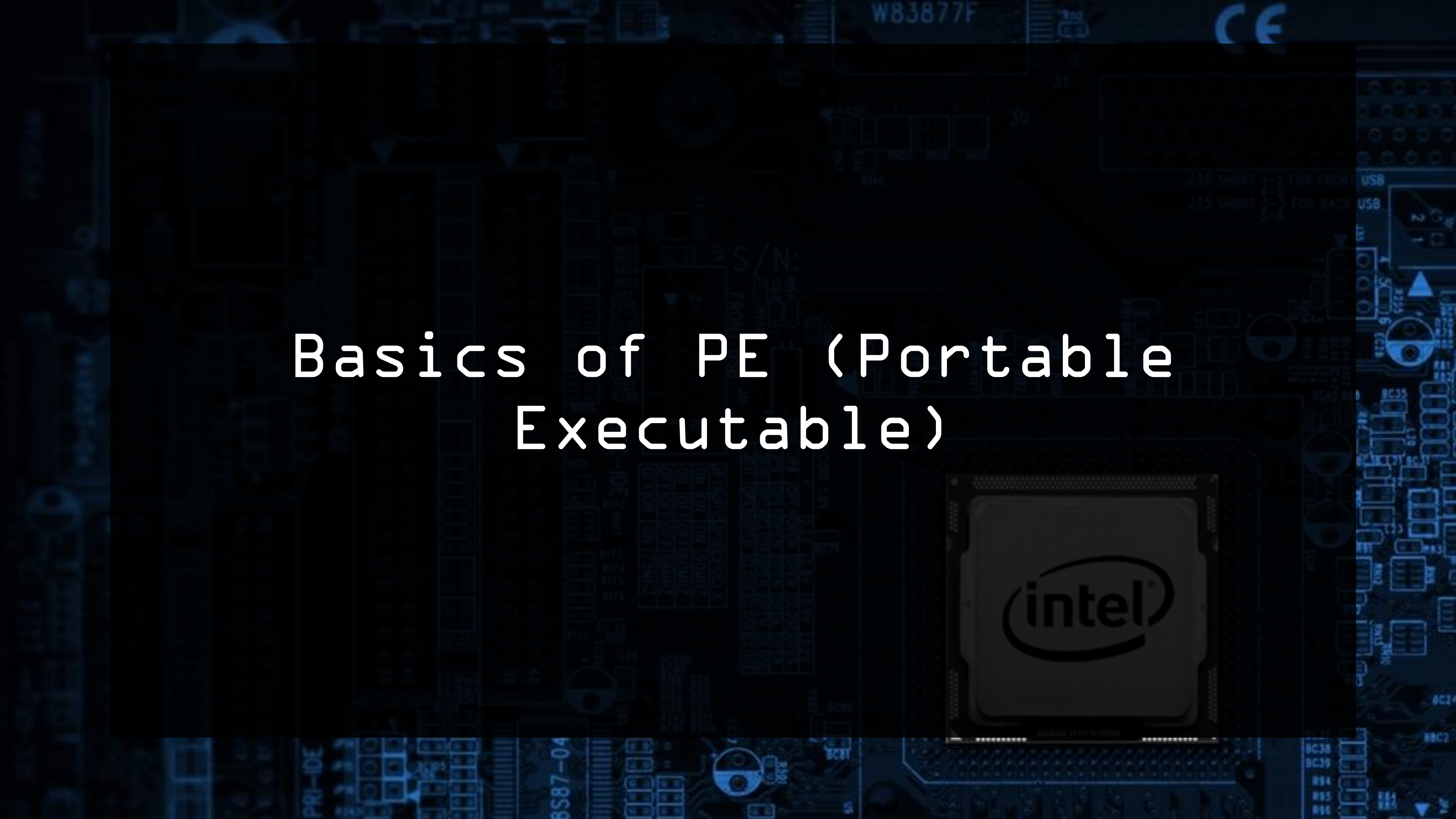
# Module 1

A journey from high level languages, through assembly, to the running process

https://github.com/hasherezade/malware_training_vol1

# Basics of PE (Portable Executable)



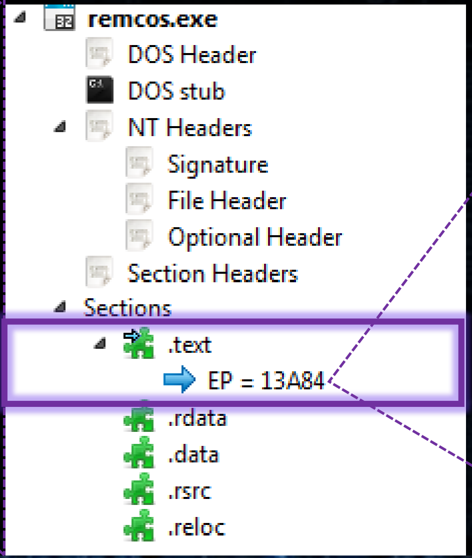
# Basics of a PE file

- PE (Portable Executable) is a native executable format on Windows
- PE files:
    - user mode: EXE, DLL
    - kernel mode: driver (.sys), kernel image (ntoskrnl.exe)
    - UEFI (run in SMM – System Managemant Mode)
    - Also OBJ files have structures similar to PE

