Physical Memory File Extraction Based on File Object Analysis

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Content

- Background
- File Object Analysis
- File Cache Analysis
- DEMO
- Q/A

Outline

- **Who am I ?**
  - Ph.d Student at Chonnam National University

- **Objectives**
  - Introducing a Physical Memory Forensic
    - Memory dump
    - Advantages
  - Window Physical Memory Analysis
    - Analysis of window file object
    - Analysis of memory mapped file data
  - Showing some demos

What can be found in Memory

- **Running process information**
  - thread, module, handle…
- **Registry hives**
- **Network Information**
  - Packet, Socket info…
- **Malware and Rootkit detection**
- **Password key and other information**
- **File Data**
  - Running process File data, Cached File Data

Memory Forensic Advantages

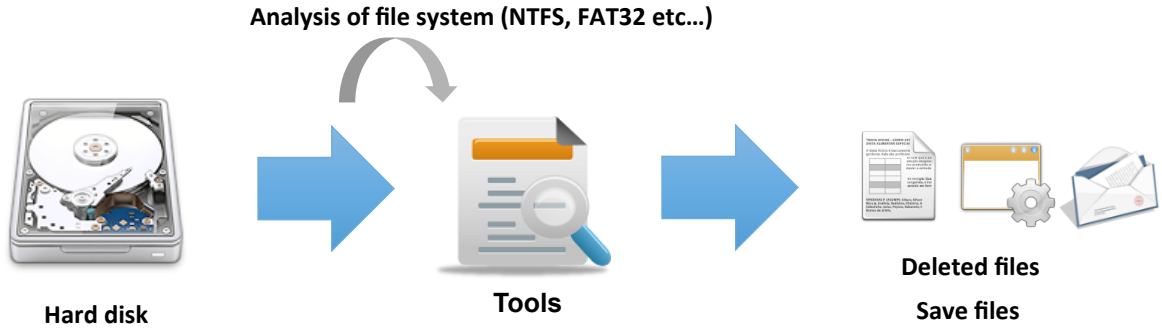
- **Analyze and track active on the system**
  - Running process analysis
  - Access file, Network Info etc…
- **Collect evidence that cannot be found in hard disk**
  - User Information
    - Messenger msg, chat data, internet activities
  - Password key data
    - Master Key
  - Original file extraction
    - When encrypted volume was mounted

Background

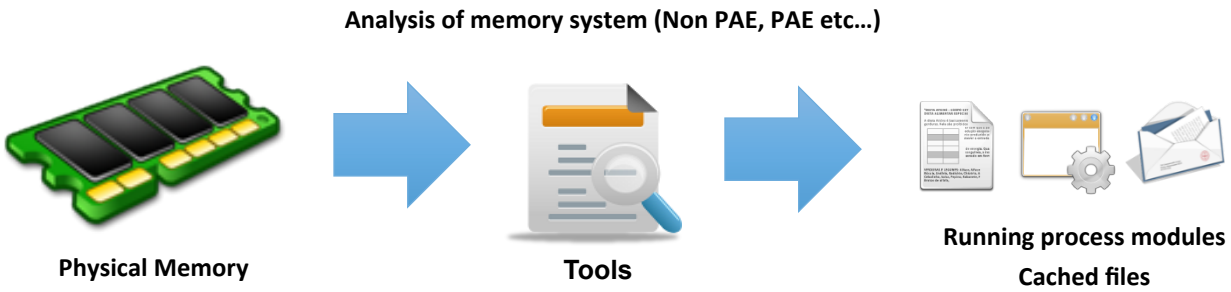
- **Physical Memory Dump**
  - Live Dump
    - Easy and general method
    - Tool : Win32/64DD, Winpmem, Dumpit etc…
  - Crash Dump
    - Window Kernel Crash Dump
    - %SystemRoot%Memory.dmp
  - Hibernate Dump
    - It contains a full dump of the memory
    - %SystemRoot%hiberfil.sys

Background

- **File Extraction**
  - Hard-Disk



  - Physical Memory Dump



Research trend

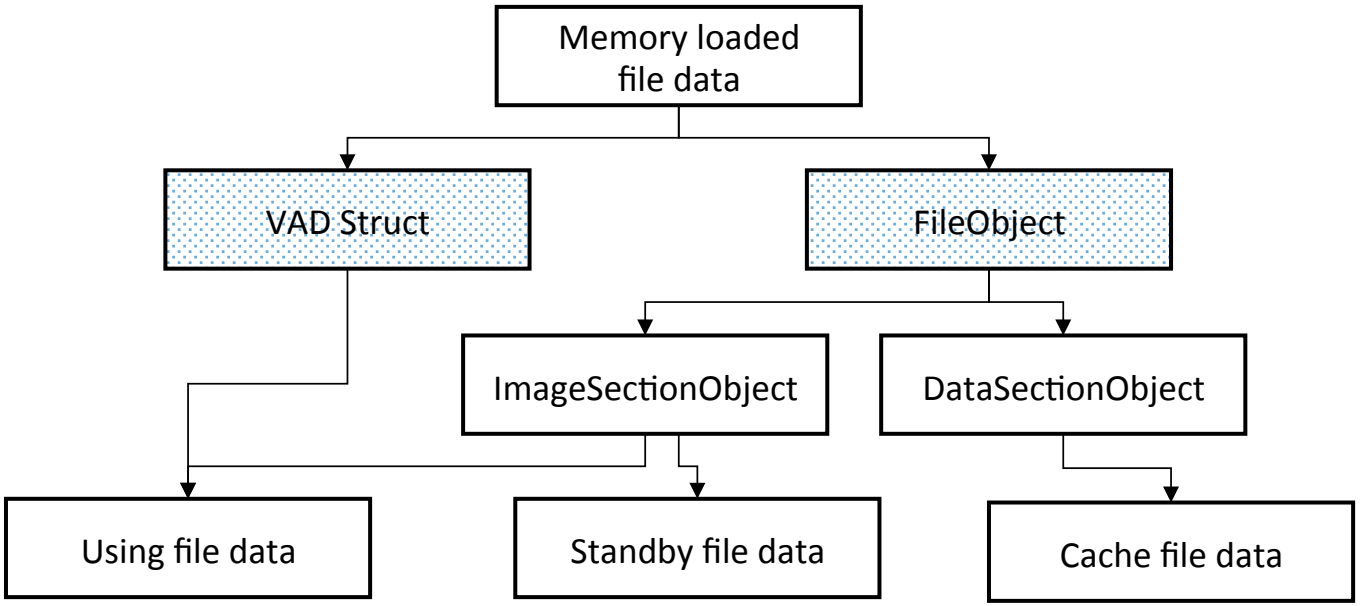
- **Analysis of Memory mapped file data**
  - FileObject Analysis
    - Blackhat USA 2011-Physical Memory Forensics for Files and Cache
    - Forensic memory analysis : Files mapped in memory - 2008
  - VAD Analysis
    - The VAD tree : A process-eye view of physical memory - 2007

Research trend

- **Extracting file data from memory dump**
  - Executable file (running process)
    - VAD Struct analysis
    - Tool : Volatility, Rekall, Responder, Memoryze (FileObject, VAD)
  - Normal file
    - File Carving (file size < 4KB)
  - Cache file
    - File I/O analysis, VACB(Virtual Address Control Block) struct analysis

