REcon Montreal 2024

Smoke and Mirrors: Driver Signatures are Optional

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Detecting malware tradecraft

Attack & defense of EDR

Presented research at:

- BlueHat IL
- Shmoocon
- Black Hat USA
- Black Hat Asia

Blue, formerly red

Chapter 1 - Windows File Sharing

More than you've ever wanted to know about sharing violations.

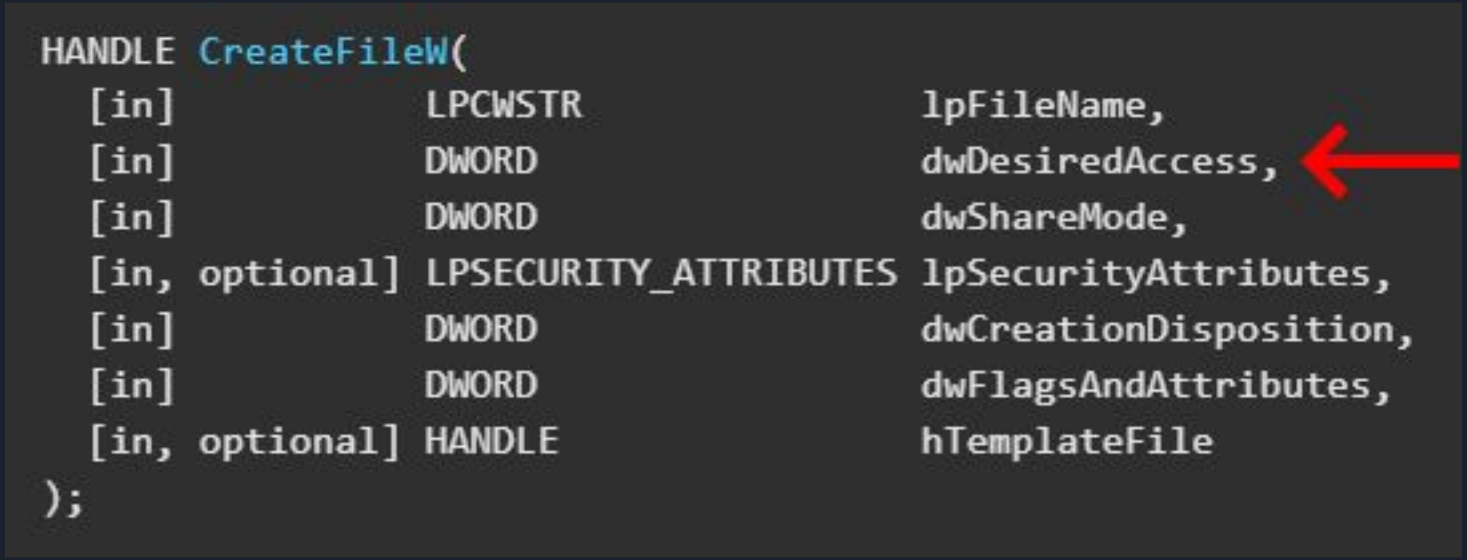
Opening Files - Access Rights

CreateFile - Win32 API to open or create files.

- ntdll analog is **NtCreateFile**.
- Kernel driver analog is **ZwCreateFile**.

Specify desired access rights:

- **FILE_READ_DATA**
- **FILE_WRITE_DATA**
- **DELETE**
- …



```
HANDLE CreateFileW(
  [in]           LPCWSTR               lpFileName,
  [in]           DWORD                 dwDesiredAccess,
  [in]           DWORD                 dwShareMode,
  [in, optional] LPSECURITY_ATTRIBUTES lpSecurityAttributes,
  [in]           DWORD                 dwCreationDisposition,
  [in]           DWORD                 dwFlagsAndAttributes,
  [in, optional] HANDLE                hTemplateFile
);
```

https://learn.microsoft.com/en-us/windows/win32/api/fileapi/nf-fileapi-createfilew
https://learn.microsoft.com/en-us/windows/win32/fileio/file-security-and-access-rights

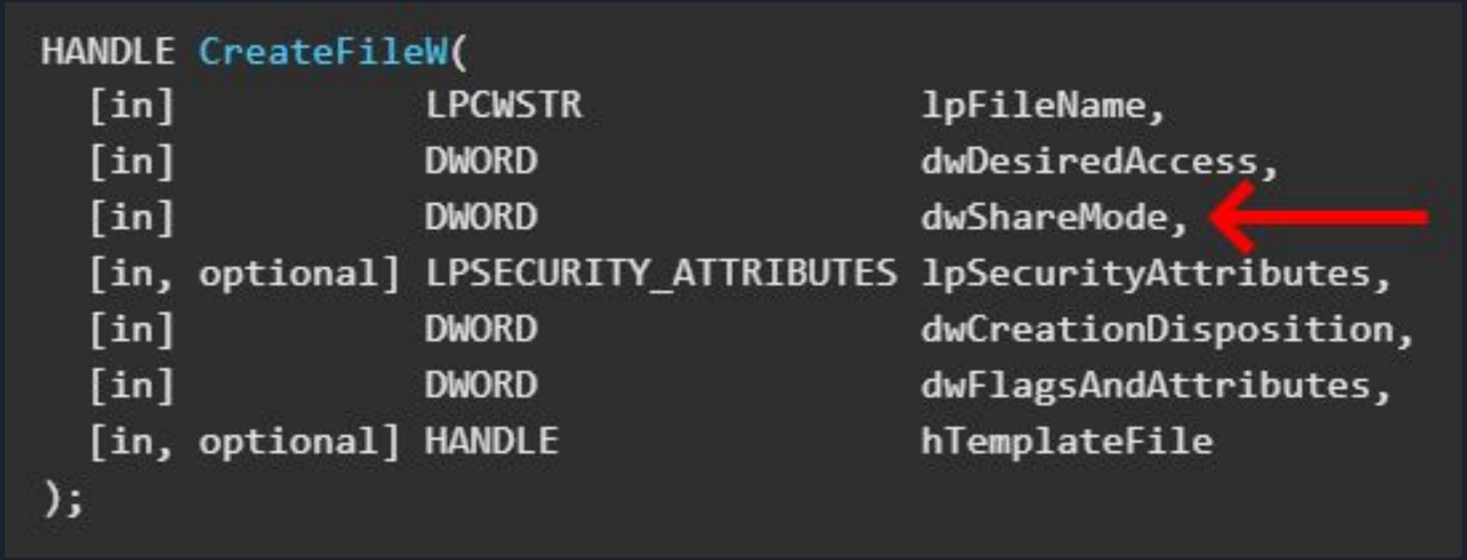
Opening Files - Share Mode

FILE_SHARE_READ / **FILE_SHARE_WRITE** / **FILE_SHARE_DELETE**

“I’m okay with others reading/writing/deleting this file while I’m using it.”

As file is opened:

- **DesiredAccess** is tested against **ShareMode** of all existing file handles
- **ShareMode** is tested against **GrantedAccess** of all existing file handles



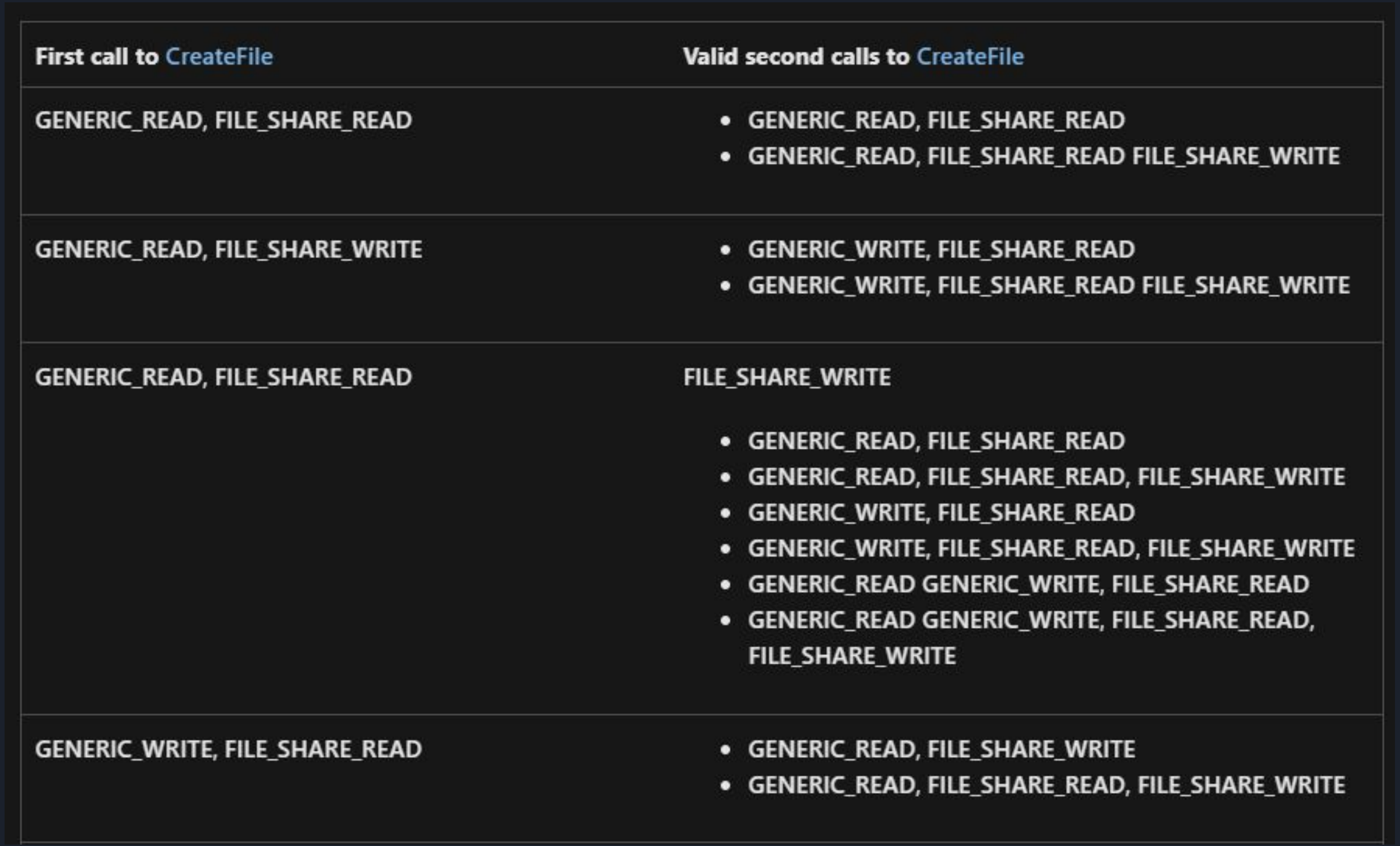
```
HANDLE CreateFileW(
  [in]           LPCWSTR               lpFileName,
  [in]           DWORD                 dwDesiredAccess,
  [in]           DWORD                 dwShareMode,
  [in, optional] LPSECURITY_ATTRIBUTES lpSecurityAttributes,
  [in]           DWORD                 dwCreationDisposition,
  [in]           DWORD                 dwFlagsAndAttributes,
  [in, optional] HANDLE                hTemplateFile
);
```

https://learn.microsoft.com/en-us/windows/win32/api/fileapi/nf-fileapi-createfilew
https://learn.microsoft.com/en-us/windows/win32/fileio/creating-and-opening-files

Opening Files - Sharing Violation

DesiredAccess/**ShareMode** incompatibilities fail the **CreateFile** call.

- **ERROR_SHARING_VIOLATION** / **STATUS_SHARING_VIOLATION**

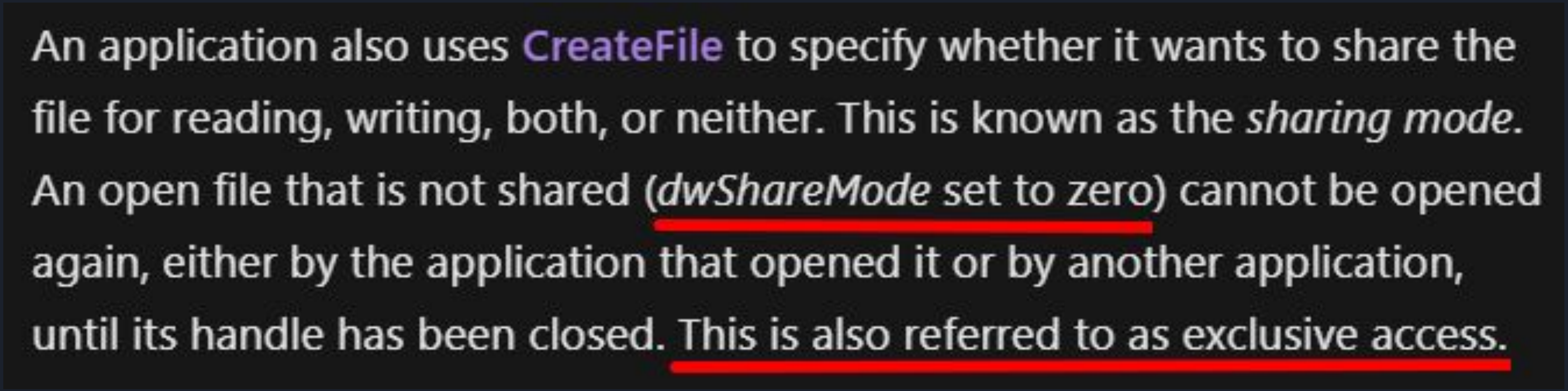


First call to CreateFile	Valid second calls to CreateFile
GENERIC_READ, FILE_SHARE_READ	• GENERIC_READ, FILE_SHARE_READ • GENERIC_READ, FILE_SHARE_READ FILE_SHARE_WRITE
GENERIC_READ, FILE_SHARE_WRITE	• GENERIC_WRITE, FILE_SHARE_READ • GENERIC_WRITE, FILE_SHARE_READ FILE_SHARE_WRITE
GENERIC_READ, FILE_SHARE_READ	FILE_SHARE_WRITE • GENERIC_READ, FILE_SHARE_READ • GENERIC_READ, FILE_SHARE_READ, FILE_SHARE_WRITE • GENERIC_WRITE, FILE_SHARE_READ • GENERIC_WRITE, FILE_SHARE_READ, FILE_SHARE_WRITE • GENERIC_READ GENERIC_WRITE, FILE_SHARE_READ • GENERIC_READ GENERIC_WRITE, FILE_SHARE_READ, FILE_SHARE_WRITE
GENERIC_WRITE, FILE_SHARE_READ	• GENERIC_READ, FILE_SHARE_WRITE • GENERIC_READ, FILE_SHARE_READ, FILE_SHARE_WRITE

https://learn.microsoft.com/en-us/windows/win32/api/fileapi/nf-fileapi-createfilew
https://learn.microsoft.com/en-us/windows/win32/fileio/creating-and-opening-files

Opening Files - Exclusive Access

Set **ShareMode**=0 for exclusive access to files until you close the handle.