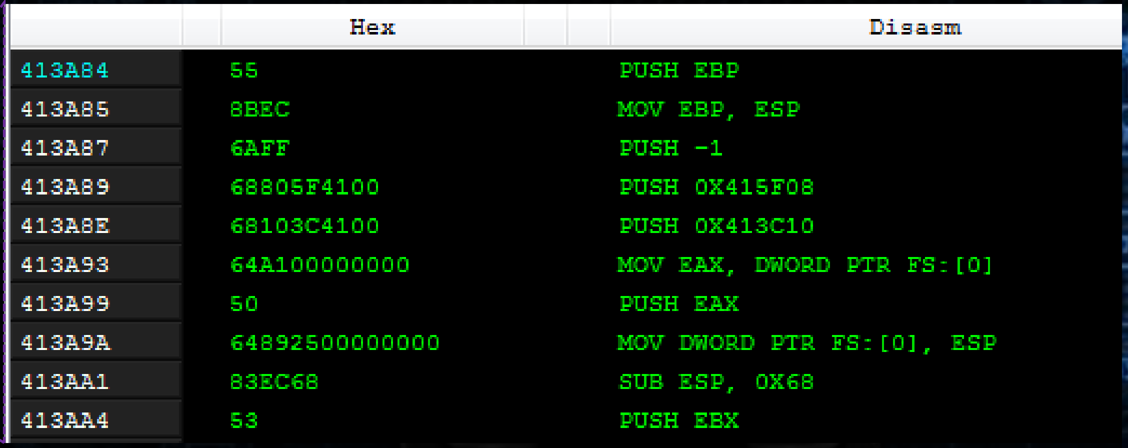
# Basics of a PE file

- PE (Portable Executable) contains information:
  - What to execute: the compiled code
  - How to execute: headers with data necessary for loading it

remcos.exe



```
remcos.exe
    DOS Header
    DOS stub
    NT Headers
        Signature
        File Header
        Optional Header
    Section Headers
    Sections
        .text
            EP = 13A84
        .rdata
        .data
        .rsrc
        .reloc
```



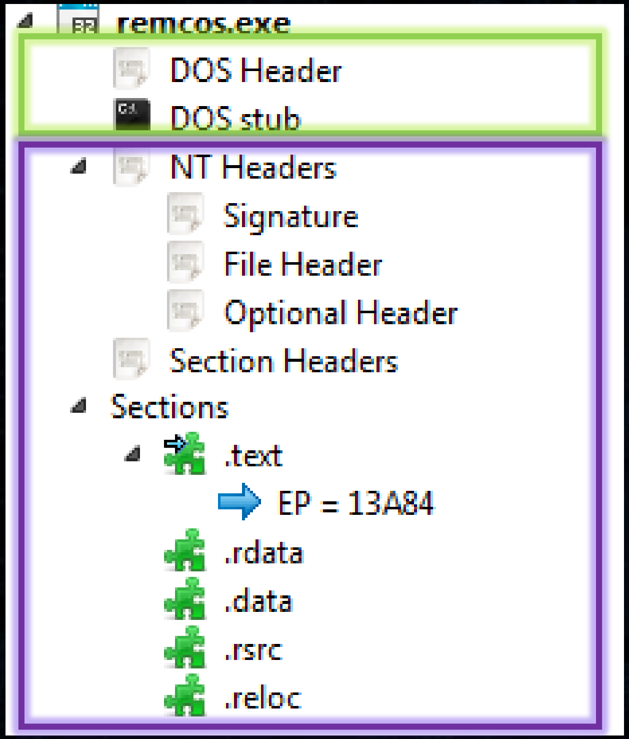
```
          Hex                Disasm
413A84    55                 PUSH EBP
413A85    8BEC               MOV EBP, ESP
413A87    6AFF               PUSH -1
413A89    68805F4100         PUSH 0X415F08
413A8E    68103C4100         PUSH 0X413C10
413A93    64A100000000       MOV EAX, DWORD PTR FS:[0]
413A99    50                 PUSH EAX
413A9A    648925000000000    MOV DWORD PTR FS:[0], ESP
413AA1    83EC68             SUB ESP, 0X68
413AA4    53                 PUSH EBX
```

# Basics of a PE file

- PE format is based on a Unix format COFF – that was used in VAX/VMS
- It was introduced as a part of specification Win32
- Throughout many years, the core of the format didn't change, only some new fields of some structures have been added
- Since introduction of 64 bit environment, PE needed to be adjusted to it: 64 bit PE was introduced
- Also, new variants have been introduced, like .NET PE – containing additional structures with intermediate code and metadata