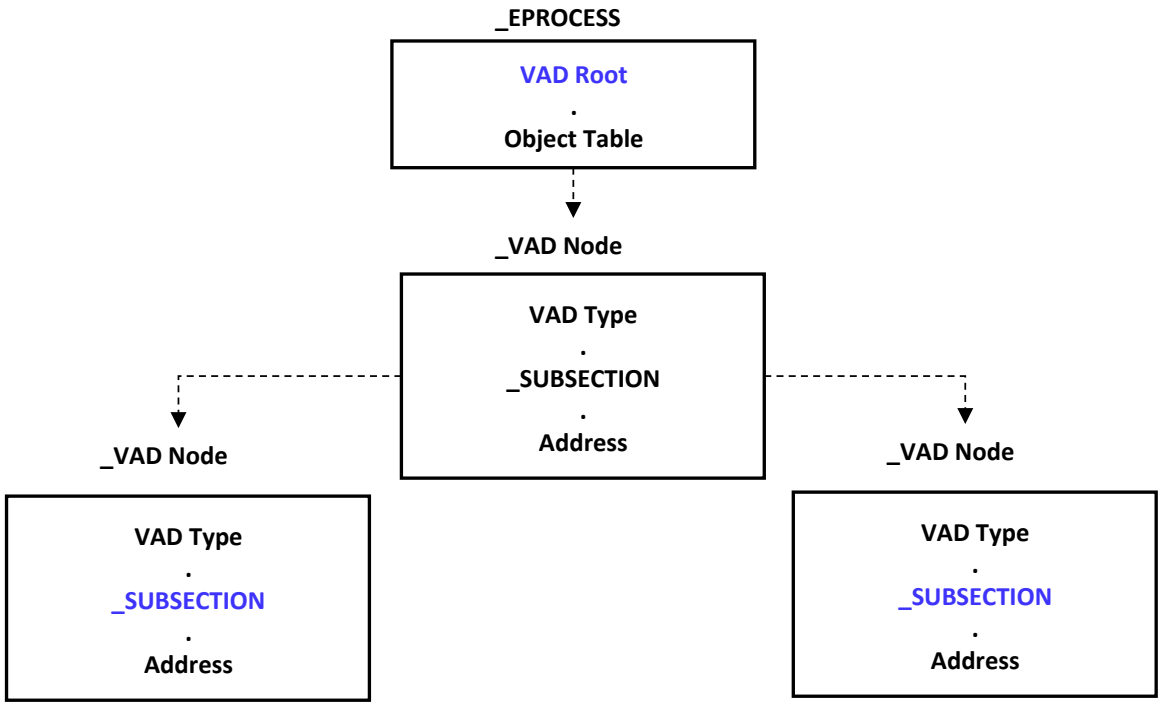
Memory mapped file

- **File data storage areas**
  - VAD struct
  - FileObject struct



Memory mapped file

- **VAD (Virtual Address Descriptor) (1/2)**
  - Describe memory rages used by a process
  - _MMVAD struct
    - Consists of a binary tree




```
kd> dt _MMVAd
nt!_MMVAD
   +0x000 u1               : <unnamed-tag>
   +0x008 LeftChild        : Ptr64 _MMVAD
   +0x010 RightChild       : Ptr64 _MMVAD
   +0x018 StartingVpn      : Uint8B
   +0x020 EndingVpn        : Uint8B
   +0x028 u                : <unnamed-tag>
   +0x030 PushLock         : _EX_PUSH_LOCK
   +0x038 u5               : <unnamed-tag>
   +0x040 u2               : <unnamed-tag>
   +0x048 Subsection       : Ptr64 _SUBSECTION
   +0x048 MappedSubsection : Ptr64 _MSUBSECTION
   +0x050 FirstPrototypePte : Ptr64 _MMPTE
   +0x058 LastContiguousPte : Ptr64 _MMPTE
   +0x060 ViewLinks        : _LIST_ENTRY
   +0x070 VadsProcess      : Ptr64 _EPROCESS
```

_MMVAD struct

Memory mapped file

- **VAD (Virtual Address Descriptor) (2/2)**
  - VAD -> File data loaded
    - _SUBSECTION is Not NULL
  - VAD -> Heap/Stack
    - _SUBSECTION is NULL

```
nt!_MMVAD
   +0x000 u1               : <unnamed-tag>
   +0x008 LeftChild        : 0xfffffa80`0dc55330 _MMVAD
   +0x010 RightChild       : (null)
   +0x018 StartingVpn      : 0x8b60
   +0x020 EndingVpn        : 0x8b60
   +0x028 u                : <unnamed-tag>
   +0x030 PushLock         : _EX_PUSH_LOCK
   +0x038 u5               : <unnamed-tag>
   +0x040 u2               : <unnamed-tag>
   +0x048 Subsection       : (null)
   +0x048 MappedSubsection : (null)
   +0x050 FirstPrototypePte : (null)
   +0x058 LastContiguousPte : (null)
   +0x060 ViewLinks        : _LIST_ENTRY [ 0x00000000`00000000 - 0x0 ]
   +0x070 VadsProcess      : (null)
```