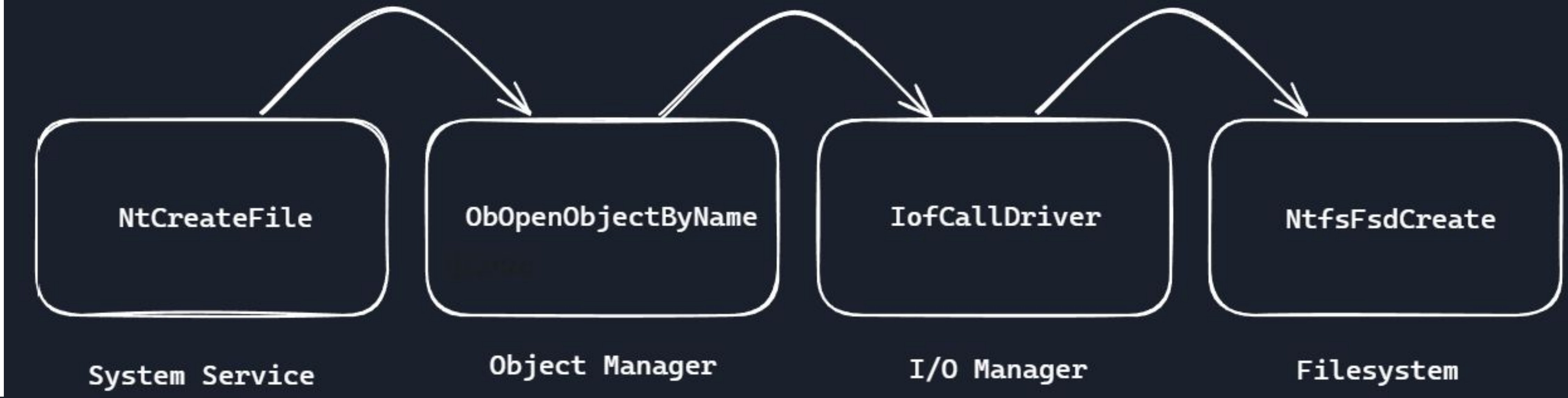


An application also uses CreateFile to specify whether it wants to share the file for reading, writing, both, or neither. This is known as the *sharing mode*. An open file that is not shared (*dwShareMode* set to zero) cannot be opened again, either by the application that opened it or by another application, until its handle has been closed. This is also referred to as exclusive access.

https://learn.microsoft.com/en-us/windows/win32/fileio/creating-and-opening-files

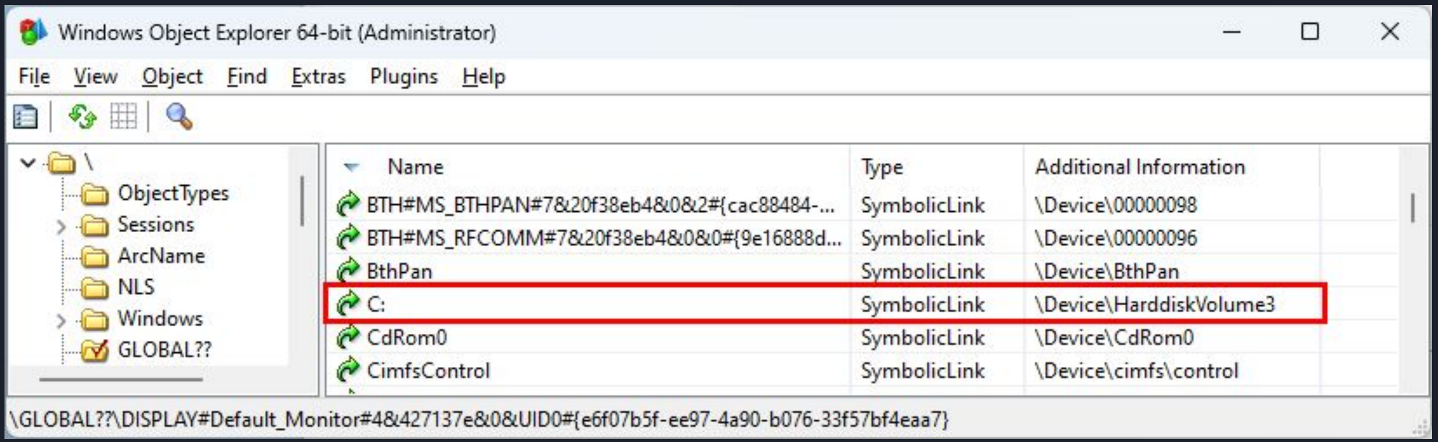
I/O Flow (Abbreviated)

What happens when a program opens a file?



NtCreateFile → ObOpenObjectByName → IofCallDriver → NtfsFsdCreate

System Service | Object Manager | I/O Manager | Filesystem



Windows Object Explorer 64-bit (Administrator)
File View Object Find Extras Plugins Help

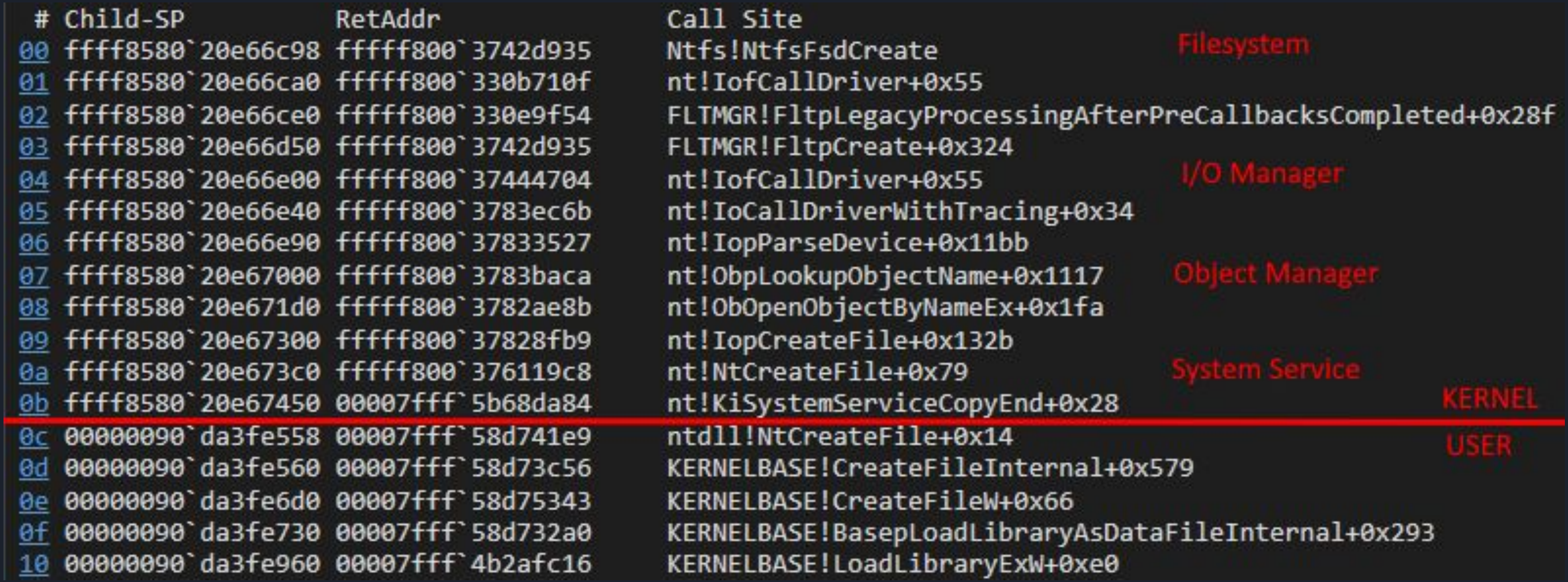
- \
  - ObjectTypes
  - Sessions
  - ArcName
  - NLS
  - Windows
  - GLOBAL??

Name	Type	Additional Information
BTH#MS_BTHPAN#7&20f38eb4&0&2#{cac88484-...	SymbolicLink	\Device\00000098
BTH#MS_RFCOMM#7&20f38eb4&0&0#{9e16888d...	SymbolicLink	\Device\00000096
BthPan	SymbolicLink	\Device\BthPan
C:	SymbolicLink	\Device\HarddiskVolume3
CdRom0	SymbolicLink	\Device\CdRom0
CimfsControl	SymbolicLink	\Device\cimfs\control

\GLOBAL??\DISPLAY#Default_Monitor#4&427137e&0&UID0#{e6f07b5f-ee97-4a90-b076-33f57bf4eaa7}

I/O Flow (Abbreviated)

What happens when a program opens a file?

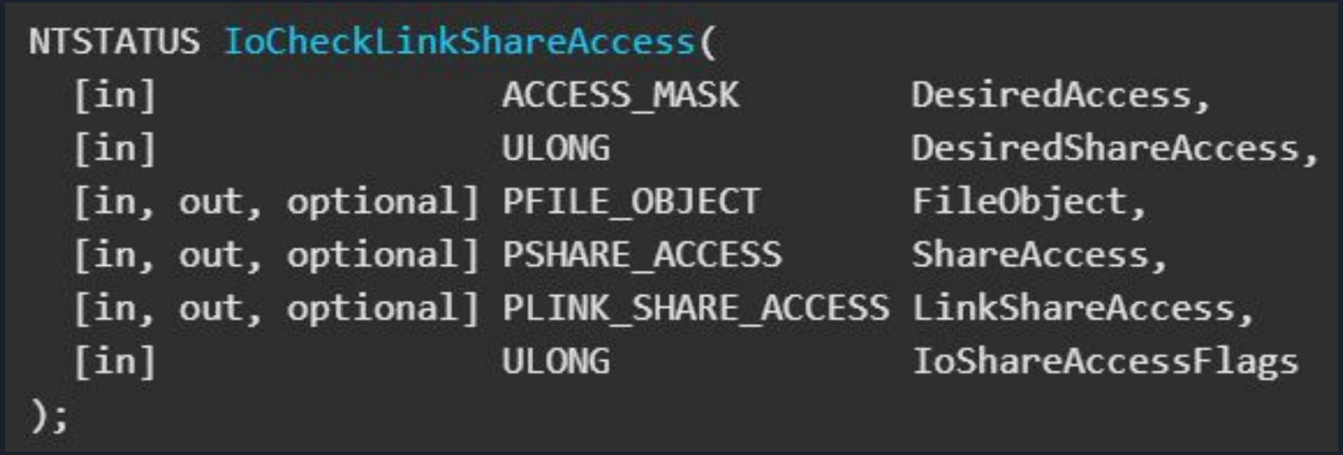


```
 # Child-SP          RetAddr               Call Site
00 ffff8580`20e66c98 fffff800`3742d935     Ntfs!NtfsFsdCreate
01 ffff8580`20e66ca0 fffff800`330b710f     nt!IofCallDriver+0x55
02 ffff8580`20e66ce0 fffff800`330e9f54     FLTMGR!FltpLegacyProcessingAfterPreCallbacksCompleted+0x28f
03 ffff8580`20e66d50 fffff800`3742d935     FLTMGR!FltpCreate+0x324
04 ffff8580`20e66e00 fffff800`37444704     nt!IofCallDriver+0x55
05 ffff8580`20e66e40 fffff800`3783ec6b     nt!IoCallDriverWithTracing+0x34
06 ffff8580`20e66e90 fffff800`37833527     nt!IopParseDevice+0x11bb
07 ffff8580`20e67000 fffff800`3783baca     nt!ObpLookupObjectName+0x1117
08 ffff8580`20e671d0 fffff800`3782ae8b     nt!ObOpenObjectByNameEx+0x1fa
09 ffff8580`20e67300 fffff800`37828fb9     nt!IopCreateFile+0x132b
0a ffff8580`20e673c0 fffff800`376119c8     nt!NtCreateFile+0x79
0b ffff8580`20e67450 00007fff`5b68da84     nt!KiSystemServiceCopyEnd+0x28
0c 00000090`da3fe558 00007fff`58d741e9     ntdll!NtCreateFile+0x14
0d 00000090`da3fe560 00007fff`58d73c56     KERNELBASE!CreateFileInternal+0x579
0e 00000090`da3fe6d0 00007fff`58d75343     KERNELBASE!CreateFileW+0x66
0f 00000090`da3fe730 00007fff`58d732a0     KERNELBASE!BasepLoadLibraryAsDataFileInternal+0x293
10 00000090`da3fe960 00007fff`4b2afc16     KERNELBASE!LoadLibraryExW+0xe0
```

Sharing Enforcement - I/O Manager

Filesystems call **IoCheckLinkShareAccess** to see whether **DesiredAccess**/**ShareMode** is compatible with existing handles.

```
NTSTATUS NtfsCheckShareAccess(FileObject, DesiredAccess, ShareAccess)
{
    ntStatus = IoCheckLinkShareAccess(
        FileObject, DesiredAccess, ShareAccess);
    if (!NT_SUCCESS(ntStatus))
    {
        return ntStatus;
    }
    ...
}
```

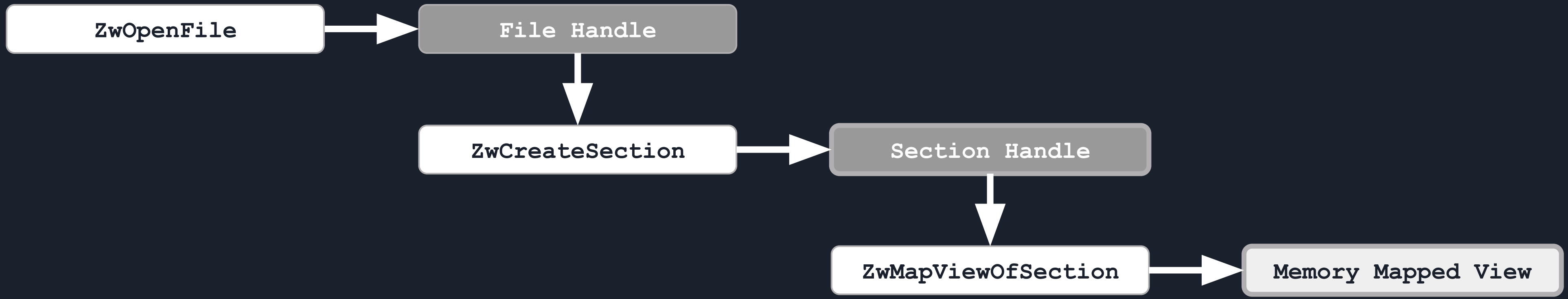


```
NTSTATUS IoCheckLinkShareAccess(
  [in]                      ACCESS_MASK        DesiredAccess,
  [in]                      ULONG              DesiredShareAccess,
  [in, out, optional] PFILE_OBJECT       FileObject,
  [in, out, optional] PSHARE_ACCESS      ShareAccess,
  [in, out, optional] PLINK_SHARE_ACCESS LinkShareAccess,
  [in]                      ULONG              IoShareAccessFlags
);
```

https://github.com/Microsoft/Windows-driver-samples/blob/622212c3fff587f23f6490a9da939fb85968f651/filesys/fastfat/create.c#L6822-L6884

Sharing Enforcement - File Mapping

File mappings (section objects) allow files to be readable/writable after handles are closed.



```
NTSTATUS NtfsOpenAttributeCheck(...)
{
    if (!FlagOn(ShareMode, FILE_SHARE_WRITE) &&
        MmDoesFileHaveUserWritableReferences(FileObject->SectionObjectPointer))
    {
        return STATUS_SHARING_VIOLATION;
    }
    ...
}
```

https://github.com/Microsoft/Windows-driver-samples/blob/622212c3fff587f23f6490a9da939fb85968f651/filesys/fastfat/create.c#L6858-L6870

Sharing Enforcement - Executables

Files mapped as executable images (EXEs/DLLs/etc) **must be immutable** while in use.