# Basics of a PE file

- PE file structure: the DOS part (legacy) and the Windows Part

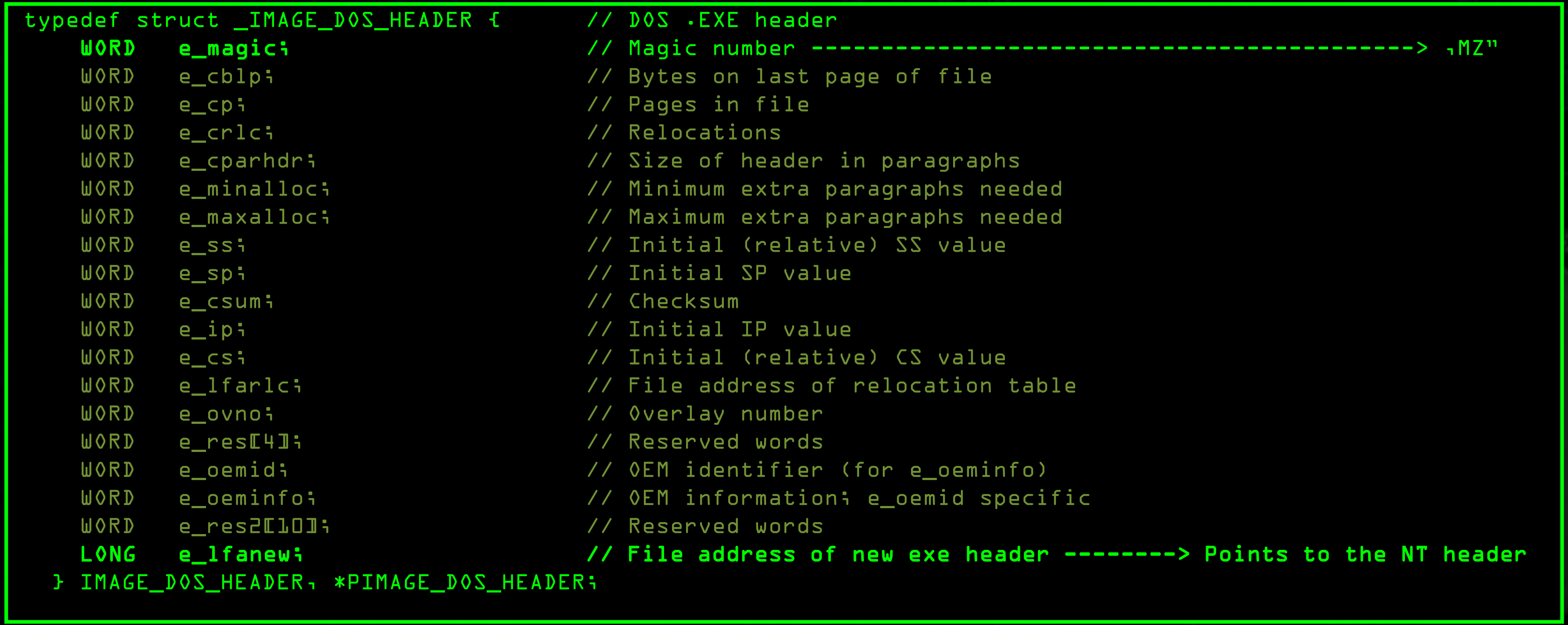


- remcos.exe
  - DOS Header
  - DOS stub
  - NT Headers
    - Signature
    - File Header
    - Optional Header
  - Section Headers
  - Sections
    - .text
      - EP = 13A84
    - .rdata
    - .data
    - .rsrc
    - .reloc

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/pe_hdr.h

# Basics of a PE file

- DOS Header: only e_magic, and e_lfnew must be filled:

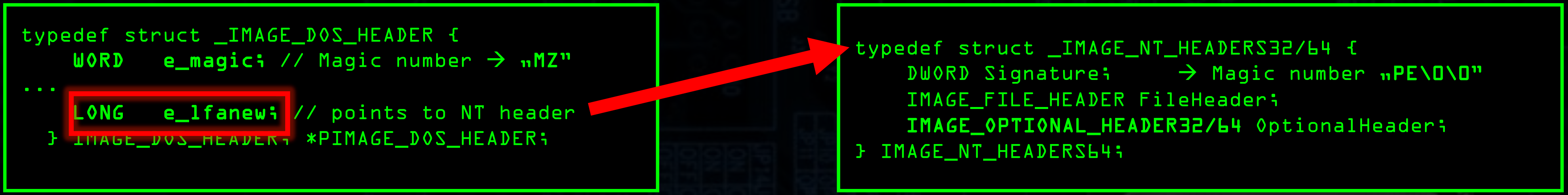


```
typedef struct _IMAGE_DOS_HEADER {      // DOS .EXE header
    WORD   e_magic;                     // Magic number ------------------------------------------> ‚MZ"
    WORD   e_cblp;                      // Bytes on last page of file
    WORD   e_cp;                        // Pages in file
    WORD   e_crlc;                      // Relocations
    WORD   e_cparhdr;                   // Size of header in paragraphs
    WORD   e_minalloc;                  // Minimum extra paragraphs needed
    WORD   e_maxalloc;                  // Maximum extra paragraphs needed
    WORD   e_ss;                        // Initial (relative) SS value
    WORD   e_sp;                        // Initial SP value
    WORD   e_csum;                      // Checksum
    WORD   e_ip;                        // Initial IP value
    WORD   e_cs;                        // Initial (relative) CS value
    WORD   e_lfarlc;                    // File address of relocation table
    WORD   e_ovno;                      // Overlay number
    WORD   e_res[4];                    // Reserved words
    WORD   e_oemid;                     // OEM identifier (for e_oeminfo)
    WORD   e_oeminfo;                   // OEM information; e_oemid specific
    WORD   e_res2[10];                  // Reserved words
    LONG   e_lfanew;                    // File address of new exe header --------> Points to the NT header
  } IMAGE_DOS_HEADER, *PIMAGE_DOS_HEADER;
```