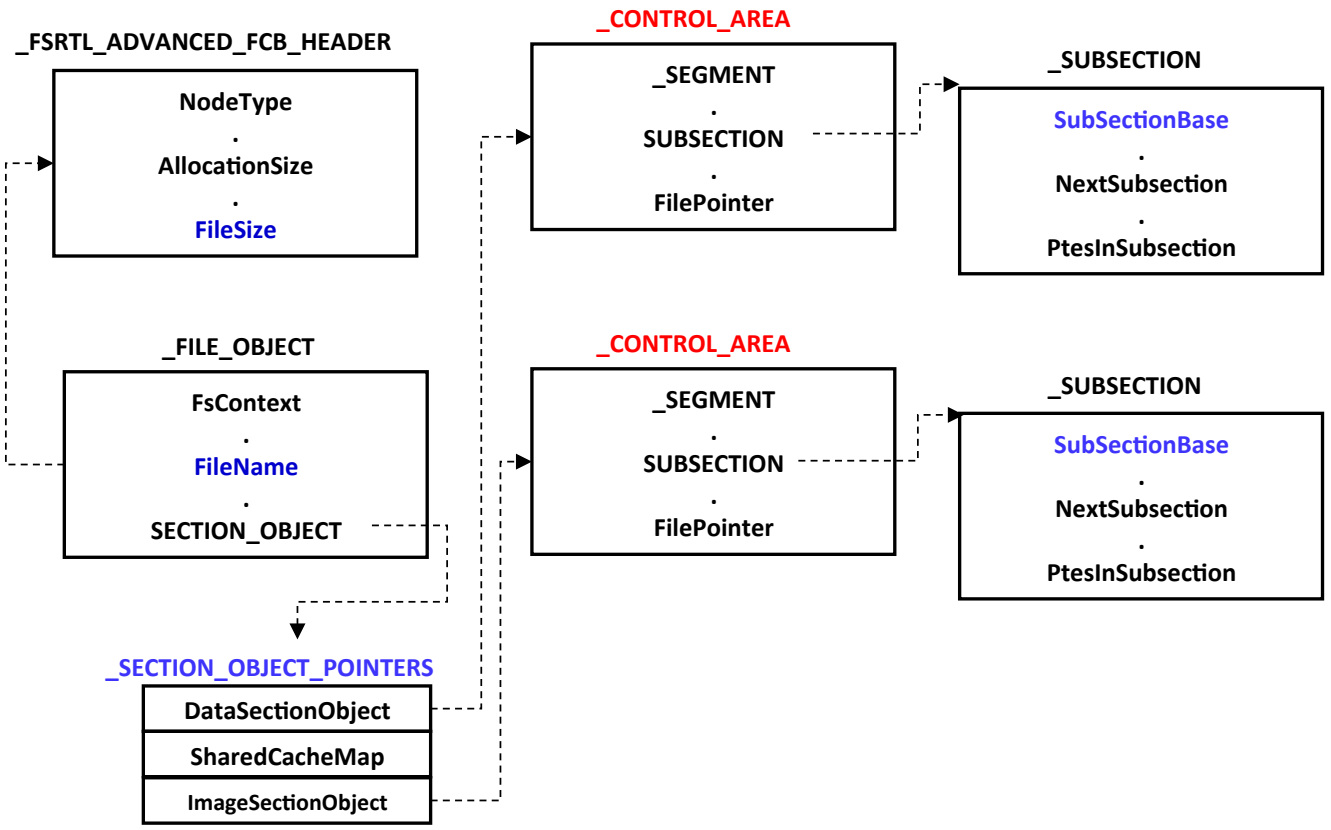
_MMVAD Heap/Stack

```
kd> dt _MMVAD fffffa800cf54f70
nt!_MMVAD
   +0x000 u1               : <unnamed-tag>
   +0x008 LeftChild        : 0xfffffa80`0ef487b0 _MMVAD
   +0x010 RightChild       : 0xfffffa80`0ef3e170 _MMVAD
   +0x018 StartingVpn      : 0x8ba0
   +0x020 EndingVpn        : 0x8c1f
   +0x028 u                : <unnamed-tag>
   +0x030 PushLock         : _EX_PUSH_LOCK
   +0x038 u5               : <unnamed-tag>
   +0x040 u2               : <unnamed-tag>
   +0x048 Subsection       : 0xfffffa80`0efba620 _SUBSECTION
   +0x048 MappedSubsection : 0xfffffa80`0efba620 _MSUBSECTION
   +0x050 FirstPrototypePte : 0xfffff8a0`01fa4a10 _MMPTE
   +0x058 LastContiguousPte : 0xfffff8a0`01fa4a20 _MMPTE
   +0x060 ViewLinks        : _LIST_ENTRY [ 0xfffffa80`0efba610 - 0xfffffa80`0efba610 ]
   +0x070 VadsProcess      : 0xfffffa80`0eb1b061 _EPROCESS
```

_MMVAD File data loaded

Memory mapped file

- **FileObject struct**
  - Managing file information



Memory mapped file

- **FileObject Analysis**
  - _SECTION_OBJECT_POINTERS
    - DataSectionObject
      - Present on binary memory mapped files and normal files
      - File : .exe .dll .jpg .pdf …
    - SharedCacheMap
      - ReadWrite I/O Data
      - VACB(Virtual Address Control Block) Struct
    - ImageSectionObject
      - Present on binary memory mapped files
      - File : .exe .dll

Memory mapped file

- **FileObject Analysis**
  - _SECTION_OBJECT_POINTERS
    - Executable file
      - ImageSectionObject, DataSectionObject

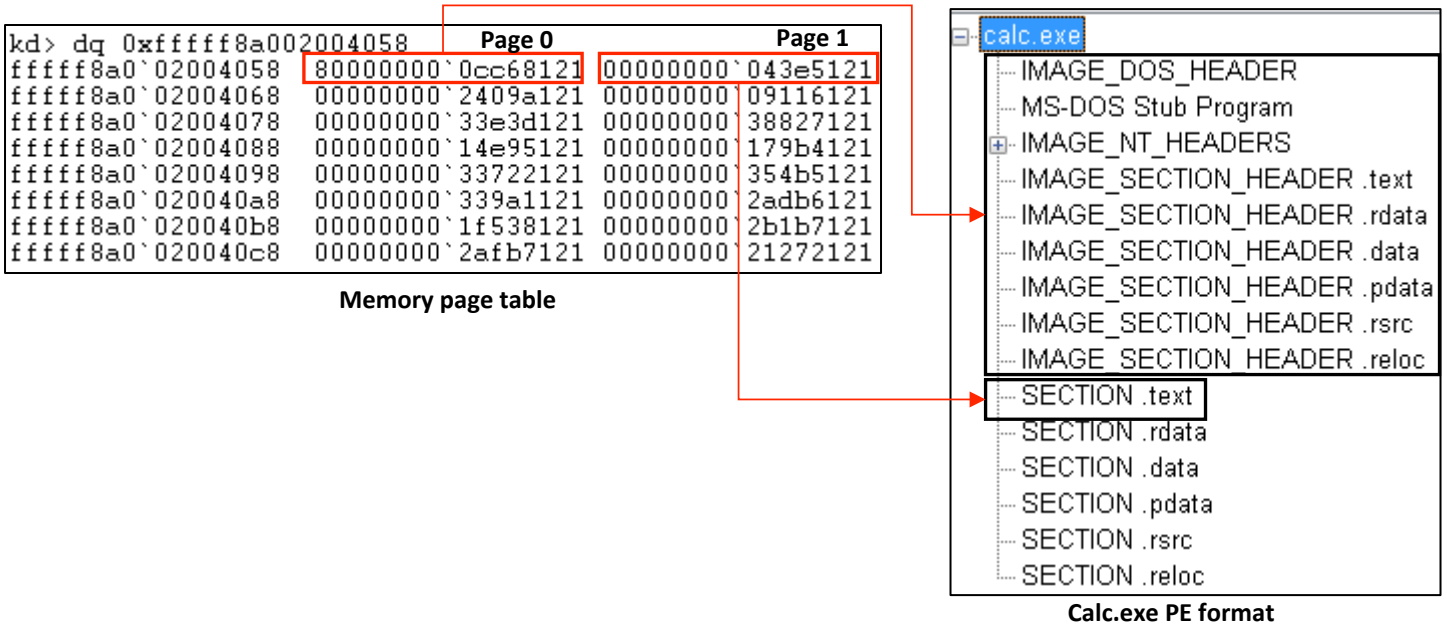
```
kd> dt _SECTION_OBJECT_POINTERS 0xfffffa80`0cf15a08
ntdll!_SECTION_OBJECT_POINTERS
   +0x000 DataSectionObject : 0xfffffa80`0cf64840 Void
   +0x008 SharedCacheMap    : (null)
   +0x010 ImageSectionObject : 0xfffffa80`0cf15440 Void
```

    - Normal file
      - DataSectionObject

```
kd> dt _SECTION_OBJECT_POINTERS 0xfffffa80`0ead0ea8
ntdll!_SECTION_OBJECT_POINTERS
   +0x000 DataSectionObject : 0xfffffa80`0edc11d0 Void
   +0x008 SharedCacheMap    : (null)
   +0x010 ImageSectionObject : (null)
```