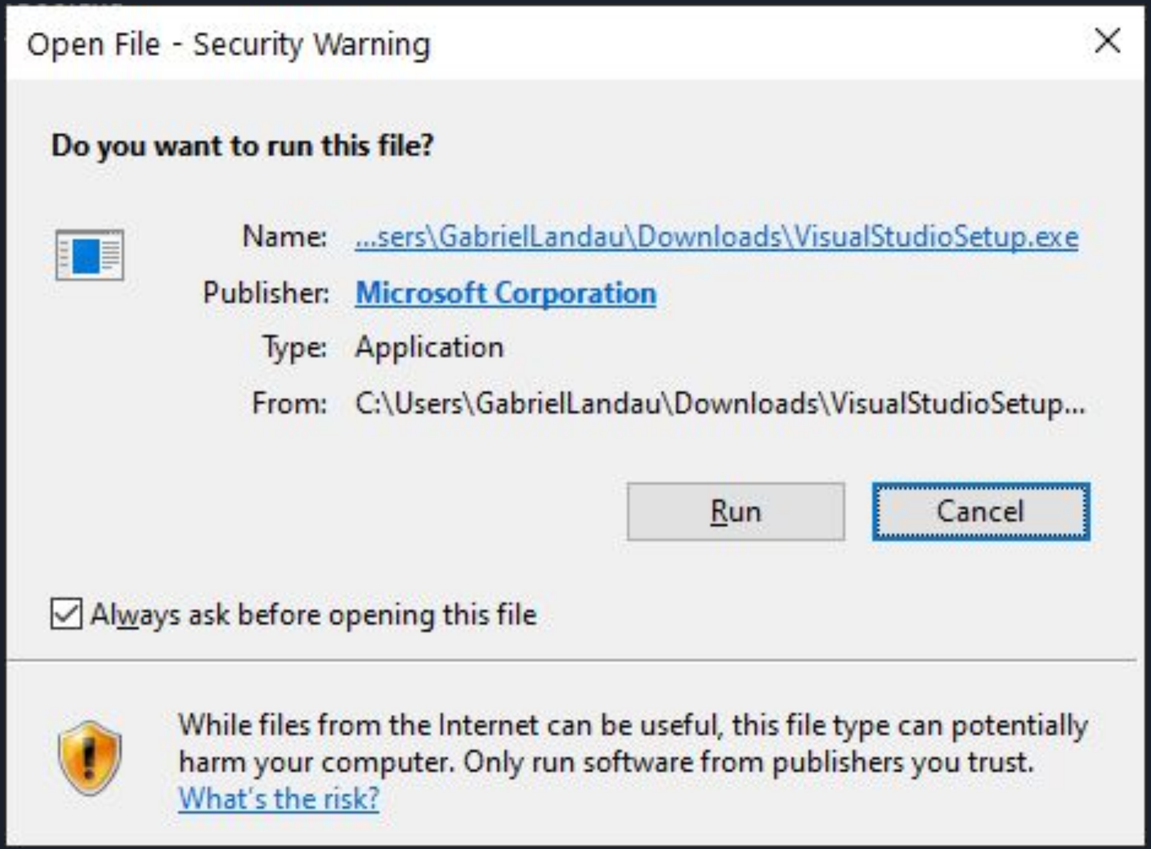
In other words, **ZwMapViewOfSection(SEC_IMAGE)** implies no-write-sharing.

```
NTSTATUS NtfsOpenAttributeCheck(...)
{
    // Block writes to active image section objects
    if (FlagOn(DesiredAccess, FILE_WRITE_DATA) &&
        FileObject->SectionObjectPointer.ImageSectionObject &&
        !MmFlushImageSection(FileObject->SectionObjectPointer), MmFlushForWrite)
        {
            return STATUS_SHARING_VIOLATION
        }
    }
    ...
}
```

https://github.com/Microsoft/Windows-driver-samples/blob/622212c3fff587f23f6490a9da939fb85968f651/filesys/fastfat/create.c#L3572-L3593

Chapter 2 - Code Integrity

How do you trust the code that's running on your system?



Open File - Security Warning

Do you want to run this file?

Name: ...sers\GabrielLandau\Downloads\VisualStudioSetup.exe

Publisher: **Microsoft Corporation**

Type: Application

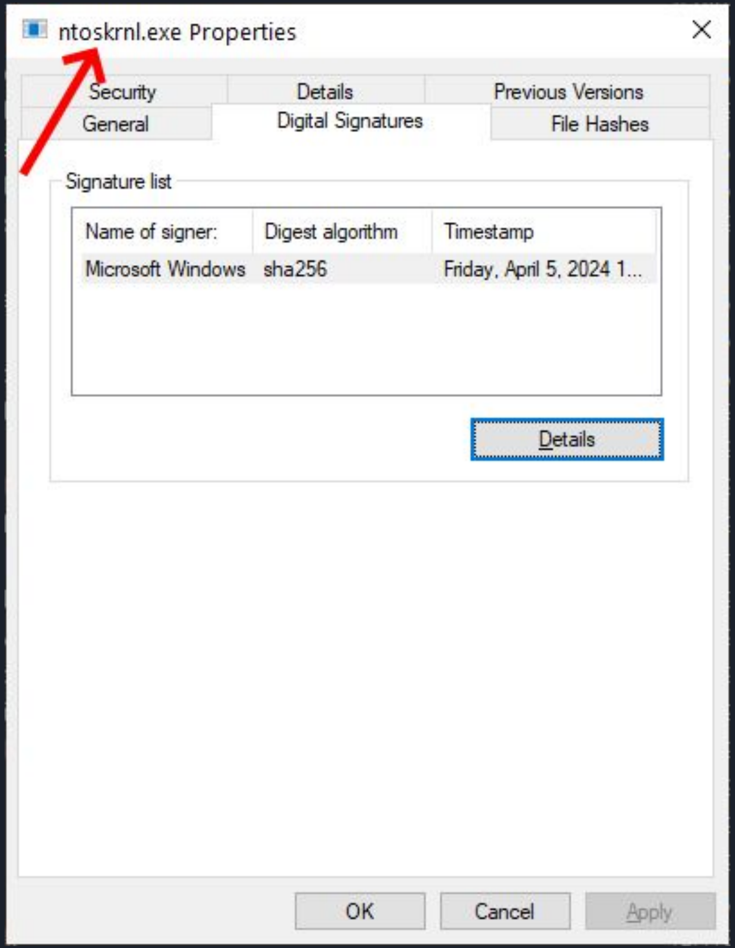
From: C:\Users\GabrielLandau\Downloads\VisualStudioSetup...

☑ Always ask before opening this file

While files from the Internet can be useful, this file type can potentially harm your computer. Only run software from publishers you trust. What's the risk?

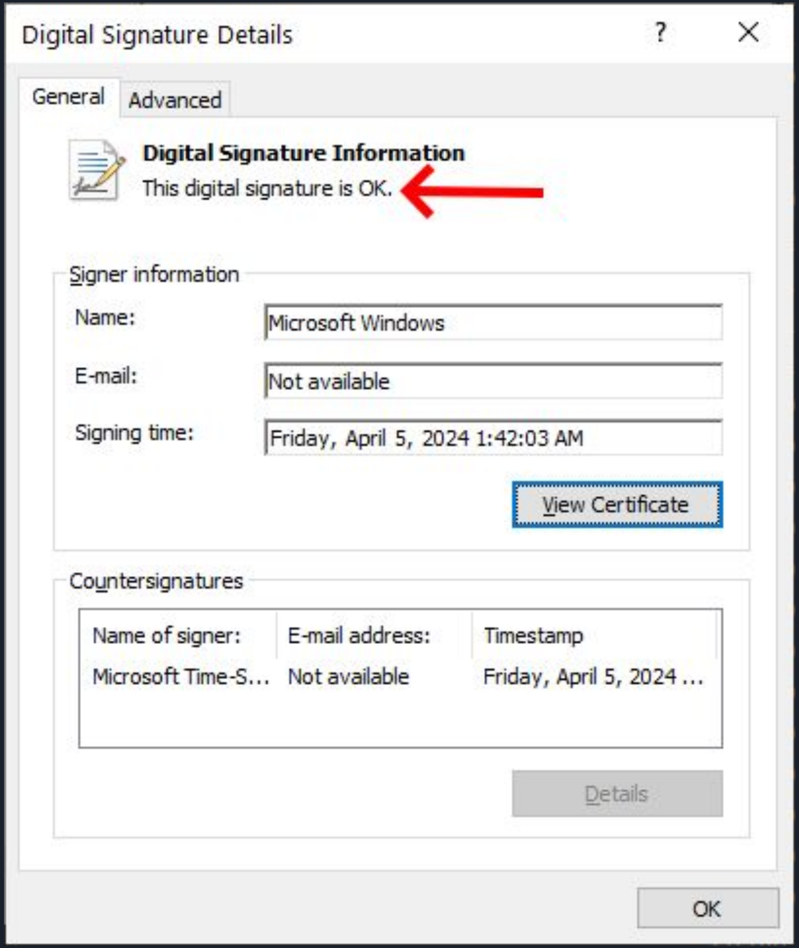
Authenticode

Microsoft specification to digitally sign Portable Executable (PE) files.



Signature list

Name of signer:	Digest algorithm	Timestamp
Microsoft Windows	sha256	Friday, April 5, 2024 1...



Digital Signature Information

This digital signature is OK.

Signer information

Name: Microsoft Windows

E-mail: Not available

Signing time: Friday, April 5, 2024 1:42:03 AM

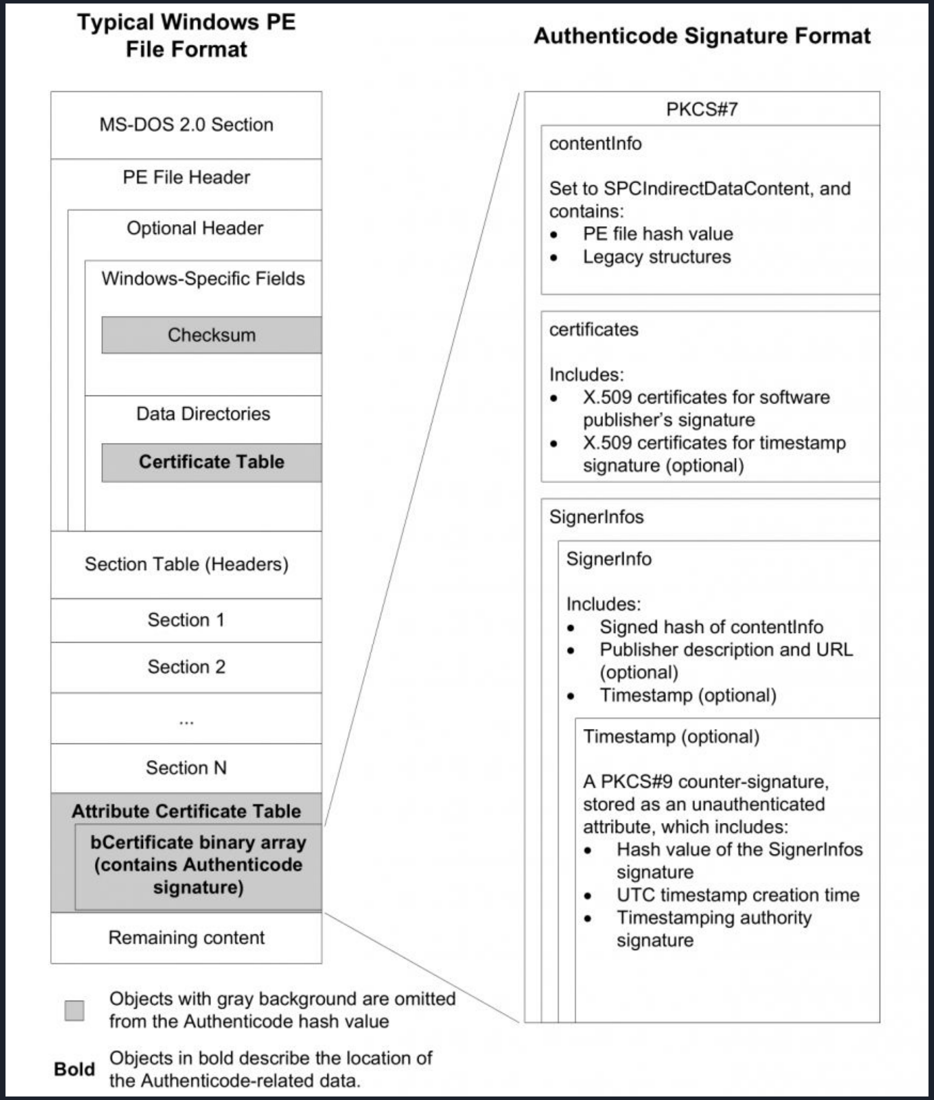
Countersignatures

Name of signer:	E-mail address:	Timestamp
Microsoft Time-S...	Not available	Friday, April 5, 2024 ...

Authenticode Signing

Authentihash algorithm computes hash over most (but not all) of the PE file.

Authentihash is signed using PKCS #7 and appended to PE as Security Directory (aka Certificate Table).


Typical Windows PE File Format
Authenticode Signature Format
MS-DOS 2.0 Section
PE File Header
Optional Header
Windows-Specific Fields
Checksum
Data Directories
Certificate Table
Section Table (Headers)
Section 1
Section 2
...
Section N
Attribute Certificate Table
bCertificate binary array (contains Authenticode signature)
Remaining content
PKCS#7
contentInfo
Set to SPCIndirectDataContent, and contains:
• PE file hash value
• Legacy structures
certificates
Includes:
• X.509 certificates for software publisher's signature
• X.509 certificates for timestamp signature (optional)
SignerInfos
SignerInfo
Includes:
• Signed hash of contentInfo
• Publisher description and URL (optional)
• Timestamp (optional)
Timestamp (optional)
A PKCS#9 counter-signature, stored as an unauthenticated attribute, which includes:
• Hash value of the SignerInfos signature
• UTC timestamp creation time
• Timestamping authority signature
Objects with gray background are omitted from the Authenticode hash value
Bold Objects in bold describe the location of the Authenticode-related data.

https://download.microsoft.com/download/9/c/5/9c5b2167-8017-4bae-9fde-d599bac8184a/authenticode_pe.docx

Authenticode Implementations

User and kernel implementations to validate signatures.

The user implementation is out of scope for this talk.

The kernel implementation is the **Code Integrity** (CI) subsystem.

CI.dll protected from tampering by Secure Boot and Trusted Boot systems.

Code Integrity

Kernel Mode Code Integrity (KMCI)

- Enforces Driver Signing Enforcement and Vulnerable Driver Blocklist.

User Mode Code Integrity (UMCI)

- CI validates the signatures of EXEs and DLLs before allowing them to load.
- Enforces Protected Processes and Protected Process Light signature requirements.
- Enforces Microsoft Signer process mitigation (**SetProcessMitigationPolicy**).
- Enforces **/INTEGRITYCHECK** for FIPS 140-2 modules.
- Exposed to consumers as **Smart App Control**.
- Exposed to businesses as **App Control for Business** (formerly WDAC).

KMCI and UMCI implement different policies for different scenarios.