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/pe_hdr.h

# Basics of a PE file

- DOS Header: fields to remember



```
typedef struct _IMAGE_DOS_HEADER {
    WORD   e_magic; // Magic number → „MZ"
...
    LONG   e_lfanew; // points to NT header
  } IMAGE_DOS_HEADER, *PIMAGE_DOS_HEADER;
```

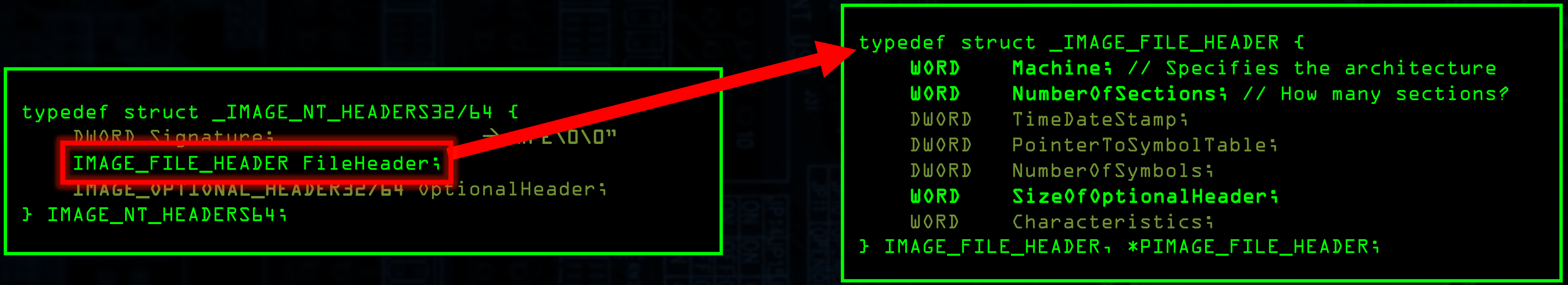
```
typedef struct _IMAGE_NT_HEADERS32/64 {
    DWORD Signature;      → Magic number „PE\0\0"
    IMAGE_FILE_HEADER FileHeader;
    IMAGE_OPTIONAL_HEADER32/64 OptionalHeader;
} IMAGE_NT_HEADERS64;
```

Let's have a look in PE-bear...

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/pe_hdr.h

# Basics of a PE file

- FileHeader: fields to remember



```
typedef struct _IMAGE_NT_HEADERS32/64 {
    DWORD Signature;                 → "PE\0\0"
    IMAGE_FILE_HEADER FileHeader;
    IMAGE_OPTIONAL_HEADER32/64 OptionalHeader;
} IMAGE_NT_HEADERS64;
```

```
typedef struct _IMAGE_FILE_HEADER {
    WORD    Machine; // Specifies the architecture
    WORD    NumberOfSections; // How many sections?
    DWORD   TimeDateStamp;
    DWORD   PointerToSymbolTable;
    DWORD   NumberOfSymbols;
    WORD    SizeOfOptionalHeader;
    WORD    Characteristics;
} IMAGE_FILE_HEADER, *PIMAGE_FILE_HEADER;
```

Let's have a look in PE-bear...

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/pe_hdr.h

# Basics of a PE file

- OptionalHeader: fields to remember

```
typedef struct _IMAGE_NT_HEADERS32/64 {
    DWORD Signature;                     → „PE\0\0"
    IMAGE_FILE_HEADER FileHeader;
    IMAGE_OPTIONAL_HEADER32/64 OptionalHeader;
} IMAGE_NT_HEADERS64;
```

```
typedef struct _IMAGE_OPTIONAL_HEADER64 {
    WORD        Magic;            // type: NT32 ? NT64?
    BYTE        MajorLinkerVersion;
    BYTE        MinorLinkerVersion;
    DWORD       SizeOfCode;
    DWORD       SizeOfInitializedData;
    DWORD       SizeOfUninitializedData;
    DWORD       AddressOfEntryPoint; // where the execution starts?
    DWORD       BaseOfCode;
    ULONGLONG   ImageBase;          //default load base
    DWORD       SectionAlignment; //unit in memory
    DWORD       FileAlignment; //unit on disk
    WORD        MajorOperatingSystemVersion;
    WORD        MinorOperatingSystemVersion;
    WORD        MajorImageVersion;
    WORD        MinorImageVersion;
    WORD        MajorSubsystemVersion;
    WORD        MinorSubsystemVersion;
    DWORD       Win32VersionValue;
    DWORD       SizeOfImage; //size of the loaded PE
    DWORD       SizeOfHeaders; //size of all the headers to map
    DWORD       CheckSum;
    WORD        Subsystem; // is it a console app? a driver? etc.
    WORD        DllCharacteristics; // features enabled
    ULONGLONG   SizeOfStackReserve;
    ULONGLONG   SizeOfStackCommit;
    ULONGLONG   SizeOfHeapReserve;
    ULONGLONG   SizeOfHeapCommit;
    DWORD       LoaderFlags;
    DWORD       NumberOfRvaAndSizes;
    IMAGE_DATA_DIRECTORY DataDirectory[DIRECTORY_ENTRIES_NUM];
} IMAGE_OPTIONAL_HEADER64;
```

Let's have a look in PE-bear...