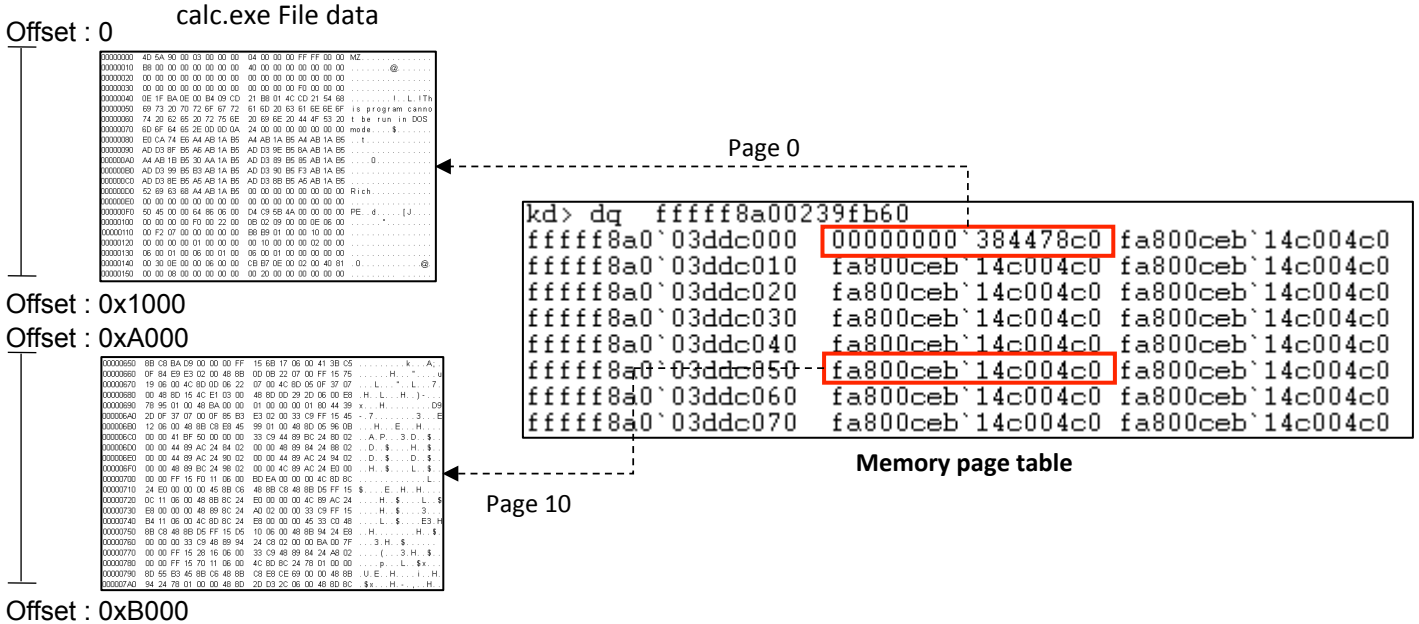
Memory mapped file

- **File data management**
  - ImageSectionObject
    - ImageSectionObject -> _CONTROL_AREA -> _SUBSECTION
    - _SUBSECTION -> SubsectionBase
      - Physical address of file data saved



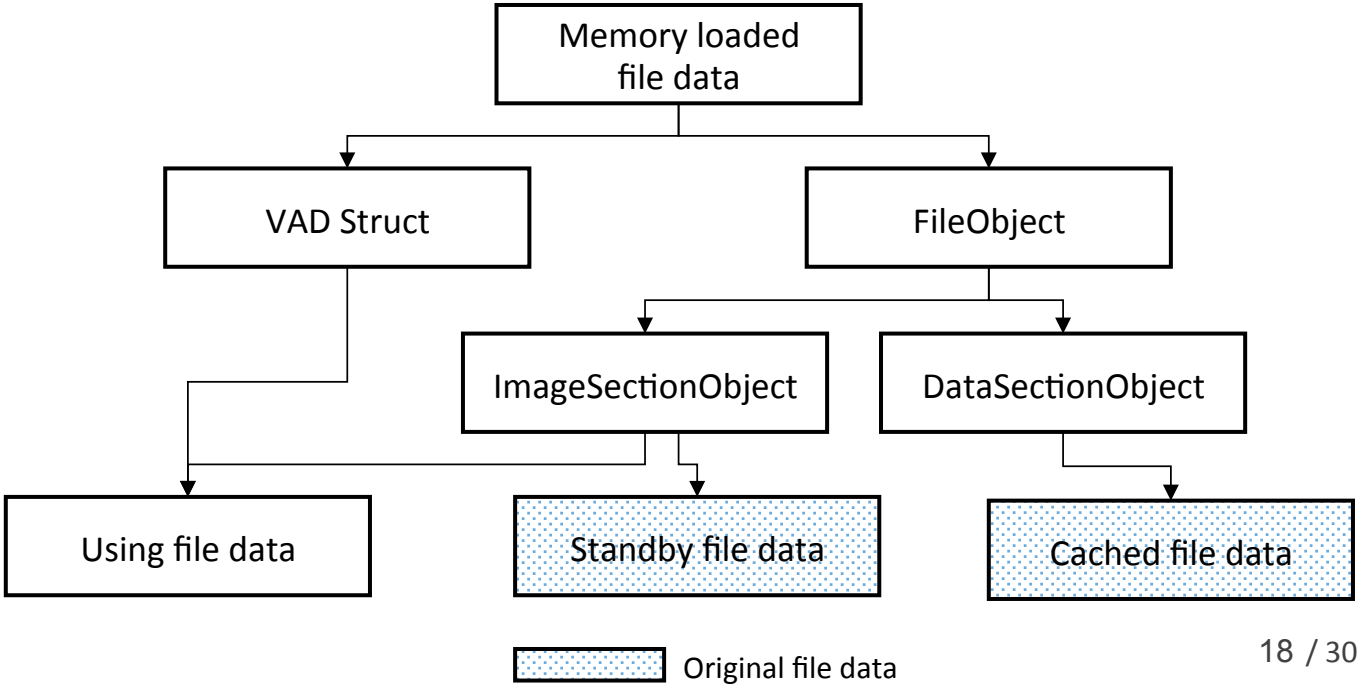
Memory mapped file

- **File data management**
  - DataSectionObject
    - DataSectionObject -> _CONTROL_AREA -> _SUBSECTION
    - _SUBSECTION -> SubsectionBase
      - Physical address of file data saved



Memory mapped file

- **Executable file data (1/3)**
  - VAD struct
    - Running process
  - Fileobject
  - ex) .exe, .dll (not .sys)



Memory mapped file

- **Executable file data (2/3)**
  - Feature of memory page table
    - File data is not modified