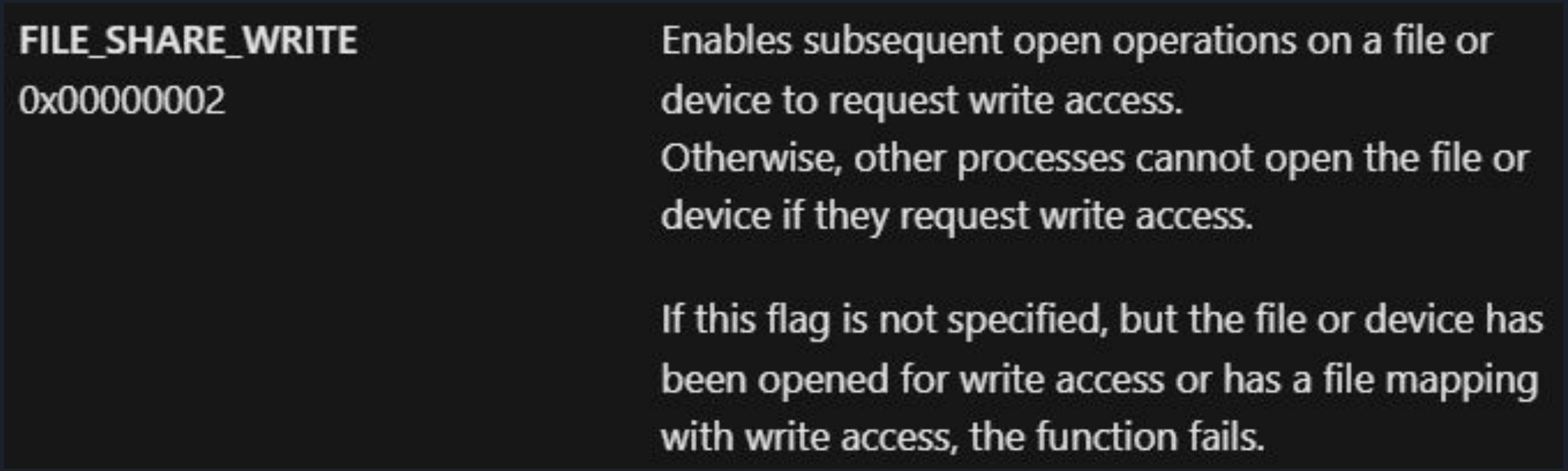
https://learn.microsoft.com/en-us/windows/security/application-security/application-control/windows-defender-application-control/design/select-types-of-rules-to-create
https://learn.microsoft.com/en-us/windows/win32/api/processthreadsapi/nf-processthreadsapi-setprocessmitigationpolicy
https://x.com/GabrielLandau/status/1668353640833114131
https://learn.microsoft.com/en-us/windows/apps/develop/smart-app-control/overview
https://learn.microsoft.com/en-us/windows/security/application-security/application-control/windows-defender-application-control/wdac
https://learn.microsoft.com/en-us/windows/security/application-security/application-control/windows-defender-application-control/design/microsoft-recommended-driver-block-rules

Chapter 3 - Incorrect Assumptions

Let’s discuss a class of vulnerabilities resulting from incorrect assumptions.

Incorrect Assumptions

Microsoft docs imply that files successfully opened without write sharing can’t be modified under you.



FILE_SHARE_WRITE 0x00000002	Enables subsequent open operations on a file or device to request write access. Otherwise, other processes cannot open the file or device if they request write access. If this flag is not specified, but the file or device has been opened for write access or has a file mapping with write access, the function fails.

What if the filesystem doesn’t know that the file’s been modified?

Executable Image Section Paging

Executable image sections originate from PE files.

MM can page these out if memory is needed:

- Never modified? Discard it. We already have a copy in the original PE.
- Modified? Save it to the pagefile.
    - Example: ntdll was detoured. MM copy-on-write created private copy.

Upon page fault:

- Never modified*? Read the page from the original PE file.
- Modified? Grab the private copy from the pagefile.

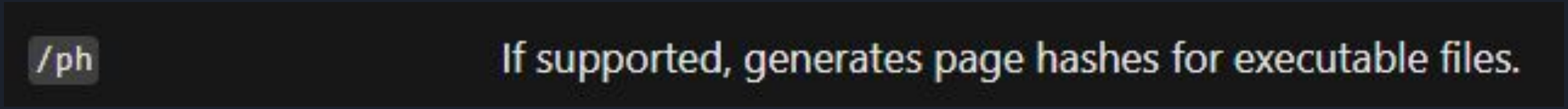
* Exception: The memory manager may treat PE-relocated pages as unmodified, dynamically reapplying relocations during page faults.

Page Hashes

Optional list of hashes of each 4KB page of PE. Allows MM to validate hashes of individual pages during page faults.

Static page hashes

- Stored within signature when file is signed.
- **signtool.exe /ph**



/ph	If supported, generates page hashes for executable files.

Dynamic page hashes

- Computed on the fly by CI when **SEC_IMAGE** is created and validated.
- Enables page hash enforcement even if signature does not include them.

Page hashes are not free - they use CPU and slow down page faults.

https://learn.microsoft.com/en-us/windows/win32/seccrypto/signtool

Attacking Code Integrity

Scenario:

1. Orphanage administrator enables macros in email attachment containing ransomware.
2. Ransomware employs UAC bypass to instantly elevate to Admin.
3. Ransomware fails to terminate AV running as Protected Process Light (PPL).
4. Ransomware author wants PPL rights so it can kill AV and ransom orphanage.

Can it launch itself directly as PPL?

❌ UMCI prevents improperly-signed EXEs and DLLs from loading into PPL.

CreateFile(FILE_WRITE_DATA) to inject code into already-in-use DLL?

❌ NTFS checks prevent **CreateFile(FILE_WRITE_DATA)** to in-use image sections.

- ○ Aforementioned **MmFlushImageSection** check.

FILE_WRITE_DATA check is in NTFS. What if we move the filesystem to another machine?

- SMB server could be a Samba server, or even a python script.

Attacker can modify a DLL server-side, bypassing sharing restrictions.

- DLLs are incorrectly assumed to be immutable.
- **False File Immutability**

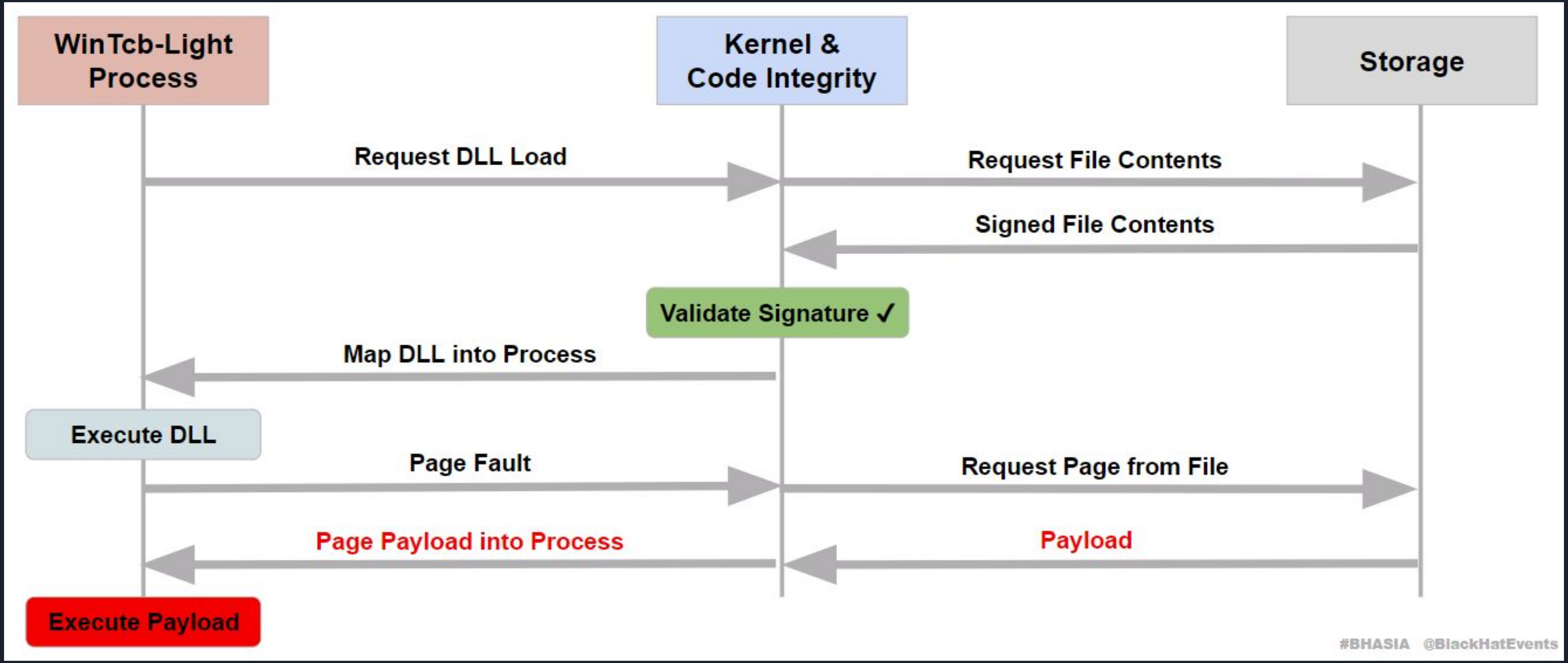
Can Attacker Exploit Paging?

Even if an attacker successfully exploits **false file immutability** to inject code into a PE, won’t page hashes catch this attack?

	Authenticode	Page Hashes
Kernel Drivers	✅	✅
Protected Processes	✅	✅
Protected Process Light (PPL)	✅	❌

Admin->PPL Exploit: PPLFault

Disclosed by me at Black Hat Asia 2023.



WinTcb-Light Process

Kernel & Code Integrity

Storage

Request DLL Load

Request File Contents

Signed File Contents

Validate Signature ✓

Map DLL into Process

Execute DLL

Page Fault

Request Page from File

Page Payload into Process

Payload

Execute Payload

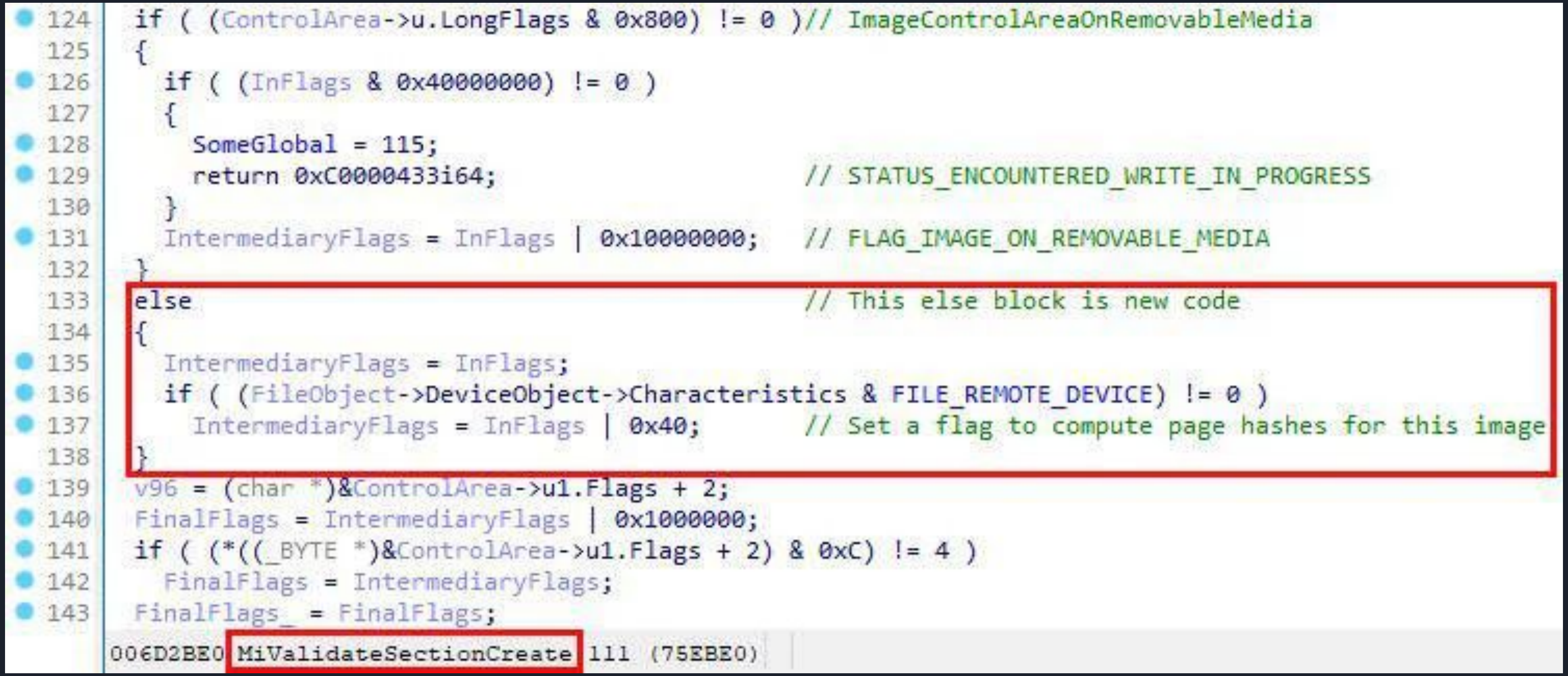
#BHASIA @BlackHatEvents

https://github.com/gabriellandau/PPLFault
https://www.youtube.com/watch?v=5xteW8Tm410
https://i.blackhat.com/Asia-23/AS-23-Landau-PPLdump-Is-Dead-Long-Live-PPLdump.pdf

Mitigating PPLFault

In February 2024, Microsoft added a check to mitigate PPLFault.

MM sets a flag requiring dynamic page hashes for images that originate from remote devices such as network redirectors like SMB.



```
if ( (ControlArea->u.LongFlags & 0x800) != 0 )// ImageControlAreaOnRemovableMedia
{
  if ( (InFlags & 0x40000000) != 0 )
  {
    SomeGlobal = 115;
    return 0xC0000433i64;                     // STATUS_ENCOUNTERED_WRITE_IN_PROGRESS
  }
  IntermediaryFlags = InFlags | 0x10000000;   // FLAG_IMAGE_ON_REMOVABLE_MEDIA
}
else                                          // This else block is new code
{
  IntermediaryFlags = InFlags;
  if ( (FileObject->DeviceObject->Characteristics & FILE_REMOTE_DEVICE) != 0 )
    IntermediaryFlags = InFlags | 0x40;       // Set a flag to compute page hashes for this image
}
v96 = (char *)&ControlArea->u1.Flags + 2;
FinalFlags = IntermediaryFlags | 0x1000000;
if ( (*((_BYTE *)&ControlArea->u1.Flags + 2) & 0xC) != 4 )
  FinalFlags = IntermediaryFlags;
FinalFlags_ = FinalFlags;
```

006D2BE0 MiValidateSectionCreate 111 (75EBE0)

https://www.elastic.co/security-labs/inside-microsofts-plan-to-kill-pplfault

PPLFault - Takeaways

What did we learn?

PPLFault successfully exploited bad assumptions in CI about DLL immutability, achieving unsigned WinTcb-Light PPL code execution. For reasons out-of-scope, it was easy to chain this to full physical memory read/write,**compromising the entire OS in a few seconds.**

The mitigation was narrow in scope - targeting images loaded from remote devices.