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/pe_hdr.h

# Basics of a PE file: sections

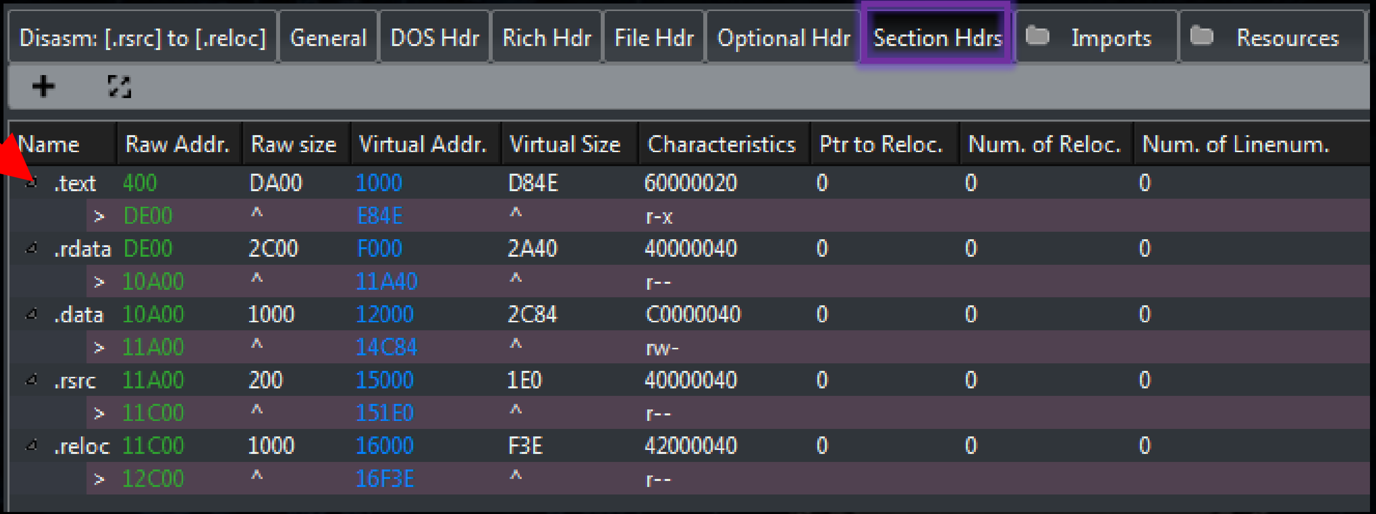
- PE is divided into sections with different permissions
- Sections introduce a logical layout of the binary, that compilers/linkers can follow
- Dividing PE on section improves security: the code is isolated from the data
- HOWEVER:
  - if DEP is disabled, page without execution permission can still be executed
  - The section containing the Entry Point will always be treated as executable

# Basics of a PE file: sections

- PE sections are defined by sections header

```
#define IMAGE_FIRST_SECTION( ntheader ) ((PIMAGE_SECTION_HEADER)  \
    ((ULONG_PTR)(ntheader) +                                       \
     FIELD_OFFSET( IMAGE_NT_HEADERS, OptionalHeader ) +            \
     ((ntheader))->FileHeader.SizeOfOptionalHeader   \
    ))
```

A macro in `winnt.h` pointing the first section

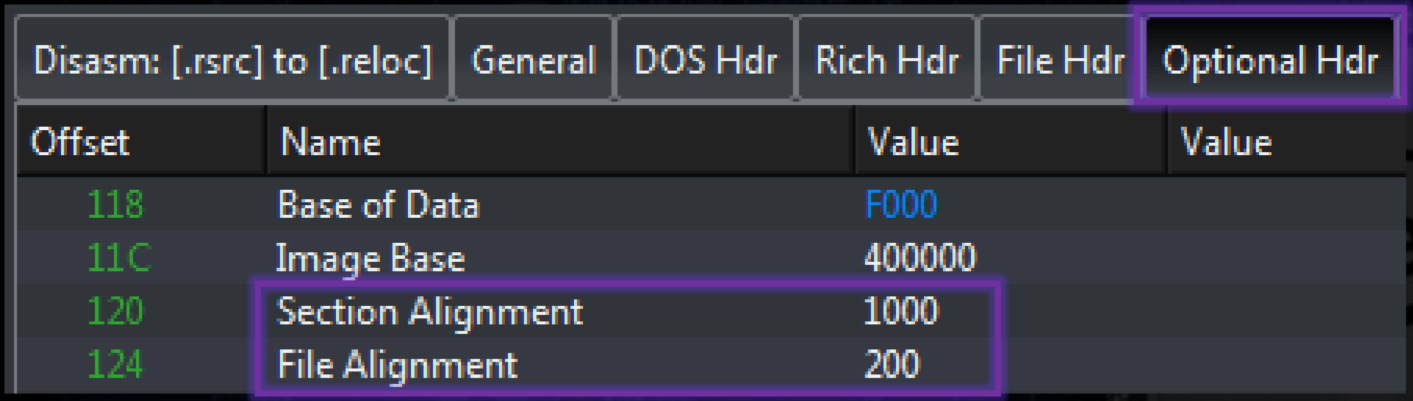


| Name | Raw Addr. | Raw size | Virtual Addr. | Virtual Size | Characteristics | Ptr to Reloc. | Num. of Reloc. | Num. of Linenum. |
|---|---|---|---|---|---|---|---|---|
| .text | 400 | DA00 | 1000 | D84E | 60000020 | 0 | 0 | 0 |
| > | DE00 | ^ | E84E | ^ | r-x | | | |
| .rdata | DE00 | 2C00 | F000 | 2A40 | 40000040 | 0 | 0 | 0 |
| > | 10A00 | ^ | 11A40 | ^ | r-- | | | |
| .data | 10A00 | 1000 | 12000 | 2C84 | C0000040 | 0 | 0 | 0 |
| > | 11A00 | ^ | 14C84 | ^ | rw- | | | |
| .rsrc | 11A00 | 200 | 15000 | 1E0 | 40000040 | 0 | 0 | 0 |
| > | 11C00 | ^ | 151E0 | ^ | r-- | | | |
| .reloc | 11C00 | 1000 | 16000 | F3E | 42000040 | 0 | 0 | 0 |
| > | 12C00 | ^ | 16F3E | ^ | r-- | | | |