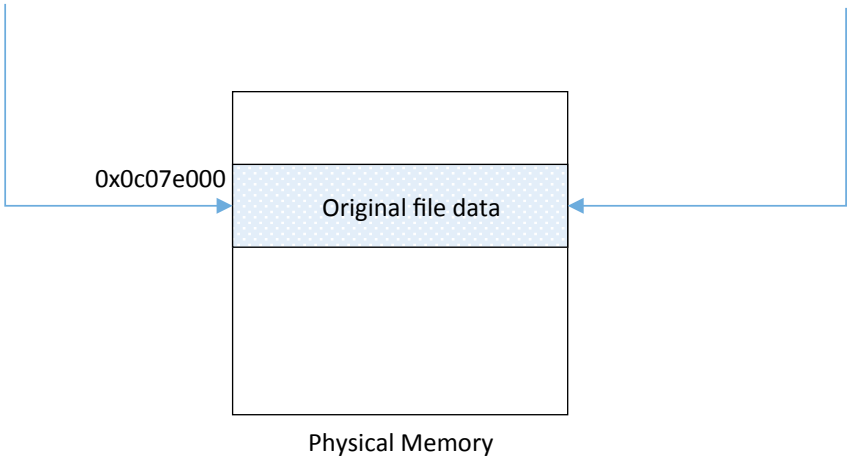
File data address : 0x0c07e000 ~

```
kd> dq fffff8a0019d0048
fffff8a0`019d0048  80000000`0c07e121 00000000`2341a121
fffff8a0`019d0058  00000000`0d81b121 00000000`0db9c121
fffff8a0`019d0068  00000000`1ed1d121 00000000`29d44860
fffff8a0`019d0078  00000000`28d9e121 00000000`2ed45860
fffff8a0`019d0088  fa800f0b`ef180460 00000000`136c6860
fffff8a0`019d0098  00000000`05b47860 00000000`0e448860
fffff8a0`019d00a8  00000000`27f1f121 00000000`19e3b860
fffff8a0`019d00b8  00000000`01d20121 00000000`28fbc860
```

ImageSectionObject -> Memory page table

```
kd> dq /p 383fc000
00000000`383fc000  e2400000`0c07e025 26900000`2341a025
00000000`383fc010  28700000`0d81b025 1fd00000`0db9c025
00000000`383fc020  10300000`1ed1d025 f8a0019d`00700400
00000000`383fc030  3bd00000`28d9e025 f8a0019d`00800400
00000000`383fc040  00000000`00000000 f8a0019d`00900400
00000000`383fc050  f8a0019d`00980400 f8a0019d`00a00400
00000000`383fc060  4aa00000`27f1f025 00000000`00000000
00000000`383fc070  35000000`01d20025 00000000`00000000
```

VAD -> Memory page table



Memory mapped file

- **Executable file data (3/3)**
  - Feature of memory page table
    - File data is modified (copy-on-write)

File data address : 0x0c07e000 ~

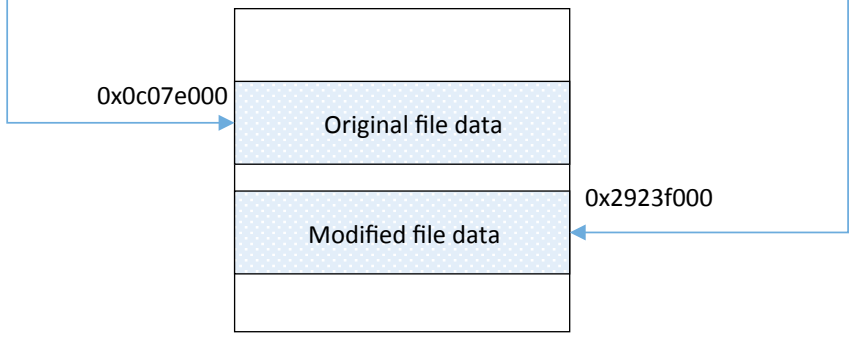
```
kd> dq fffff8a0019d0048
fffff8a0`019d0048  80000000`0c07e820 00000000`2341a121
fffff8a0`019d0058  00000000`0d81b121 00000000`0db9c121
fffff8a0`019d0068  00000000`1ed1d121 00000000`29d44860
fffff8a0`019d0078  00000000`28d9e121 00000000`2ed45860
fffff8a0`019d0088  fa800f0b`ef180460 00000000`136c6860
fffff8a0`019d0098  00000000`05b47860 00000000`0e448860
fffff8a0`019d00a8  00000000`27f1f121 00000000`19e3b860
fffff8a0`019d00b8  00000000`01d20121 00000000`28fbc860
```

ImageSectionObject -> Memory page table

File data address : 0x2923f000 ~

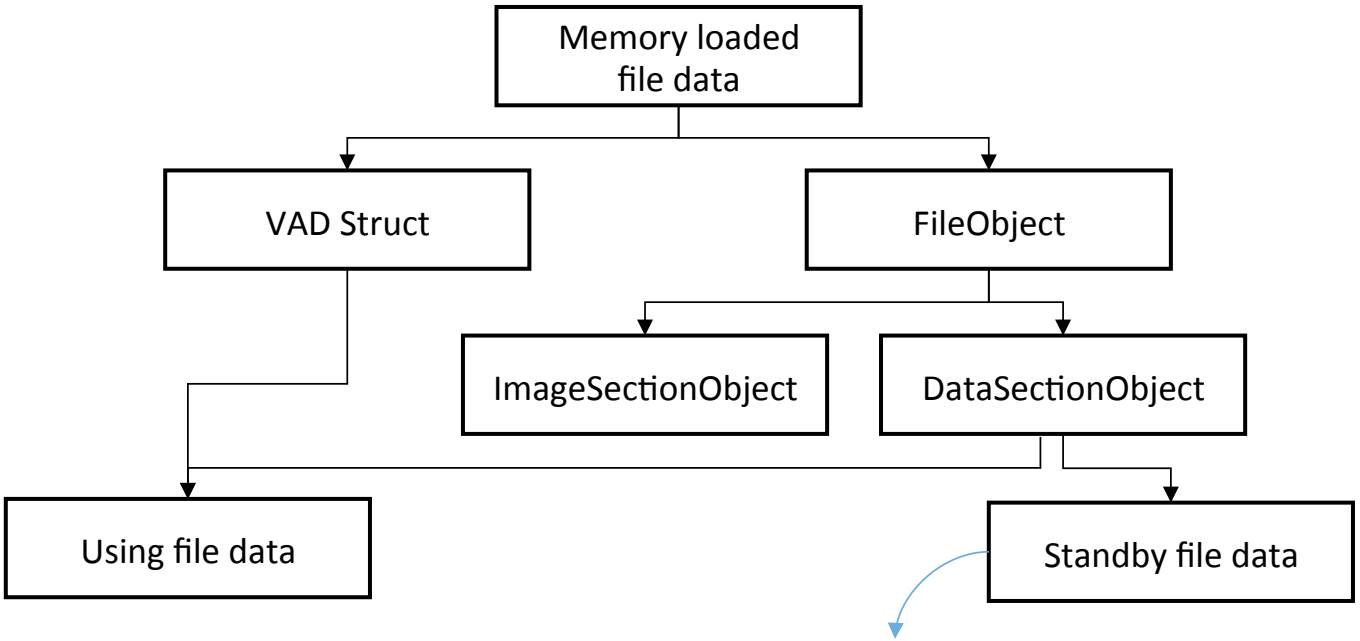
```
kd> dq /p 383fc000
00000000`383fc000  e2400000`2923f025 26900000`2341a025
00000000`383fc010  28700000`0d81b025 1fd00000`0db9c025
00000000`383fc020  10300000`1ed1d025 f8a0019d`00700400
00000000`383fc030  3bd00000`28d9e025 f8a0019d`00800400
00000000`383fc040  00000000`00000000 f8a0019d`00900400
00000000`383fc050  f8a0019d`00980400 f8a0019d`00a00400
00000000`383fc060  4aa00000`27f1f025 00000000`00000000
00000000`383fc070  35000000`01d20025 00000000`00000000
```