Chapter 4 - New Research

Can we exploit false file immutability in other ways?

Let’s look beyond executable image sections.

What about attacks against data files?

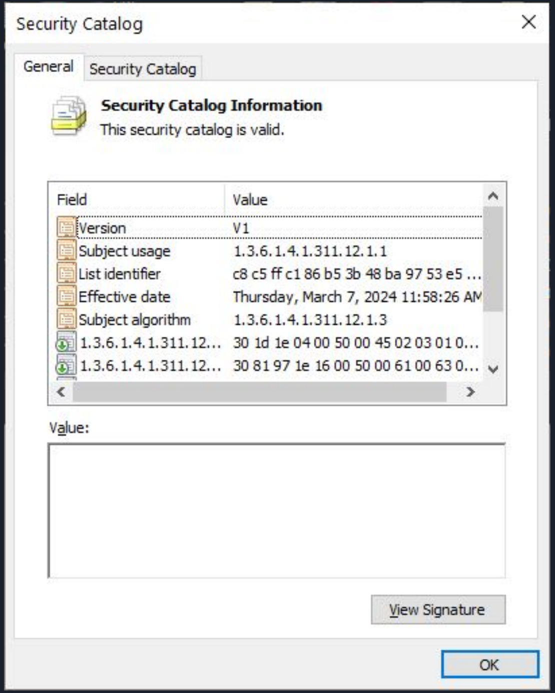
Authenticode – Security Catalogs

Security catalogs – detached Authenticode signatures.

Signed array of Authentihashes in .cat files in **C:\Windows\System32\CatRoot**

Every PE with Authentihash in list is considered to be signed by that signer.

Hash	**Hash**	**Hash**	**Hash**	**Hash**	**Hash**	**Hash**	**Hash**	**Hash**	**Hash**	**Hash**	**Hash**	**Hash**	**Signature**



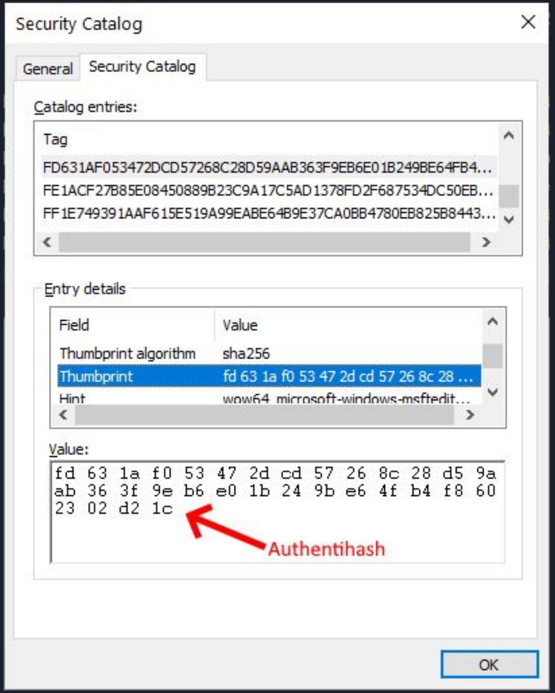
Security Catalog

Security Catalog Information

This security catalog is valid.

Field	Value
Version	V1
Subject usage	1.3.6.1.4.1.311.12.1.1
List identifier	c8 c5 ff c1 86 b5 3b 48 ba 97 53 e5 ...
Effective date	Thursday, March 7, 2024 11:58:26 AM
Subject algorithm	1.3.6.1.4.1.311.12.1.3
1.3.6.1.4.1.311.12...	30 1d 1e 04 00 50 00 45 02 03 01 0...
1.3.6.1.4.1.311.12...	30 81 97 1e 16 00 50 00 61 00 63 0...

Value:



Security Catalog

Catalog entries:

Tag
FD631AF053472DCD57268C28D59AAB363F9EB6E01B249BE64FB4...
FE1ACF27B85E08450889B23C9A17C5AD1378FD2F687534DC50EB...
FF1E749391AAF615E519A99EABE64B9E37CA0BB4780EB825B8443...

Entry details

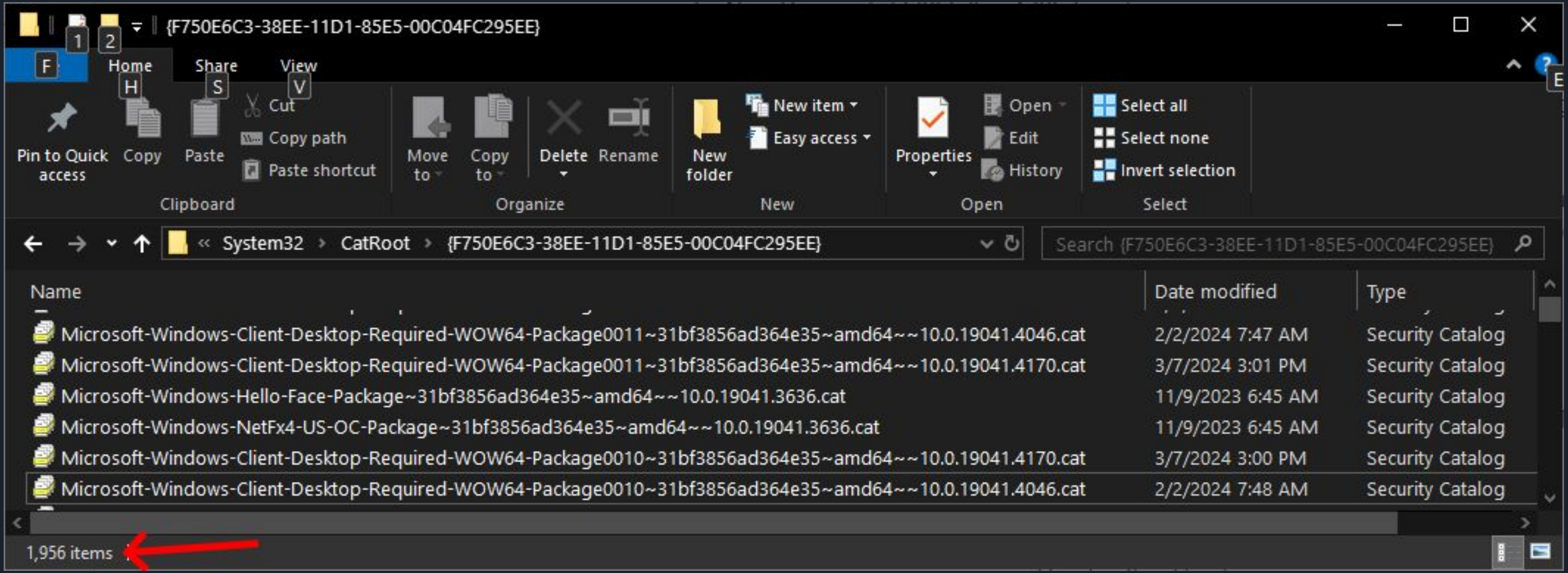
Field	Value
Thumbprint algorithm	sha256
Thumbprint	fd 63 1a f0 53 47 2d cd 57 26 8c 28 ...
Hint	wow64_microsoft-windows-msftedit...

Value:

```
fd 63 1a f0 53 47 2d cd 57 26 8c 28 d5 9a
ab 36 3f 9e b6 e0 1b 24 9b e6 4f b4 f8 60
23 02 d2 1c
```

Authenticode - Security Catalogs

Large list of catalogs. CI loads them into kernel pool for fast lookup.



Name	Date modified	Type
Microsoft-Windows-Client-Desktop-Required-WOW64-Package0011~31bf3856ad364e35~amd64~~10.0.19041.4046.cat	2/2/2024 7:47 AM	Security Catalog
Microsoft-Windows-Client-Desktop-Required-WOW64-Package0011~31bf3856ad364e35~amd64~~10.0.19041.4170.cat	3/7/2024 3:01 PM	Security Catalog
Microsoft-Windows-Hello-Face-Package~31bf3856ad364e35~amd64~~10.0.19041.3636.cat	11/9/2023 6:45 AM	Security Catalog
Microsoft-Windows-NetFx4-US-OC-Package~31bf3856ad364e35~amd64~~10.0.19041.3636.cat	11/9/2023 6:45 AM	Security Catalog
Microsoft-Windows-Client-Desktop-Required-WOW64-Package0010~31bf3856ad364e35~amd64~~10.0.19041.4170.cat	3/7/2024 3:00 PM	Security Catalog
Microsoft-Windows-Client-Desktop-Required-WOW64-Package0010~31bf3856ad364e35~amd64~~10.0.19041.4046.cat	2/2/2024 7:48 AM	Security Catalog

1,956 items

Code Integrity - Catalog Parsing

Map File Into Memory

Validate Signature

Parse Catalog

```
nt!ZwOpenFile(
  GENERIC_READ,
  FILE_SHARE_READ)

nt!ZwCreateSection(
  SEC_COMMIT)

nt!ZwMapViewOfSection
```

```
CI!MinCrypK_
 VerifySignedDataKModeEx
```

```
CI!I_MapFileHashes
```

Catalog Parsing - Key Insights

ZwOpenFile(GENERIC_READ, FILE_SHARE_READ)

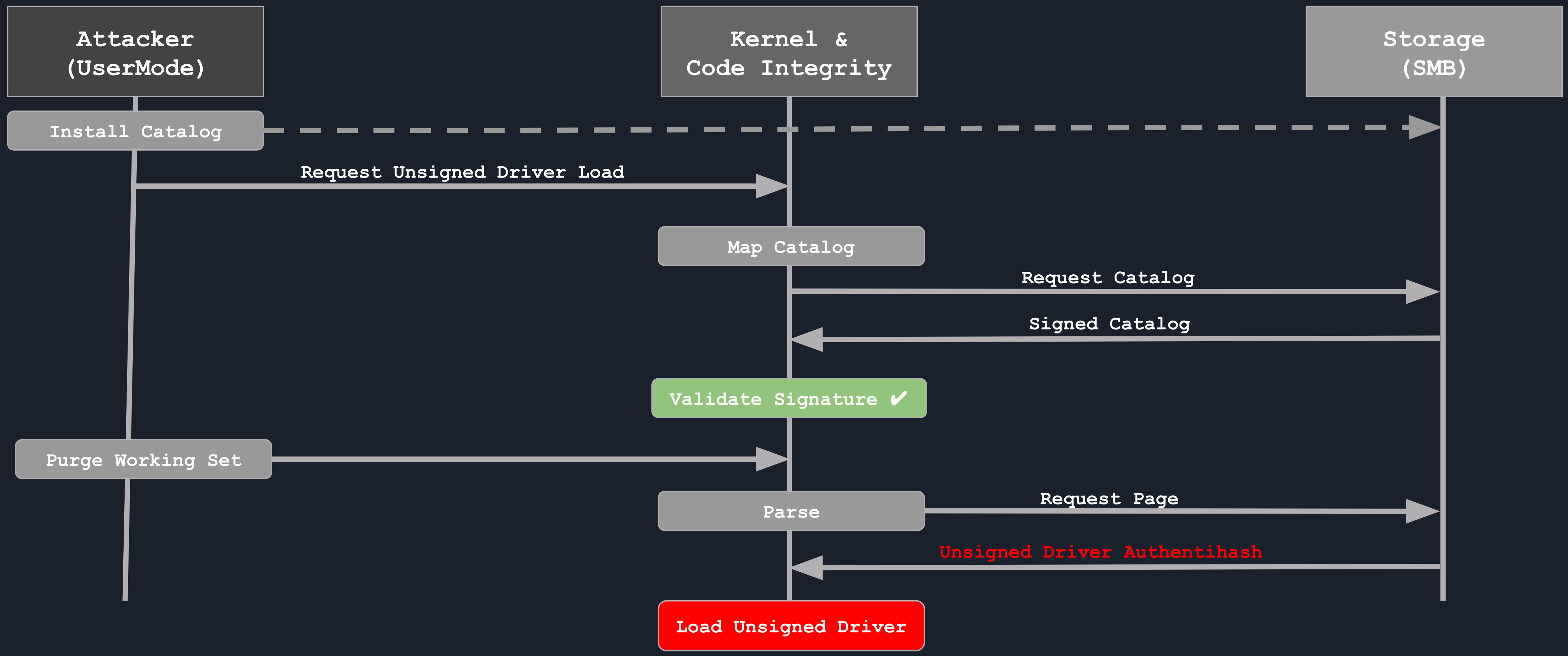
- Denies write sharing to prevent catalog modifications during processing.
- Bad assumption - **false file immutability**.

ZwCreateSection(SEC_COMMIT)

- Creates a data section.
- Not an image section - no page hashes.

Can we perform a PPLFault-style attack on security catalogs?

Exploiting Security Catalogs



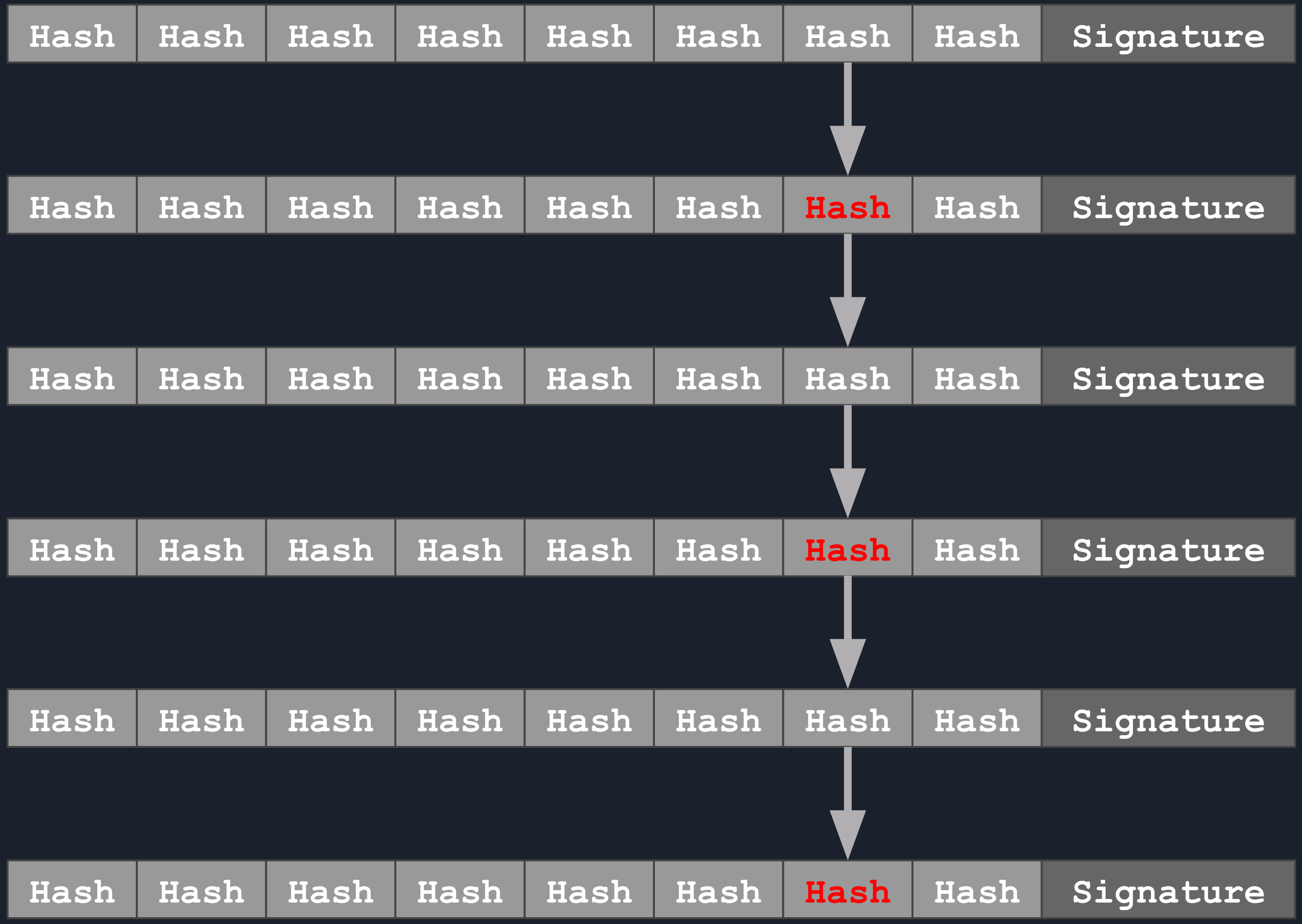
Exploit - Toggling the Catalog

PPLFault used an oplock to deterministically pause the victim process then switch to the payload DLL contents.

