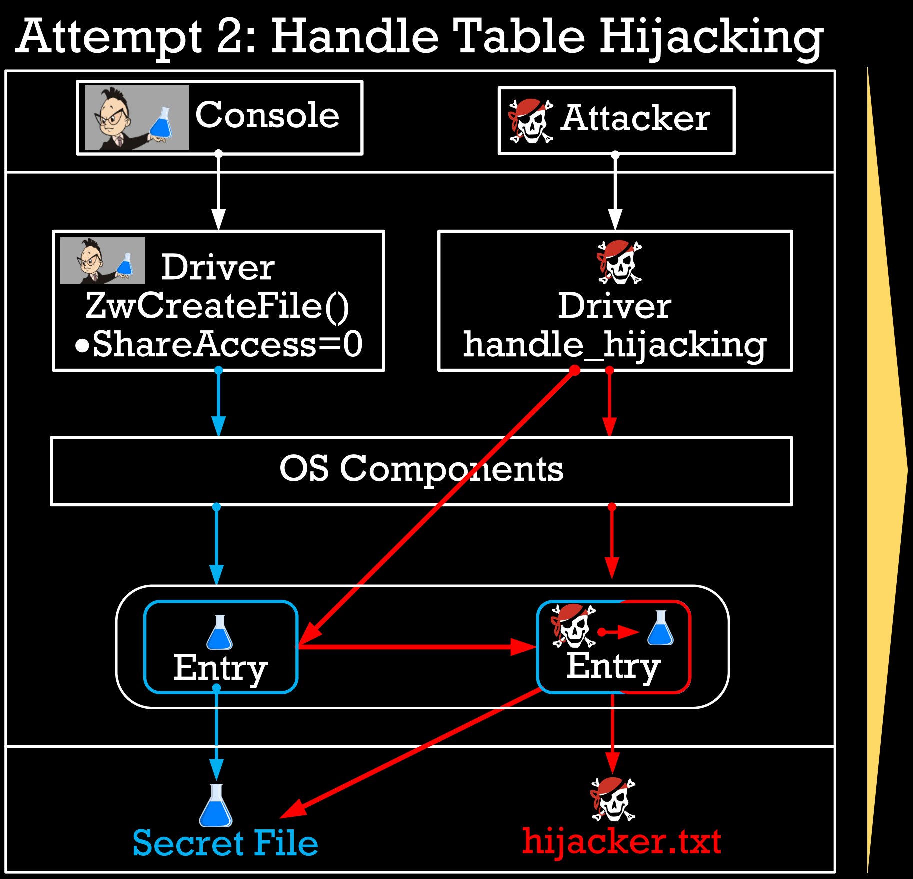
Thank You!