VAD -> Memory page table



Memory mapped file

- **Normal file data (1/3)**
  - VAD struct
    - Running process
  - Fileobject
  - ex) .jpg .pdf .png …



Memory mapped file

- **Normal file data (2/3)**
  - Feature of memory page table
    - File data is not modified / File data is modified

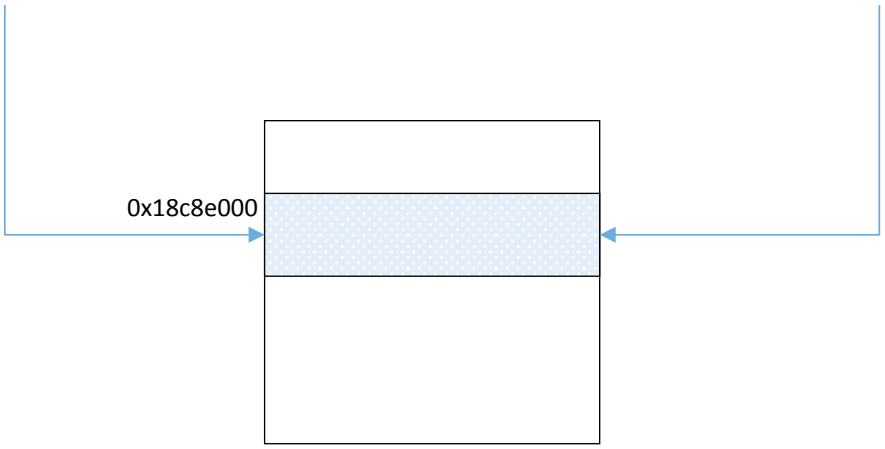
File data address : 0x18c8e000 ~

```
kd> dq fffff8a007b612c0
fffff8a0`07b612c0  00000000`18c8e963 fffffa80`0ccad150
fffff8a0`07b612d0  74536d4d`03070002 fffffa80`0ccad1b0
fffff8a0`07b612e0  fffffa80`0eec2420 00080000`00000002
fffff8a0`07b612f0  00000000`00000002 00000000`00002000
fffff8a0`07b61300  00000000`00000000 00000000`00000000
fffff8a0`07b61310  fffffa80`0d986060 00000000`03760000
fffff8a0`07b61320  fffff8a0`07b61328 80000000`1b5fa880
fffff8a0`07b61330  80000000`1b67a880 00fcfcfc`00fcfcfc
```

VAD -> Memory page table

```
kd> dq /p 10b1c80
00000000`010b1c80  acd00000`18c8e825 fffffff`00000480
00000000`010b1c90  fffffff`00000480 00000000`00000000
00000000`010b1ca0  00000000`00000000 00000000`00000000
00000000`010b1cb0  00000000`00000000 00000000`00000000
00000000`010b1cc0  00000000`00000000 00000000`00000000
00000000`010b1cd0  00000000`00000000 00000000`00000000
00000000`010b1ce0  00000000`00000000 00000000`00000000
00000000`010b1cf0  00000000`00000000 00000000`00000000
```

DataSectionObject-> Memory page table



Memory mapped file

- **Normal file data (3/3)**
  - Feature of memory page table
    - Checkout file data modified~

```
kd>  dq /p 10b1c80
00000000`010b1c80  acd00000`18c8e825 b3600000`19631805
00000000`010b1c90  ffffffff`00000480 00000000`00000000
00000000`010b1ca0  00000000`00000000 00000000`00000000
00000000`010b1cb0  00000000`00000000 00000000`00000000
00000000`010b1cc0  00000000`00000000 00000000`00000000
00000000`010b1cd0  00000000`00000000 00000000`00000000
00000000`010b1ce0  00000000`00000000 00000000`00000000
00000000`010b1cf0  00000000`00000000 00000000`00000000
```

VAD -> Memory page table

```
ntdll!_HARDWARE_PTE
   +0x000 Valid            : 0y1
   +0x000 Write            : 0y0
   +0x000 Owner            : 0y1
   +0x000 WriteThrough     : 0y0
   +0x000 CacheDisable     : 0y0
   +0x000 Accessed         : 0y1
   +0x000 Dirty            : 0y0
   +0x000 LargePage        : 0y0
   +0x000 Global           : 0y0
   +0x000 CopyOnWrite      : 0y0
   +0x000 Prototype        : 0y0
   +0x000 reserved0        : 0y1
   +0x000 PageFrameNumber  : 0y00000000000011000110010001110 (0x18c8e)
   +0x000 reserved1        : 0y000000000000 (0)
   +0x000 SoftwareWsIndex  : 0y01011001101 (0x2cd)
   +0x000 NoExecute        : 0y1
```

Bit Pos 6 - 1Bit

Original file data

```
kd> dq /p 10b1c80
00000000`010b1c80  acd00000`18c8e867 b3600000`19631825
00000000`010b1c90  c6d00000`30132825 c6e00000`1eab3825
00000000`010b1ca0  c6f00000`0081d825 c7000000`3ab1e825
00000000`010b1cb0  c7100000`1961f825 c7200000`38820825
00000000`010b1cc0  c7300000`32da1825 c7400000`03422825
00000000`010b1cd0  c7500000`16da3825 c7600000`01b24825
00000000`010b1ce0  c7700000`01826825 c7800000`27ca7825
00000000`010b1cf0  c7900000`2d1a8825 c7a00000`20729825
```