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/remap.h

# Basics of a PE file: sections

- on the disk PE is stored in a raw format (the unit is defined by File Alignment)
- In memory PE is mapped to its virtual format (the unit is defined by Section Alignment) – usually of the granularity of one page (0x1000)

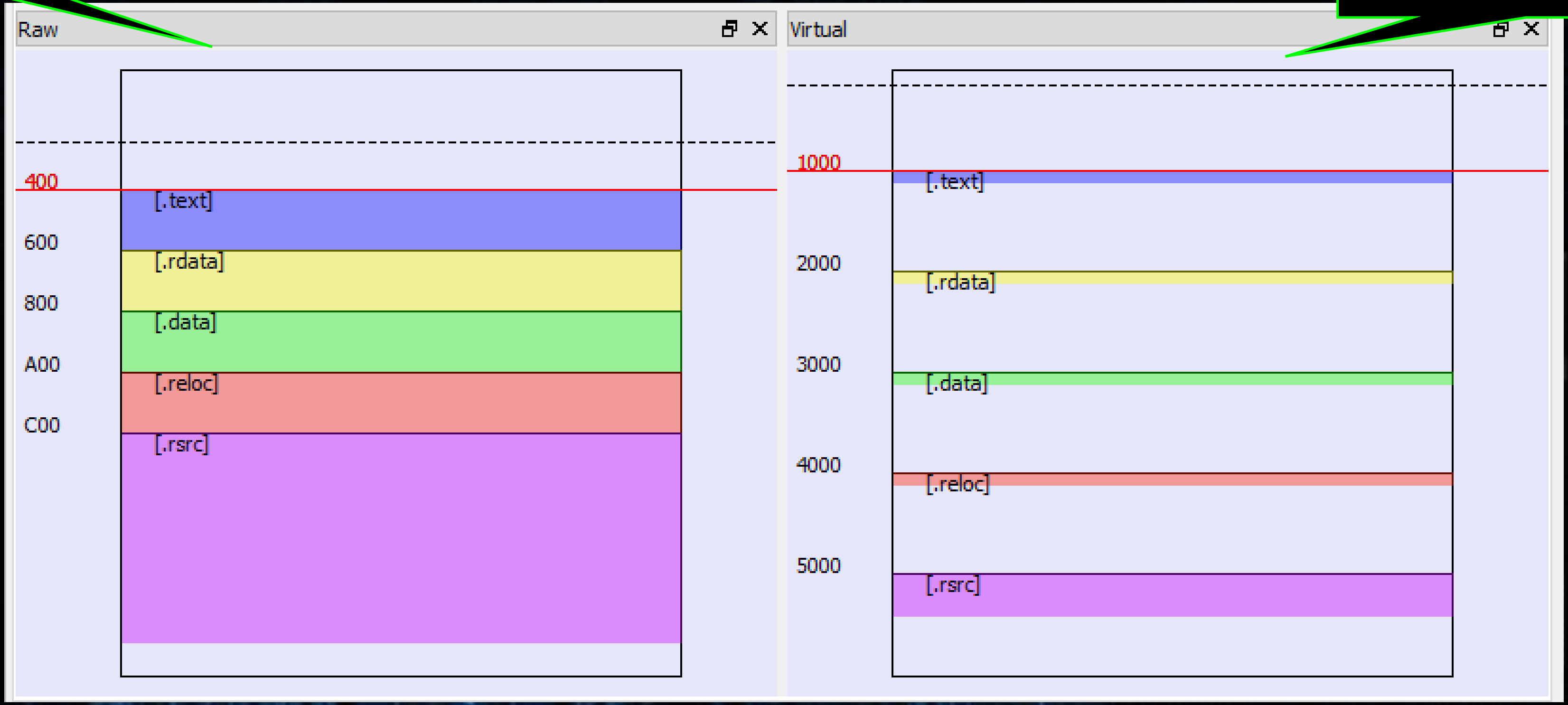


| Offset | Name | Value | Value |
|---|---|---|---|
| 118 | Base of Data | F000 | |
| 11C | Image Base | 400000 | |
| 120 | Section Alignment | 1000 | |
| 124 | File Alignment | 200 | |

# Basics of a PE file: sections

Raw
(file on the disk)

Virtual
(mapped in the process memory)