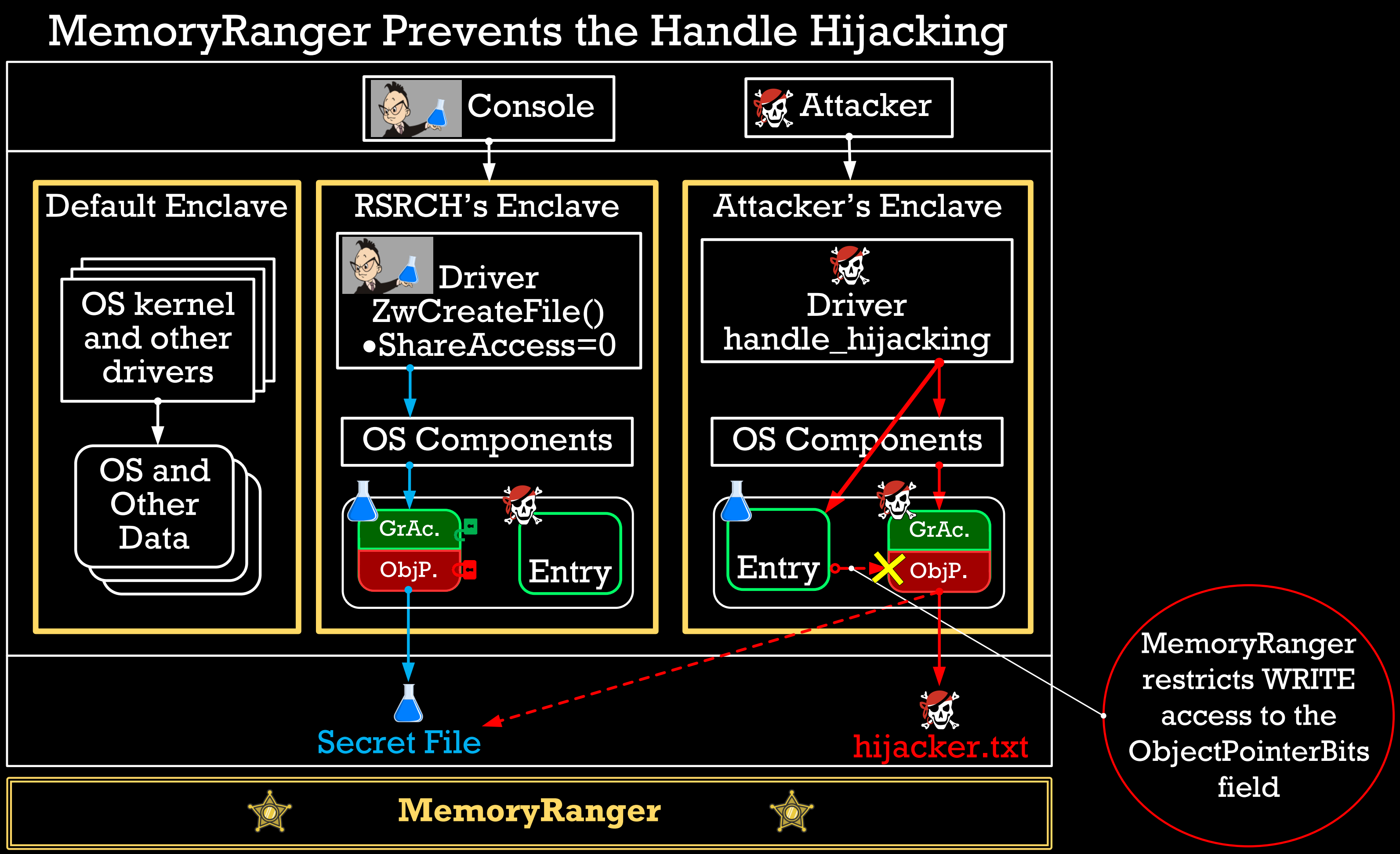
HITB LOCKDOWN 002 livestream

Igor Korkin * igor.korkin@gmail.com * igorkorkin.blogspot.com

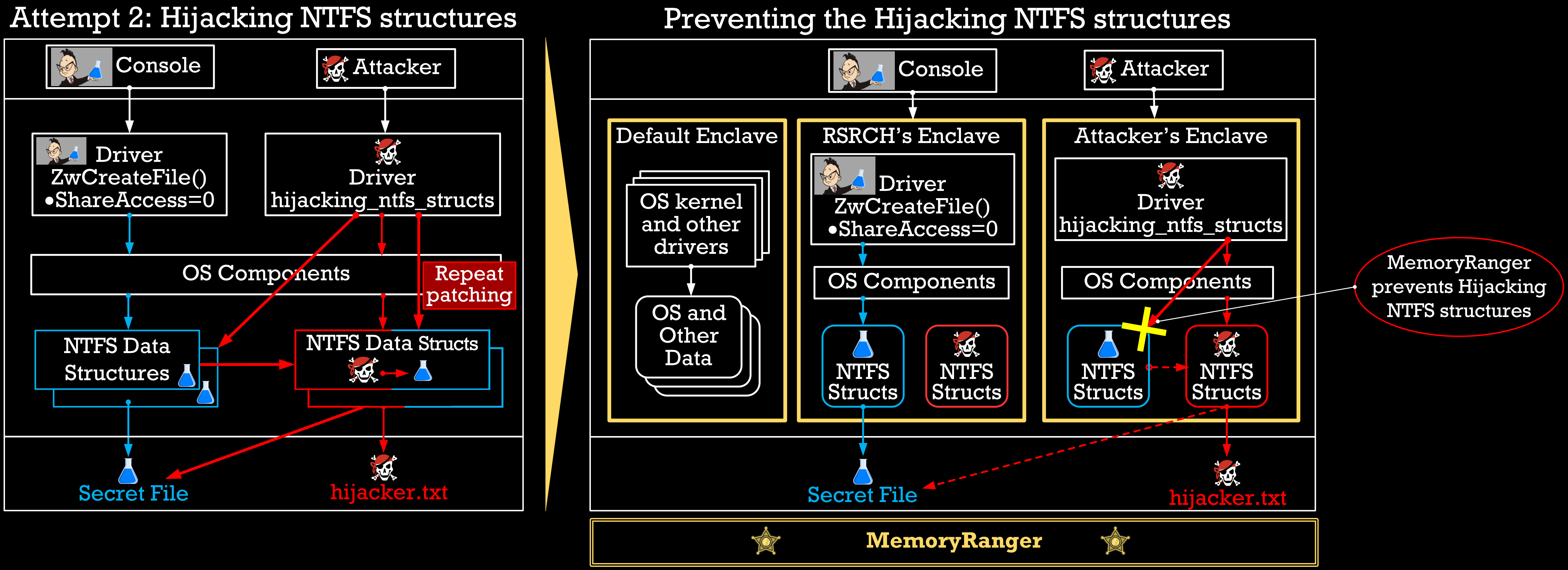
EXTRA SLIDES

DEMO: PREVENTING THE HANDLE HIJACKING ATTACK





DEMO: PREVENTING THE HIJACKING NTFS STRUCTURES


Attempt 2: Hijacking NTFS structures
Console
Attacker
Driver
ZwCreateFile()
•ShareAccess=0
Driver
hijacking_ntfs_structs
OS Components
Repeat patching
NTFS Data Structures
NTFS Data Structs
Secret File
hijacker.txt
Preventing the Hijacking NTFS structures
Console
Attacker
Default Enclave
OS kernel and other drivers
OS and Other Data
RSRCH's Enclave
Driver
ZwCreateFile()
•ShareAccess=0
OS Components
NTFS Structs
NTFS Structs
Attacker's Enclave
Driver
hijacking_ntfs_structs
OS Components
NTFS Structs
NTFS Structs
MemoryRanger prevents Hijacking NTFS structures
Secret File
hijacker.txt
MemoryRanger