VAD -> Memory page table

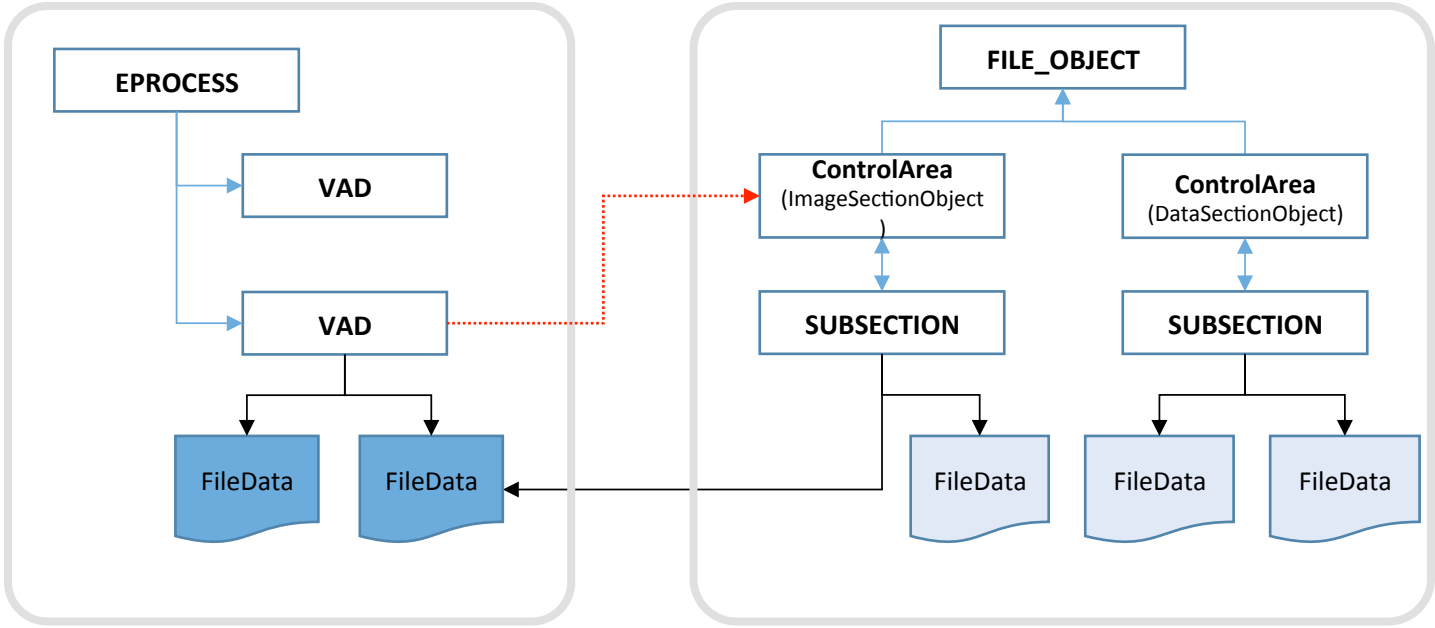
```
ntdll!_HARDWARE_PTE
   +0x000 Valid            : 0y1
   +0x000 Write            : 0y1
   +0x000 Owner            : 0y1
   +0x000 WriteThrough     : 0y0
   +0x000 CacheDisable     : 0y0
   +0x000 Accessed         : 0y1
   +0x000 Dirty            : 0y1
   +0x000 LargePage        : 0y0
   +0x000 Global           : 0y0
   +0x000 CopyOnWrite      : 0y0
   +0x000 Prototype        : 0y0
   +0x000 reserved0        : 0y1
   +0x000 PageFrameNumber  : 0y00000000000011000110010001110 (0x18c8e)
   +0x000 reserved1        : 0y000000000000 (0)
   +0x000 SoftwareWsIndex  : 0y01011001101 (0x2cd)
   +0x000 NoExecute        : 0y1
```