No good opportunities here for oplocks.

Rapidly toggle the catalog between benign and malicious - probabilistic approach.

Choose hash near end of catalog because parsing is [probably] linear.



Hash Hash Hash Hash Hash Hash Hash Hash Signature

Hash Hash Hash Hash Hash Hash Hash Hash Signature

Hash Hash Hash Hash Hash Hash Hash Hash Signature

Hash Hash Hash Hash Hash Hash Hash Hash Signature

Hash Hash Hash Hash Hash Hash Hash Hash Signature

Hash Hash Hash Hash Hash Hash Hash Hash Signature

Exploit - Race Condition

Attacker needs CI to trigger a page fault between validation and parsing, but the page is already resident from recent validation. Without a page fault, CI will use the same pages for validation and parsing.

To evict page from kernel memory, attacker must empty working set between **MinCrypK_VerifySignedDataKModeEx** and **I_MapFileHashes**.

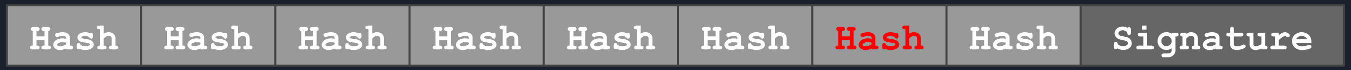
Very short race window. Employ multiple approaches to slow CI and improve chances of winning race:

- Choose large security catalog (4MB).
- Dedicated thread emptying working set.
- Dedicated thread repeatedly loading unsigned driver.
- High-priority dummy threads spinning CPU cores to starve system worker threads.

Fail - Signature Check Failed

If the payload Authentihash is read during the signature check, the catalog will be rejected.

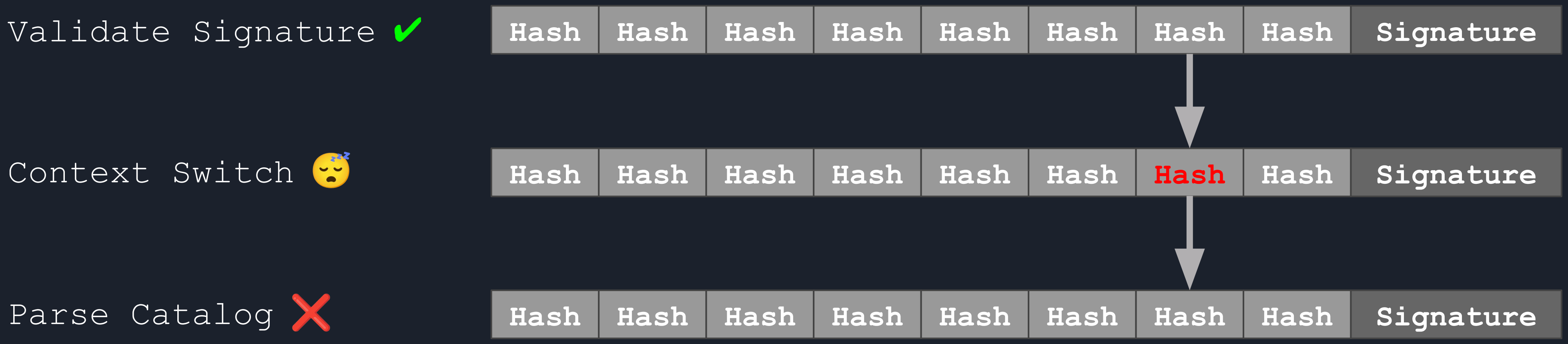
Validate Signature ❌



Hash	Hash	Hash	Hash	Hash	Hash	Hash	Hash	Signature

Fail - Benign Catalog Parsed

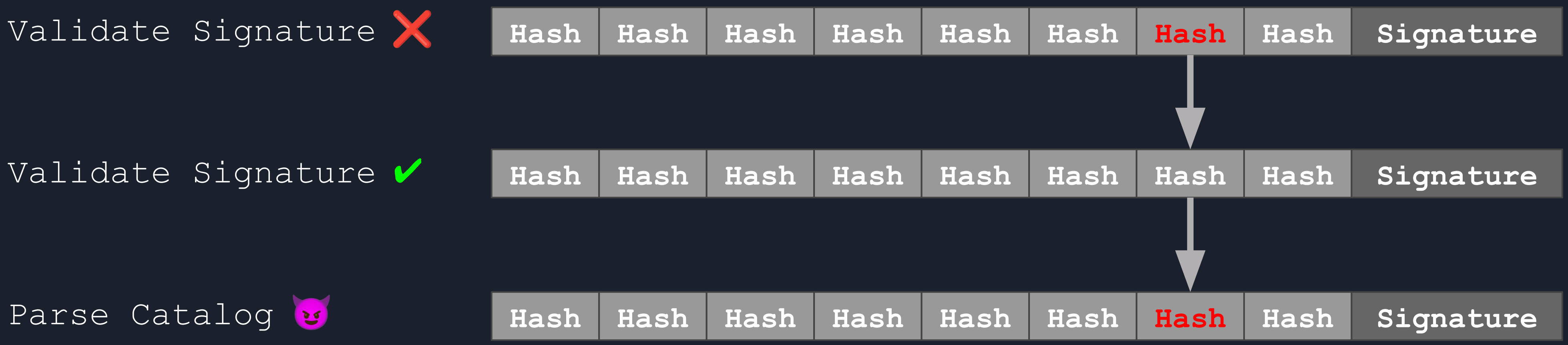
An even number of swaps (including zero) between signature validation and parsing means CI will parse the benign hash and reject our driver.



Validate Signature ✔	Hash	Hash	Hash	Hash	Hash	Hash	Hash	Hash	Signature
Context Switch 😴	Hash	Hash	Hash	Hash	Hash	Hash	Hash	Hash	Signature
Parse Catalog ❌	Hash	Hash	Hash	Hash	Hash	Hash	Hash	Hash	Signature

Win – Payload Catalog Parsed

CI must validate a benign catalog then parse a malicious one.



Validate Signature ❌ | Hash | Hash | Hash | Hash | Hash | Hash | Hash | Hash | Signature

Validate Signature ✔ | Hash | Hash | Hash | Hash | Hash | Hash | Hash | Hash | Signature

Parse Catalog 😈 | Hash | Hash | Hash | Hash | Hash | Hash | Hash | Hash | Signature

Exploit Demo!

Windows 11 23H2 22631.3447 (April 2024)

Chapter 4 - Avoiding Pitfalls

To avoid this type of bug, we first need to understand it better.

Double Read / Fetch

Imagine a shared memory mapping for an IPC mechanism. Double Read is a TOCTOU where victim reads a value from attacker-controlled shared memory twice.

Attacker changes memory between the reads, resulting in a unexpected victim behavior.

```
struct IPC_PACKET
{
    SIZE_T length;
    UCHAR data[];
};
```

Example:

- Attacker initially specifies a small length field.
  - **pPacket->length = 16;**
- Victim code allocates a small buffer to hold data.
  - **pBuffer = malloc(pPacket->length);**
- Attacker changes to large length value.
  - **pPacket->length = 32;**
- Victim code uses new length, copying too much data and overflowing buffer.
  - **memcpy(pBuffer, pPacket->data, pPacket->length);** 💥

Windows kernel (and drivers) often operate directly on user mode memory.

- Significant consideration for **METHOD_DIRECT** IOCTL handlers.

Recent example: https://exploits.forsale/24h2-nt-exploit/

Call To Action

Treat attacker-writable files as subject to double-read vulnerabilities.

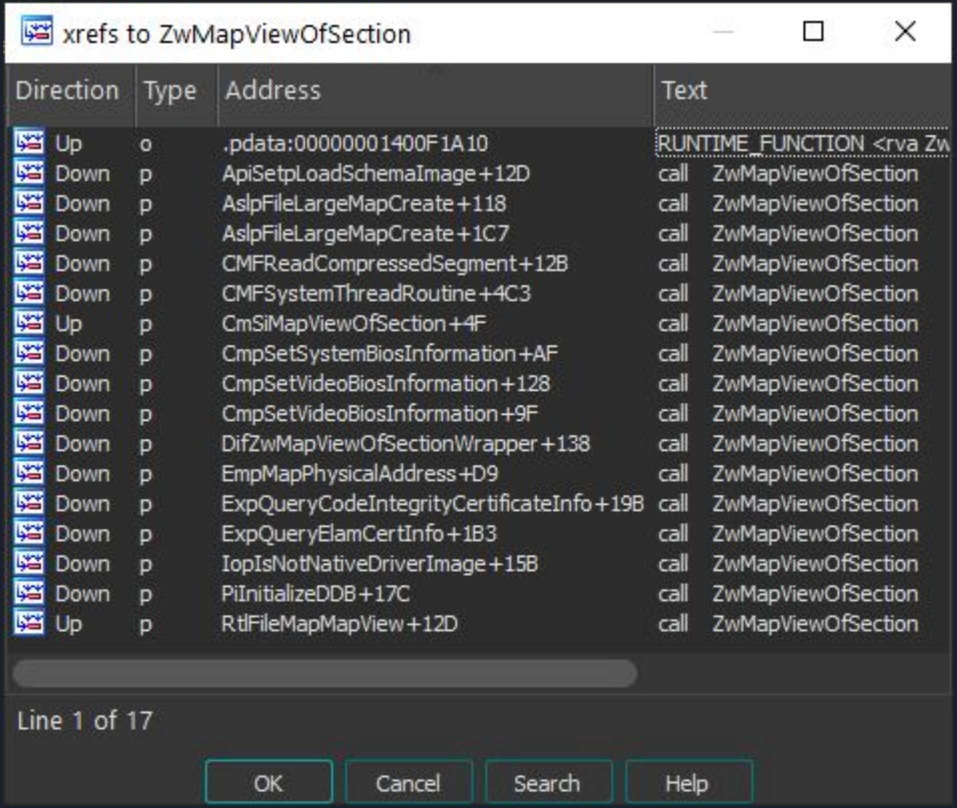
Denying write sharing does not necessarily prevent modification.

Affected Operations

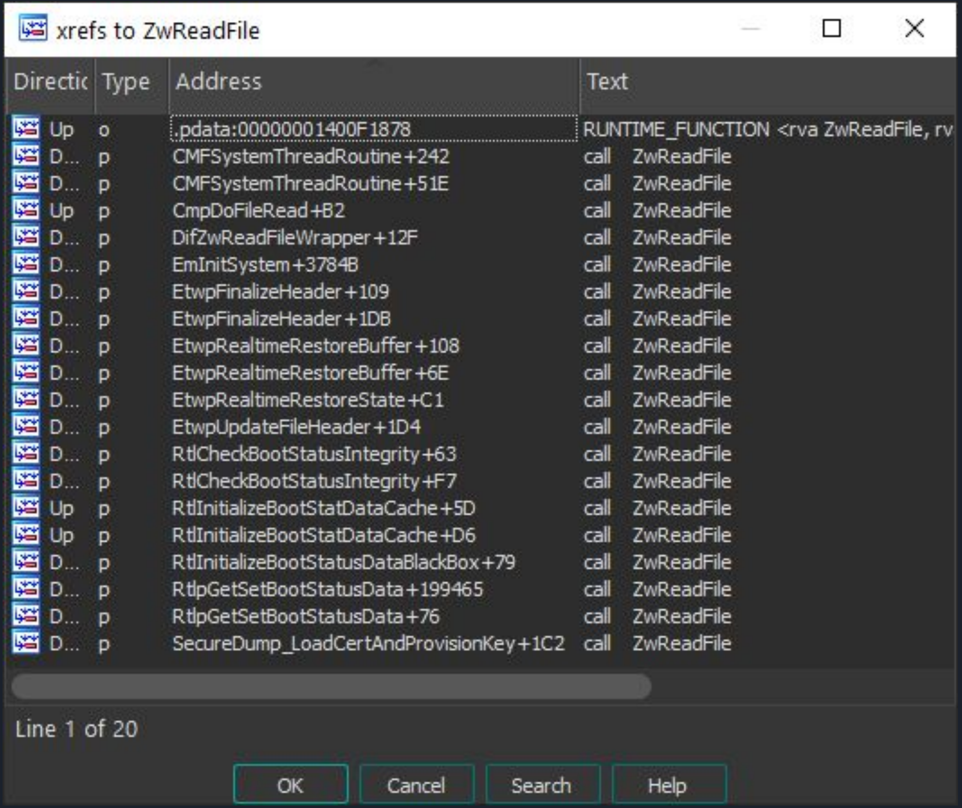
What types of operations are affected by **False File Immutability**?

Operation	API	Mitigations
Image Sections	**CreateProcess** **LoadLibrary**	1. Enable Page Hashes.
Data Sections	**MapViewOfFile**	1. Avoid double reads. 2. Copy the file to a heap buffer before processing. 3. Prevent paging via **MmProbeAndLockPages/VirtualLock**.
Regular I/O	**ReadFile**	1. Avoid double reads. 2. Copy the file to a heap buffer before processing.

What Else Could Be Vulnerable?