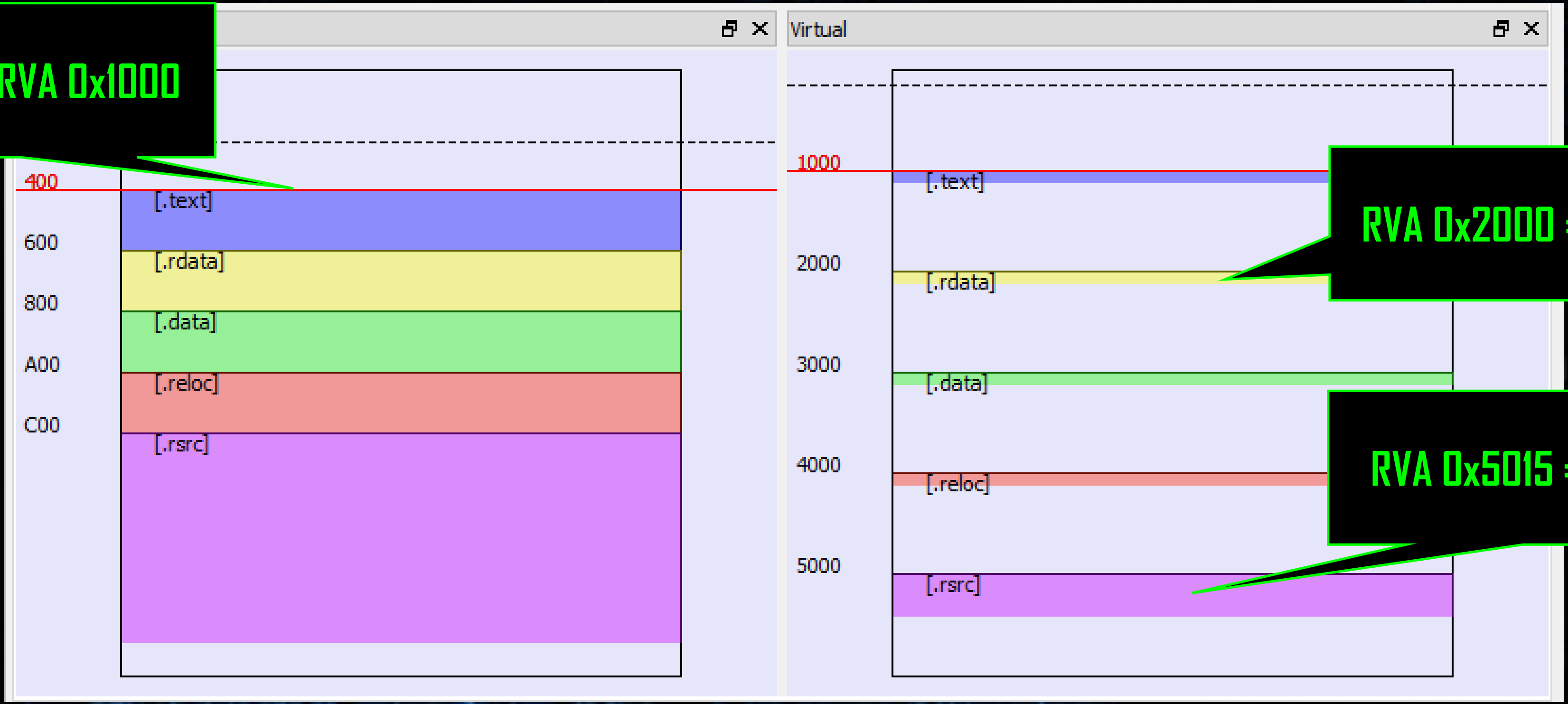
https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/remap.h

# Basics of a PE file: caves

- The space reserved for a section is always rounded up to some unit (FileAlignment in a raw format, SectionAlignment in virtual)
- The size of the actual section content may be smaller
- The additional space is unused, and filled with padding. It is called a section cave. A cave in an executable section is often referenced as code cave.
- Caves may be virtual or raw
- Sometimes they may be used for installing code implants

# Basics of a PE file: addresses

- Raw addresses (in file) usually correspond to virtual addresses (in memory) and vice versa