Bit Pos 6 - 1Bit

Modified l file data

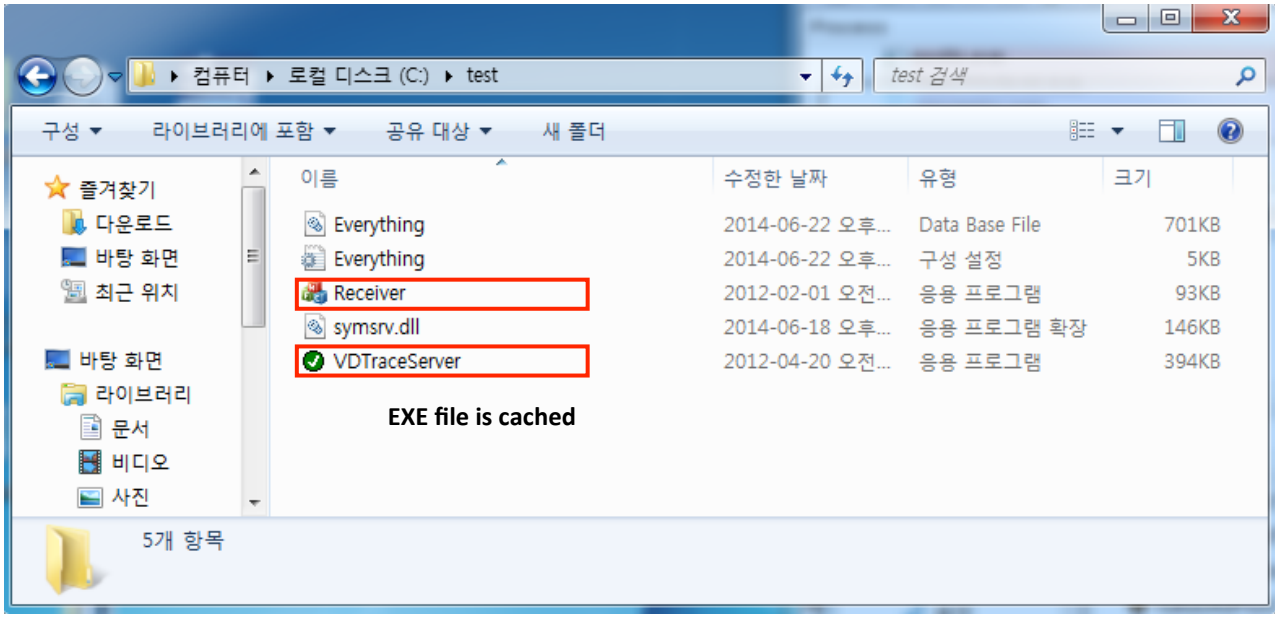
Memory mapped file

- **Management of memory loaded file data**
  - VAD
  - FILE_OBJECT



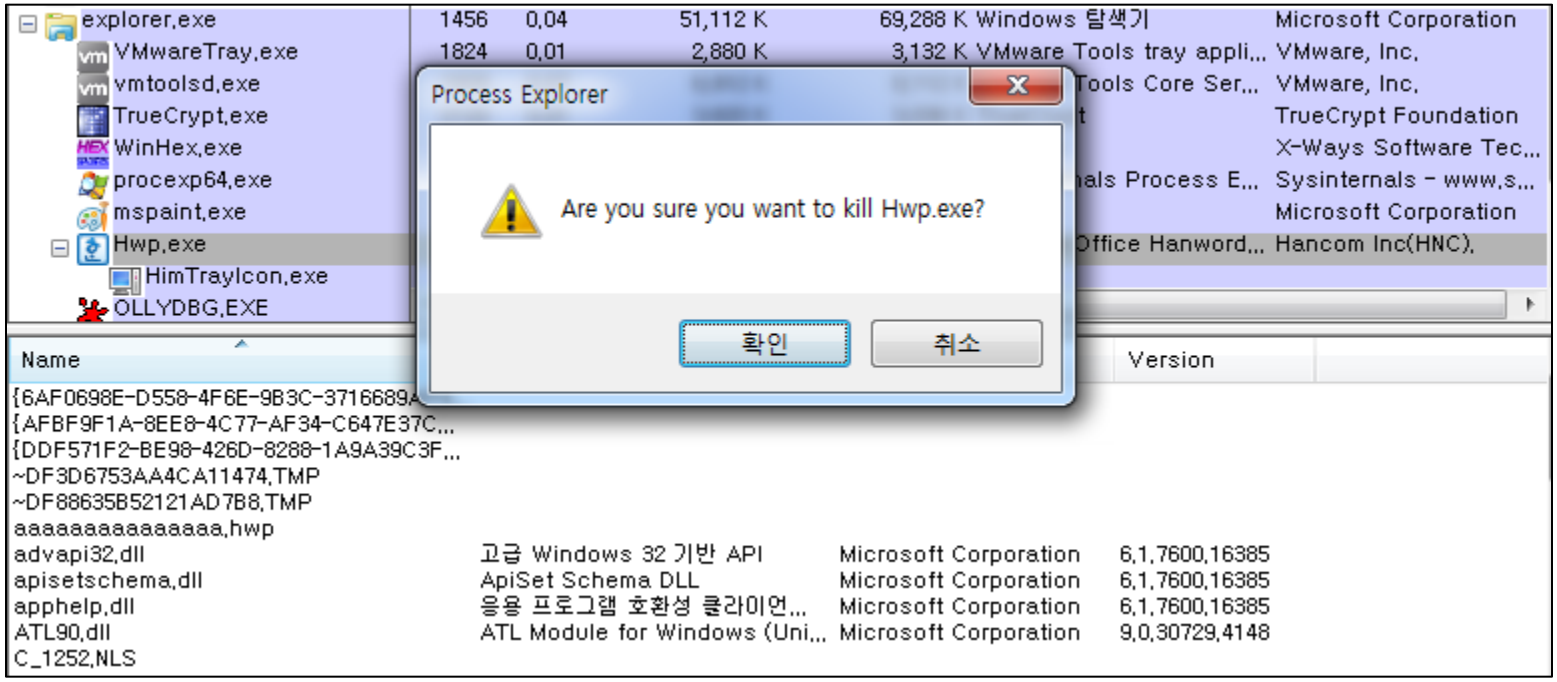
File cache

- **Feature of window file cache**
  - Access Folder -> *.exe file is cached by memory management



File cache

- **Feature of window file cache**
  - Process End
    - Process file(.exe) is cached by memory management
    - MMF(memory mapped file) is cached by memory management

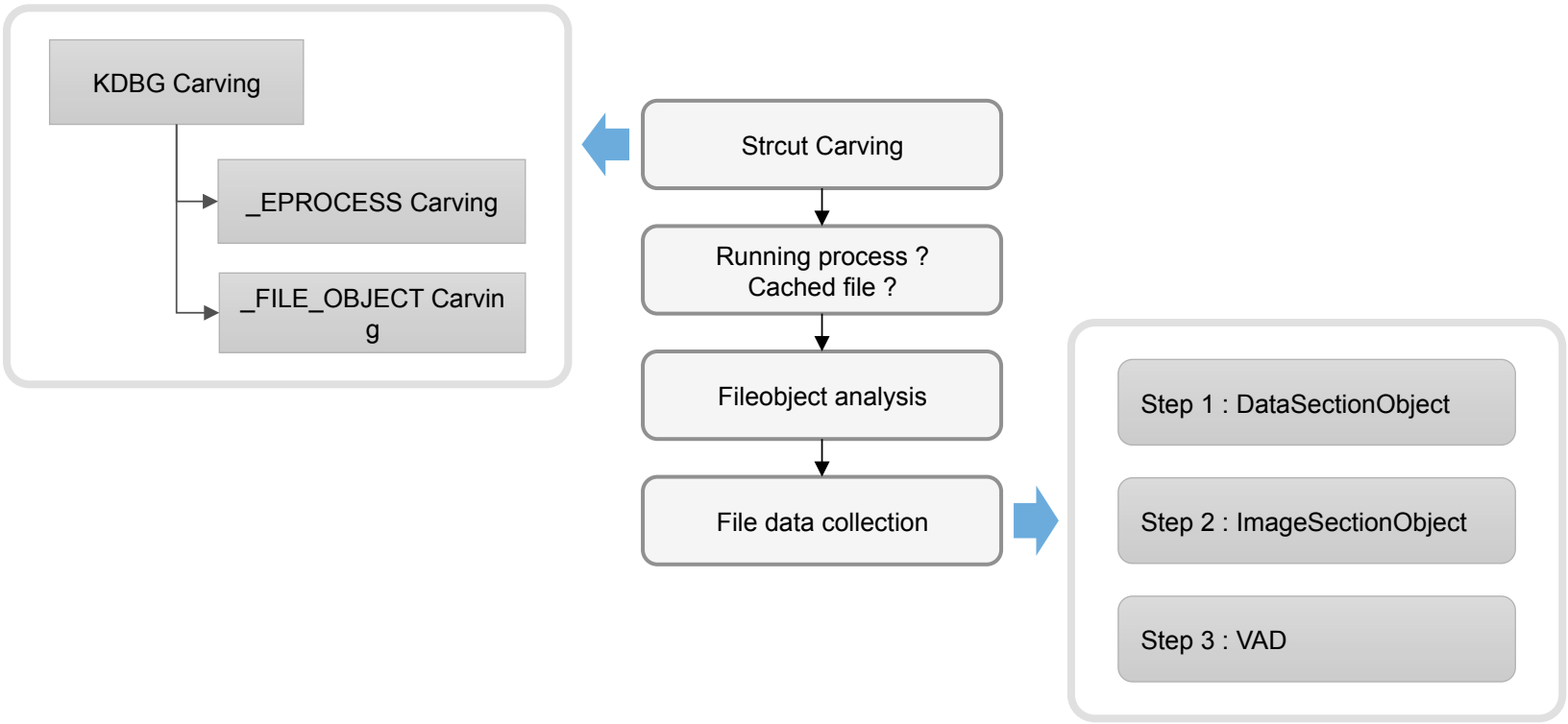


File cache

- **How to find cached file in memory dump ?**
  - Carving _FILE_OBJCET struct
    - PoolTag = 0xE56c6946
    - PoolIndex = 0
    - OBJECT_HEADER.TypeIndex == TYPE_FILE (0x28)
  - Check VAD
    - Running Process file data
      - VAD -> _SUBSECTION -> _CONTROL_AREA -> _FILE_OBJECT

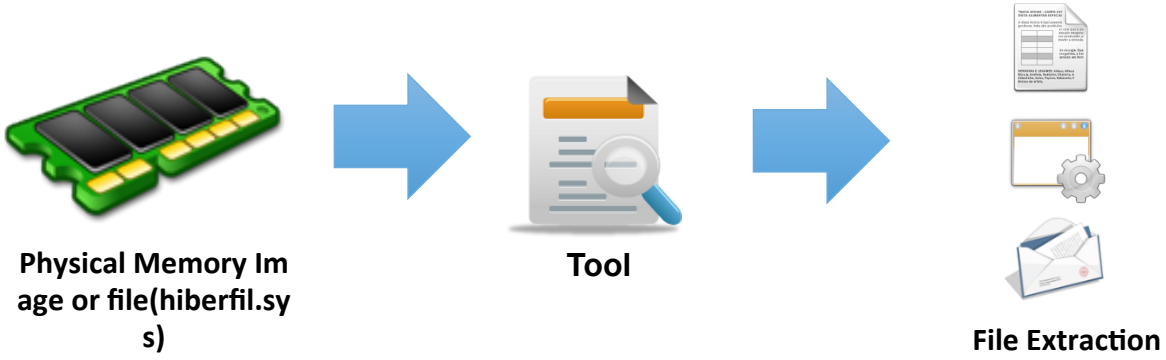
Procedure for file data extraction

- **Procedure**
  - Kernel struct carving
  - Extract file information
  - File data extraction



Demo

- It’s demo time!



Questions ?