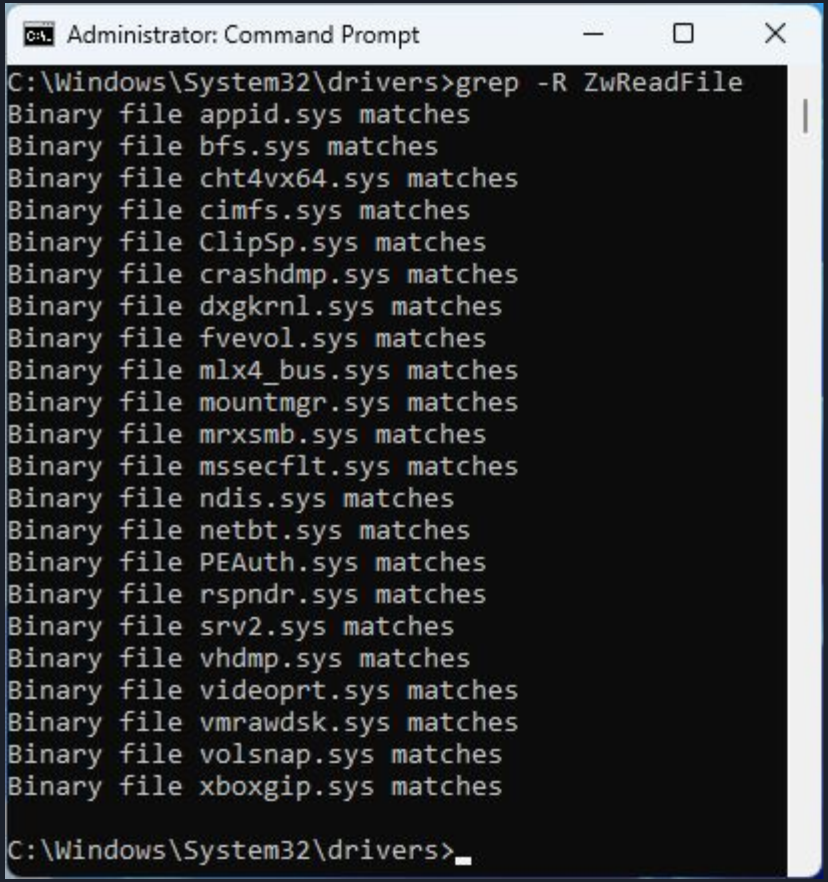
Direction	Type	Address	Text
Up	o	.pdata:00000001400F1A10	RUNTIME_FUNCTION <rva Zw
Down	p	ApiSetpLoadSchemaImage+12D	call ZwMapViewOfSection
Down	p	AslpFileLargeMapCreate+118	call ZwMapViewOfSection
Down	p	AslpFileLargeMapCreate+1C7	call ZwMapViewOfSection
Down	p	CMFReadCompressedSegment+12B	call ZwMapViewOfSection
Down	p	CMFSystemThreadRoutine+4C3	call ZwMapViewOfSection
Up	p	CmSiMapViewOfSection+4F	call ZwMapViewOfSection
Down	p	CmpSetSystemBiosInformation+AF	call ZwMapViewOfSection
Down	p	CmpSetVideoBiosInformation+128	call ZwMapViewOfSection
Down	p	CmpSetVideoBiosInformation+9F	call ZwMapViewOfSection
Down	p	DifZwMapViewOfSectionWrapper+138	call ZwMapViewOfSection
Down	p	EmpMapPhysicalAddress+D9	call ZwMapViewOfSection
Down	p	ExpQueryCodeIntegrityCertificateInfo+19B	call ZwMapViewOfSection
Down	p	ExpQueryElamCertInfo+1B3	call ZwMapViewOfSection
Down	p	IopIsNotNativeDriverImage+15B	call ZwMapViewOfSection
Down	p	PiInitializeDDB+17C	call ZwMapViewOfSection
Up	p	RtlFileMapMapView+12D	call ZwMapViewOfSection



Directic	Type	Address	Text
Up	o	.pdata:00000001400F1878	RUNTIME_FUNCTION <rva ZwReadFile, rv
D...	p	CMFSystemThreadRoutine+242	call ZwReadFile
D...	p	CMFSystemThreadRoutine+51E	call ZwReadFile
Up	p	CmpDoFileRead+B2	call ZwReadFile
D...	p	DifZwReadFileWrapper+12F	call ZwReadFile
D...	p	EmInitSystem+3784B	call ZwReadFile
D...	p	EtwpFinalizeHeader+109	call ZwReadFile
D...	p	EtwpFinalizeHeader+1DB	call ZwReadFile
D...	p	EtwpRealtimeRestoreBuffer+108	call ZwReadFile
D...	p	EtwpRealtimeRestoreBuffer+6E	call ZwReadFile
D...	p	EtwpRealtimeRestoreState+C1	call ZwReadFile
D...	p	EtwpUpdateFileHeader+1D4	call ZwReadFile
D...	p	RtlCheckBootStatusIntegrity+63	call ZwReadFile
D...	p	RtlCheckBootStatusIntegrity+F7	call ZwReadFile
Up	p	RtlInitializeBootStatDataCache+5D	call ZwReadFile
Up	p	RtlInitializeBootStatDataCache+D6	call ZwReadFile
D...	p	RtlInitializeBootStatusDataBlackBox+79	call ZwReadFile
D...	p	RtlpGetSetBootStatusData+199465	call ZwReadFile
D...	p	RtlpGetSetBootStatusData+76	call ZwReadFile
D...	p	SecureDump_LoadCertAndProvisionKey+1C2	call ZwReadFile

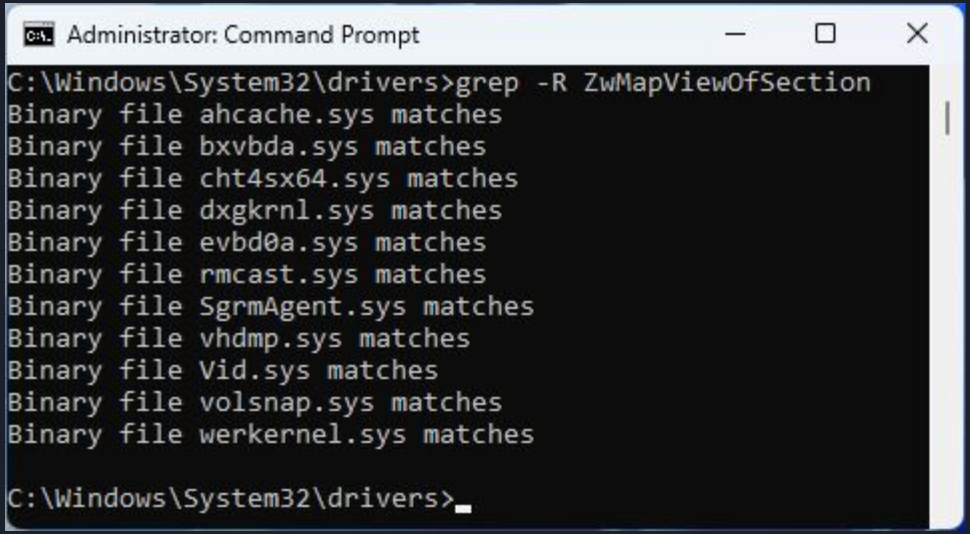
Note: **ZwReadFile** may be used for more than just files. Only uses on files (or those which could be coerced into operating on files) could be vulnerable.

What Else Could Be Vulnerable?



```
C:\Windows\System32\drivers>grep -R ZwReadFile
Binary file appid.sys matches
Binary file bfs.sys matches
Binary file cht4vx64.sys matches
Binary file cimfs.sys matches
Binary file ClipSp.sys matches
Binary file crashdmp.sys matches
Binary file dxgkrnl.sys matches
Binary file fvevol.sys matches
Binary file mlx4_bus.sys matches
Binary file mountmgr.sys matches
Binary file mrxsmb.sys matches
Binary file mssecflt.sys matches
Binary file ndis.sys matches
Binary file netbt.sys matches
Binary file PEAuth.sys matches
Binary file rspndr.sys matches
Binary file srv2.sys matches
Binary file vhdmp.sys matches
Binary file videoprt.sys matches
Binary file vmrawdsk.sys matches
Binary file volsnap.sys matches
Binary file xboxgip.sys matches

C:\Windows\System32\drivers>
```



```
C:\Windows\System32\drivers>grep -R ZwMapViewOfSection
Binary file ahcache.sys matches
Binary file bxvbda.sys matches
Binary file cht4sx64.sys matches
Binary file dxgkrnl.sys matches
Binary file evbd0a.sys matches
Binary file rmcast.sys matches
Binary file SgrmAgent.sys matches
Binary file vhdmp.sys matches
Binary file Vid.sys matches
Binary file volsnap.sys matches
Binary file werkernel.sys matches

C:\Windows\System32\drivers>
```

Note: **ZwReadFile** may be used for more than just files. Only uses on files (or those which could be coerced into operating on files) could be vulnerable.

Don’t Forget About User Mode

Any user-mode application that calls **ReadFile**, **MapViewOfFile**, or **LoadLibrary** on an attacker-controllable file, denying write sharing for immutability, may be vulnerable.

Hypothetical examples:

- **MapViewOfFile**
  - Auto-elevate installers that apply downloaded patches if correctly signed
- **ReadFile**
  - Memory corruption in file parsers by changing double-read values
    - AV engines
    - Search indexers
- **LoadLibrary**
  - RPC server relying on **SetProcessMitigationPolicy(ProcessSignaturePolicy)** to prevent DLL injection via impersonation system drive remapping attacks.

https://bugs.chromium.org/p/project-zero/issues/detail?id=2451

Chapter 5 - Mitigating the Exploit

MSRC won’t service Admin -> Kernel vulnerabilities by default.

- “service” means “fix via security update.”

As a third-party AV dev, I can’t fix CI.dll. How can I protect my customers?

What can Microsoft do to fix it?

https://www.microsoft.com/en-us/msrc/windows-security-servicing-criteria

Third-Party Mitigation

To mitigate **ItsNotASecurityBoundary**, I wrote **FineButWeCanStillEasilyStopIt.sys**

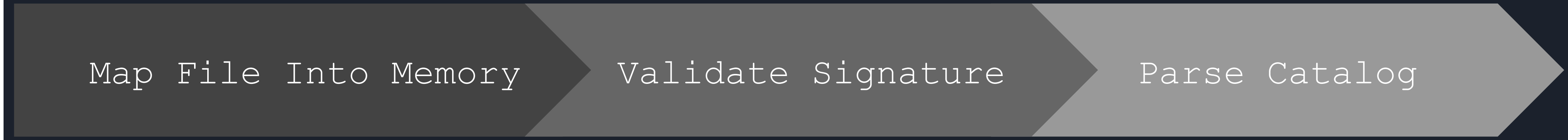
Filesystem Minifilter. In Pre **IRP_MJ_ACQUIRE_FOR_SECTION_SYNCHRONIZATION** callback invoked during **ZwCreateSection**, if:

- **SyncType == SyncTypeCreateSection &&**
- **PageProtection == PAGE_READONLY &&**
- **FlagOn(TargetFileObject->DeviceObject->Characteristics, FILE_REMOTE_DEVICE) &&**
- **Data->RequestorMode == KernelMode &&**
- **FltGetRequestorProcess(Data) == PsInitialSystemProcess &&**
- **IsCalledByCodeIntegrity() && // Check caller via RtlWalkFrameChain**
- **Contains catalog magic bytes and Certificate Trust List PKCS #7 OID.**

then deny the operation.

Messy, right? It’s likely imperfect too. Compare that to a three-line fix in CI.

DSE Exploit Mitigation #1



Map File Into Memory

Validate Signature

Parse Catalog

```
nt!ZwOpenFile(
  GENERIC_READ,
  FILE_SHARE_READ)

nt!ZwCreateSection(
  SEC_COMMIT)

nt!ZwMapViewOfSection
```

nt!ExAllocatePool2

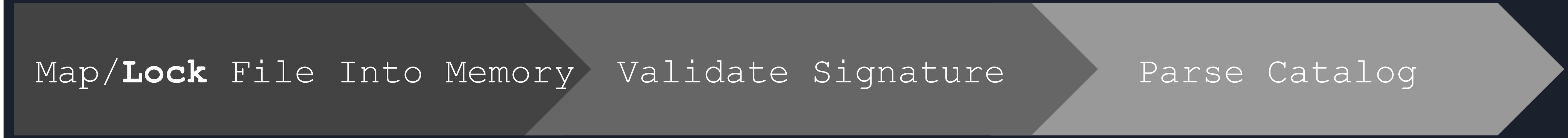
nt!RtlCopyMemory

Copy the file to a heap buffer before processing.

```
CI!MinCrypK_
 VerifySignedDataKModeEx
```

```
CI!I_MapFileHashes
```

DSE Exploit Mitigation #2



Map/**Lock** File Into Memory

Validate Signature

Parse Catalog

```
nt!ZwOpenFile(
  GENERIC_READ,
  FILE_SHARE_READ)

nt!ZwCreateSection(
  SEC_COMMIT)

nt!ZwMapViewOfSection
```

nt!IoAllocateMdl

nt!MmProbeAndLockPages

Lock pages into RAM to block working set eviction.

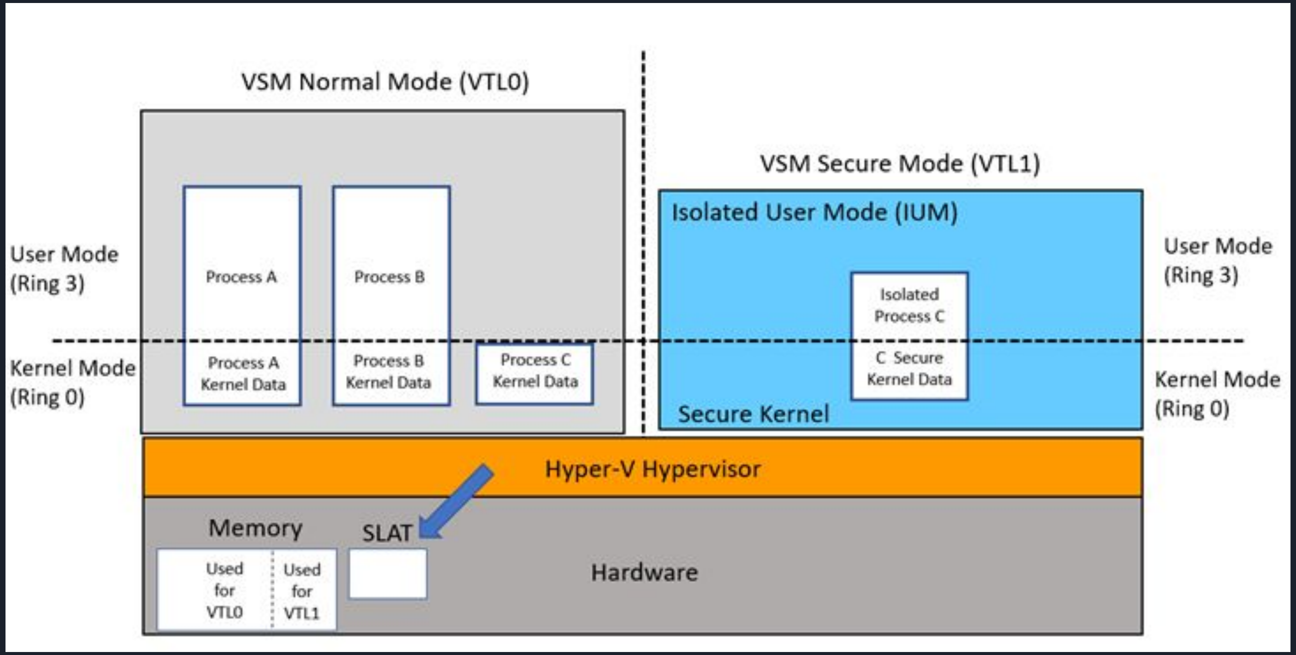
```
CI!MinCrypK_
 VerifySignedDataKModeEx
```

```
CI!I_MapFileHashes
```

Mitigating the Exploit - HVCI

If HVCI is enabled, CI.dll doesn’t do catalog parsing.

- CI sends the catalog contents to the Secure Kernel (SK)
- SK runs in a separate virtual machine.
- SK puts catalog contents in its own secure allocation.
- Signature validation and parsing are done from this secure allocation.
- Attack is mitigated because file changes have no effect on the secure allocation.



https://learn.microsoft.com/en-us/windows/win32/procthread/isolated-user-mode--ium--processes

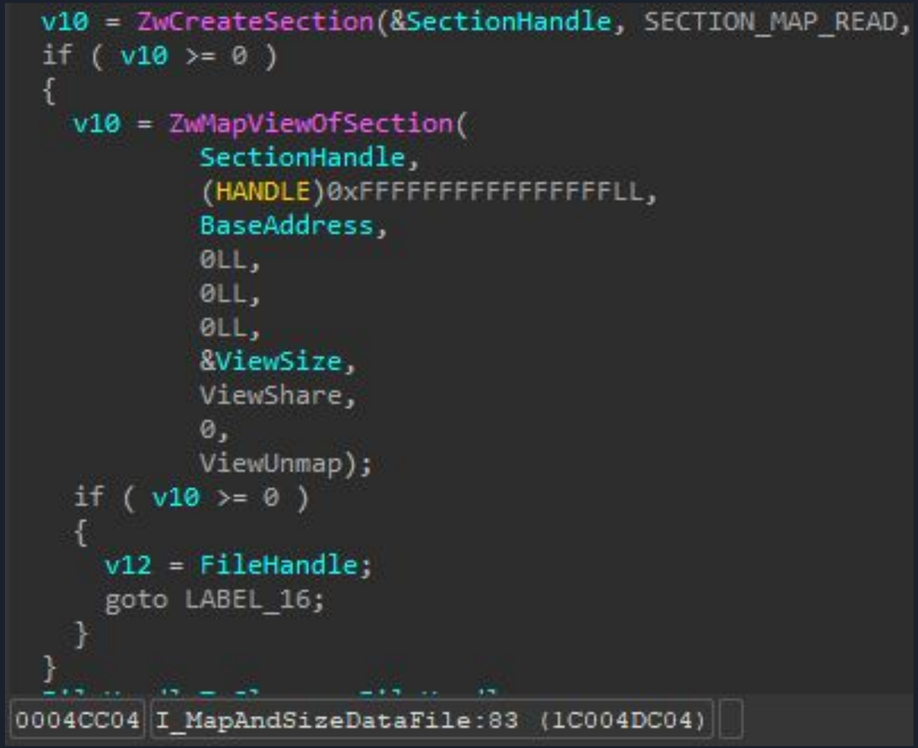
Disclosure Timeline

- 2024-02-14 Reported **ItsNotASecurityBoundary** and **FineButWeCanStillEasilyStopIt** to MSRC as VULN-119340, suggesting **ExAllocatePool** and **MmProbeAndLockPages** as fixes, and offering to coordinate disclosure.
- 2024-02-22 I asked MSRC for an update
- 2024-02-29 Windows Defender team reached out to coordinate disclosure.
- 2024-04-23 Microsoft releases KB5036980 preview with**MmProbeAndLockPages** fix.
- 2024-05-14 Fix reaches GA for desktop releases.
- 2024-05-20 I gave this talk at BlueHat IL

https://support.microsoft.com/en-us/topic/april-23-2024-kb5036980-os-builds-22621-3527-and-22631-3527-preview-5a0d6c49-e42e-4eb4-8541-33a7139281ed

Inside The Mitigation

I_MapAndSizeDataFile is the legacy vulnerable code.



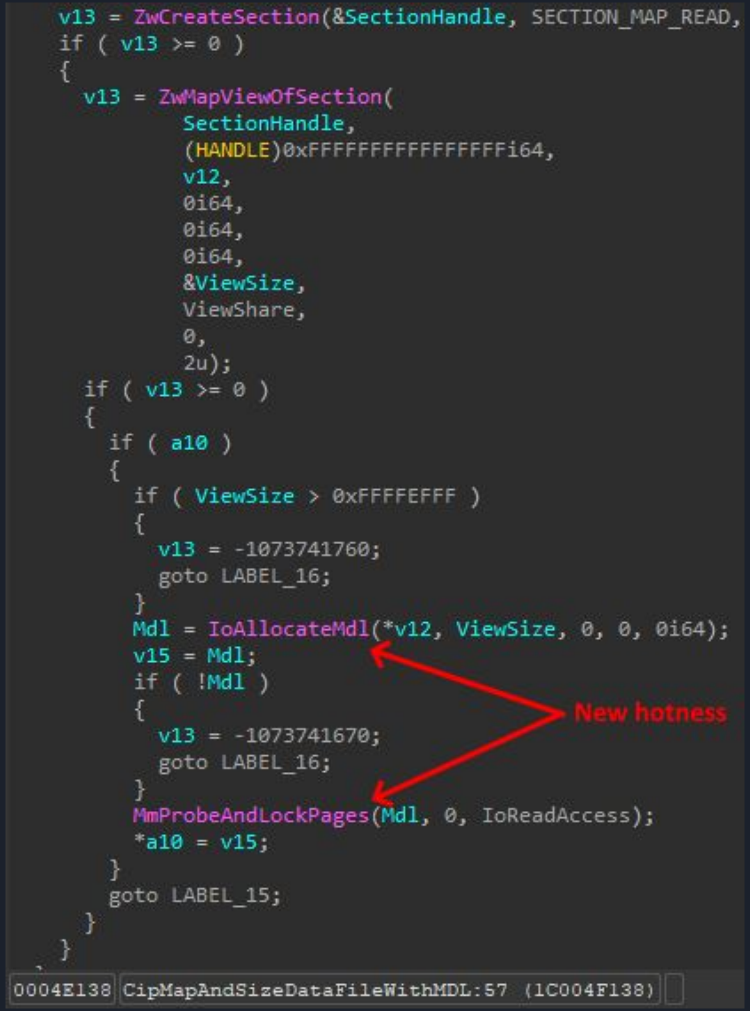
```
v10 = ZwCreateSection(&SectionHandle, SECTION_MAP_READ,
if ( v10 >= 0 )
{
  v10 = ZwMapViewOfSection(
          SectionHandle,
          (HANDLE)0xFFFFFFFFFFFFFFFFLL,
          BaseAddress,
          0LL,
          0LL,
          0LL,
          &ViewSize,
          ViewShare,
          0,
          ViewUnmap);
  if ( v10 >= 0 )
  {
    v12 = FileHandle;
    goto LABEL_16;
  }
}
```

```
0004CC04 I_MapAndSizeDataFile:83 (1C004DC04)
```

https://www.youtube.com/watch?v=ha-uagjJQ9k

Inside The Mitigation

CipMapAndSizeDataFileWithMDL contains the fix.



```
v13 = ZwCreateSection(&SectionHandle, SECTION_MAP_READ,
if ( v13 >= 0 )
{
  v13 = ZwMapViewOfSection(
          SectionHandle,
          (HANDLE)0xFFFFFFFFFFFFFFFFi64,
          v12,
          0i64,
          0i64,
          0i64,
          &ViewSize,
          ViewShare,
          0,
          2u);
  if ( v13 >= 0 )
  {
    if ( a10 )
    {
      if ( ViewSize > 0xFFFFEFFF )
      {
        v13 = -1073741760;
        goto LABEL_16;
      }
      Mdl = IoAllocateMdl(*v12, ViewSize, 0, 0, 0i64);
      v15 = Mdl;
      if ( !Mdl )
      {
        v13 = -1073741670;
        goto LABEL_16;
      }
      MmProbeAndLockPages(Mdl, 0, IoReadAccess);
      *a10 = v15;
    }
    goto LABEL_15;
  }
}
```

New hotness

0004E138 CipMapAndSizeDataFileWithMDL:57 (1C004F138)

https://www.youtube.com/watch?v=ha-uagjJQ9k

Disclosure Timeline

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- 2024-02-22 I asked MSRC for an update
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- 2024-04-23 Microsoft releases KB5036980 preview with **MmProbeAndLockPages** fix.
- 2024-05-14 Fix reaches GA for desktop releases.
- 2024-05-20 I gave this talk at BlueHat IL
- **2024-06-14 MSRC responded:**
  - **“We have completed our investigation and determined that the case doesn't meet our bar for servicing at this time. As a result, we have opened a next-version candidate bug for the issue, and it will be evaluated for upcoming releases. Thanks, again, for sharing this report with us.”**

https://support.microsoft.com/en-us/topic/april-23-2024-kb5036980-os-builds-22621-3527-and-22631-3527-preview-5a0d6c49-e42e-4eb4-8541-33a7139281ed

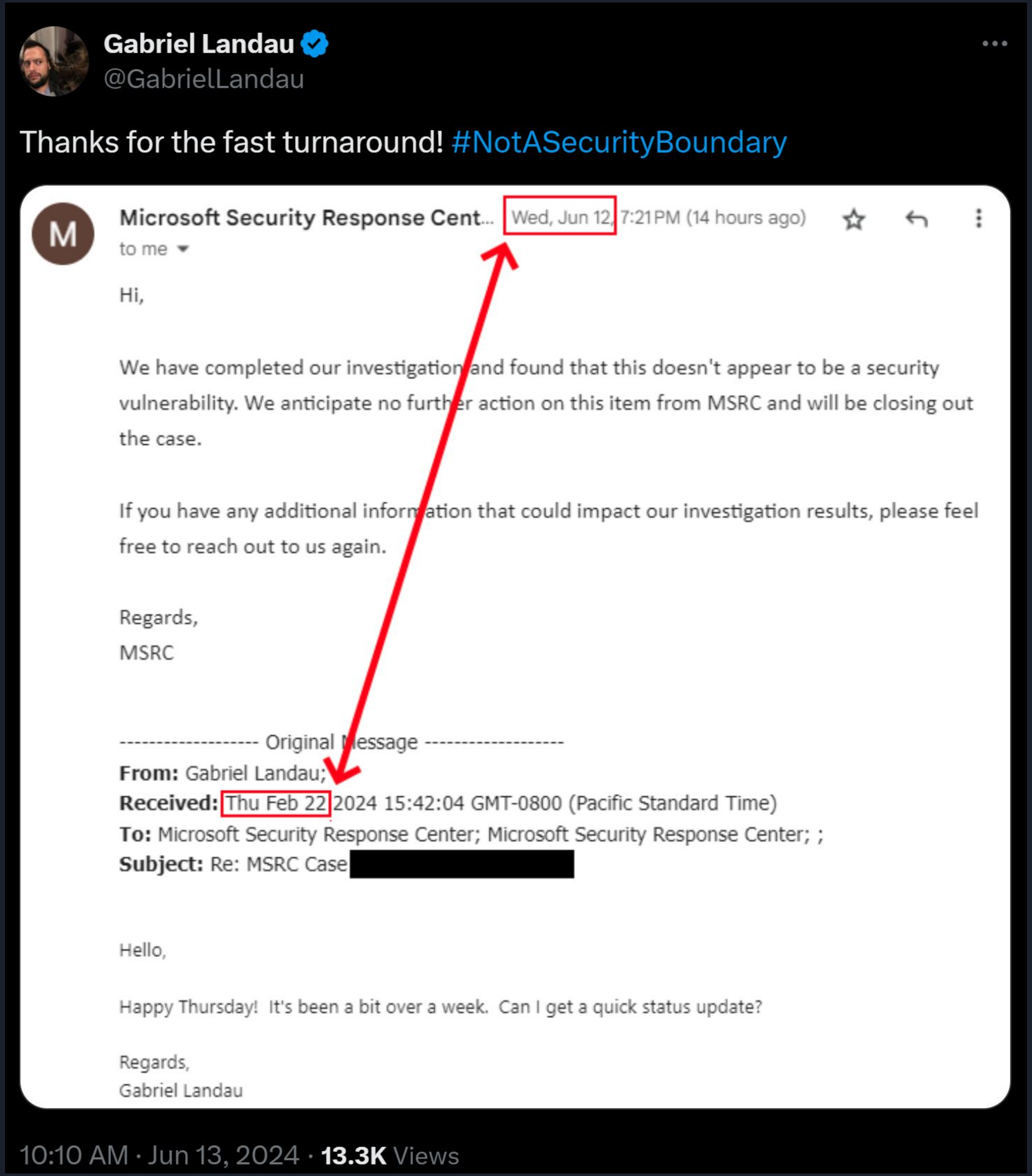
It's All About Incentives

Admin -> PPL / Kernel bugs:

- 4 months for MSRC response.
- Multiple occurrences, not just one.
- This is a different bug 👉
- My cable company is more responsive.
- *Is MSRC sufficiently staffed?*

Researchers must wait months for expected WONTFIX responses before publishing.

- Disrespectful of our time.



Gabriel Landau
@GabrielLandau

Thanks for the fast turnaround! #NotASecurityBoundary

Microsoft Security Response Cent... Wed, Jun 12, 7:21 PM (14 hours ago)
to me

Hi,

We have completed our investigation and found that this doesn't appear to be a security vulnerability. We anticipate no further action on this item from MSRC and will be closing out the case.

If you have any additional information that could impact our investigation results, please feel free to reach out to us again.

Regards,
MSRC

------------------- Original Message -------------------
From: Gabriel Landau;
Received: Thu Feb 22 2024 15:42:04 GMT-0800 (Pacific Standard Time)
To: Microsoft Security Response Center; Microsoft Security Response Center; ;
Subject: Re: MSRC Case [redacted]

Hello,

Happy Thursday! It's been a bit over a week. Can I get a quick status update?

Regards,
Gabriel Landau

10:10 AM · Jun 13, 2024 · **13.3K** Views

https://x.com/GabrielLandau/status/1801255800607797321

It’s All About Incentives

Many such bugs eventually get fixed, which acknowledges that these bugs DO matter.

- No credit.
- No bounty.
- No CVE.
- Why bother reporting?
- Can there be a middle ground between WONTFIX and Security Boundary?
- Is MSRC creating perverse incentives?

“Did I report these issues to Microsoft? Microsoft has made it clear that they will not fix issues only affecting PP and PPL in a security bulletin. Without a security bulletin the researcher receives no acknowledgement for the find, such as a CVE. The issue will not be fixed in current versions of Windows although it might be fixed in the next major version. Previously confirming Microsoft’s policy on fixing a particular security issue was based on precedent, however they’ve recently published a list of Windows technologies that will or will not be fixed in the Windows Security Service Criteria which, as shown below for Protected Process Light, Microsoft will not fix or pay a bounty for issues relating to the feature. **Therefore, from now on I will not be engaging Microsoft if I discover issues which I believe to only affect PP or PPL.**”

James Forshaw

https://googleprojectzero.blogspot.com/2018/10/injecting-code-into-windows-protected.html

Summary

Bug class: False File Immutability

PPLFault: Admin -> PPL [-> Kernel via GodFault/AngryOrchard]

- Exploits bad immutability assumptions about image sections in CI/MM.
- Reported September 2022
- Patched February 2024 (~510 days)

ItsNotASecurityBoundary: Admin -> Kernel

- Exploits bad immutability assumptions about data sections in CI.
- Reported February 2024
- Patched May 2024 (~90 days)

Call to action

- Treat attacker-writable files as subject to double-read vulnerabilities.
- Denying write sharing is insufficient to prevent modification.

More exploits: TBA 😀

https://x.com/GabrielLandau/status/1757818200127946922
https://twitter.com/GabrielLandau/status/1801255800607797321

Conclusion

Gabriel Landau at Elastic Security. Any opinions expressed are my own.

Thanks to the Windows Defender team for collaborating on disclosure and fixes!

Exploit PoC to be released on Twitter later today.

Twitter/𝕏: @GabrielLandau

elastic security labs