Raw 0x400 = RVA 0x1000

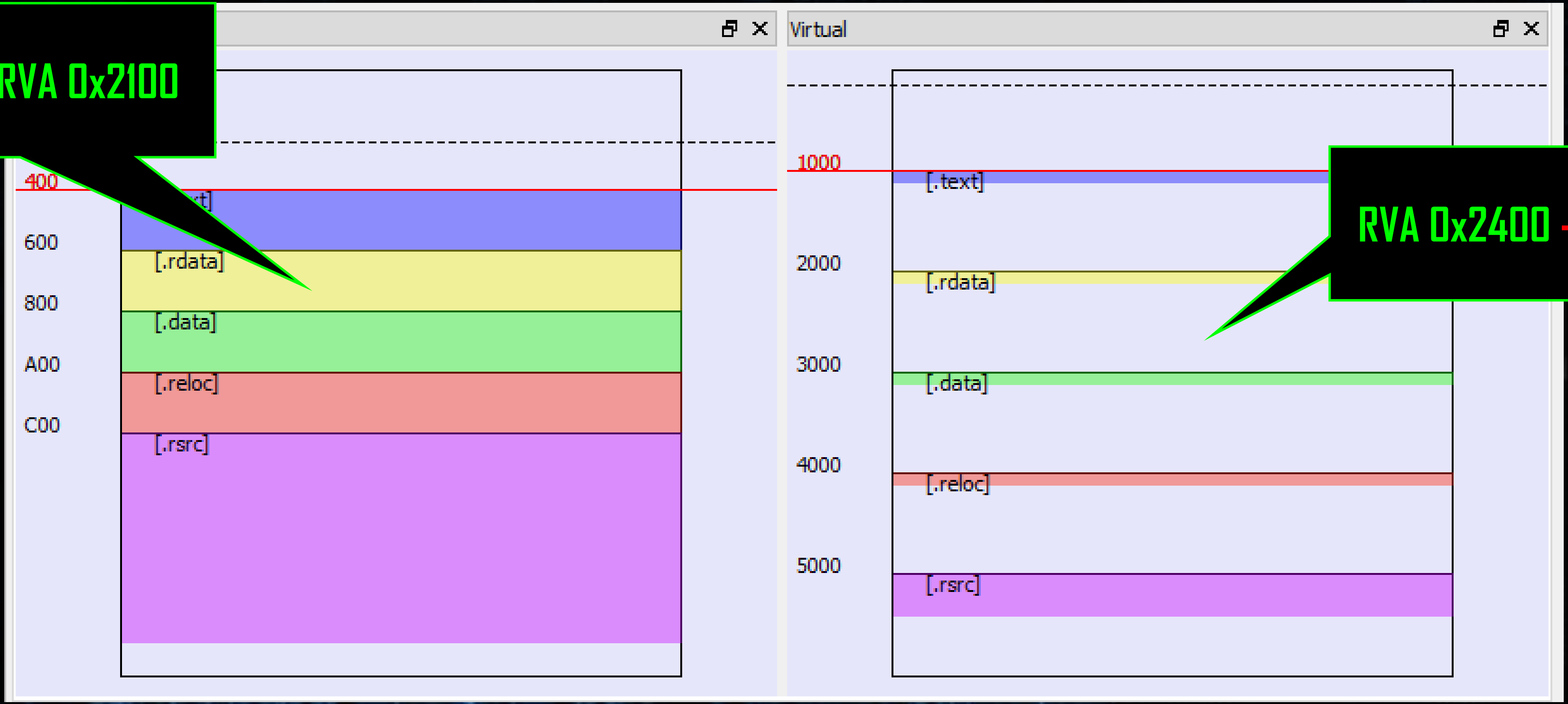
RVA 0x2000 = raw 0x600

RVA 0x5015 = raw 0xC15

- **RVA** : Relative Virtual Address (without Image Base)
- **VA**: absolute Virtual Address (with Image Base)

# Basics of a PE file: addresses

- Raw addresses (in file) *usually* correspond to virtual addresses (in memory) and vice versa



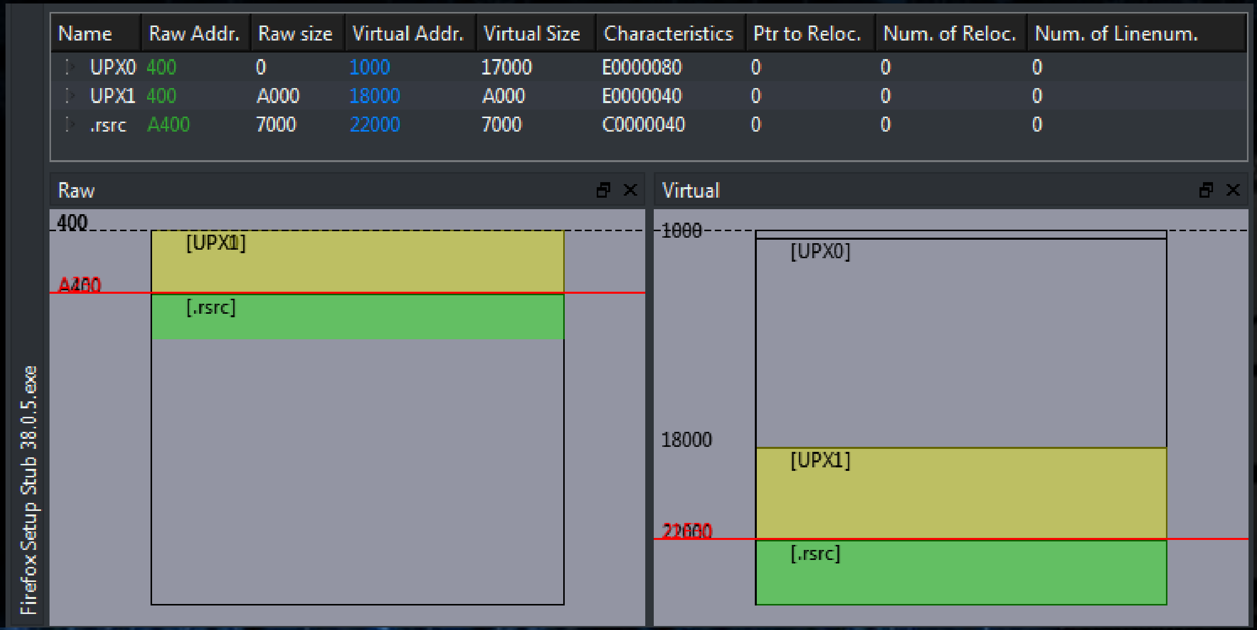
Raw 0x700 = RVA 0x2100

RVA 0x2400 -> invalid raw

- **RVA** : Relative Virtual Address (without Image Base)
- **VA**: absolute Virtual Address (with Image Base)

# Basics of a PE file: addresses

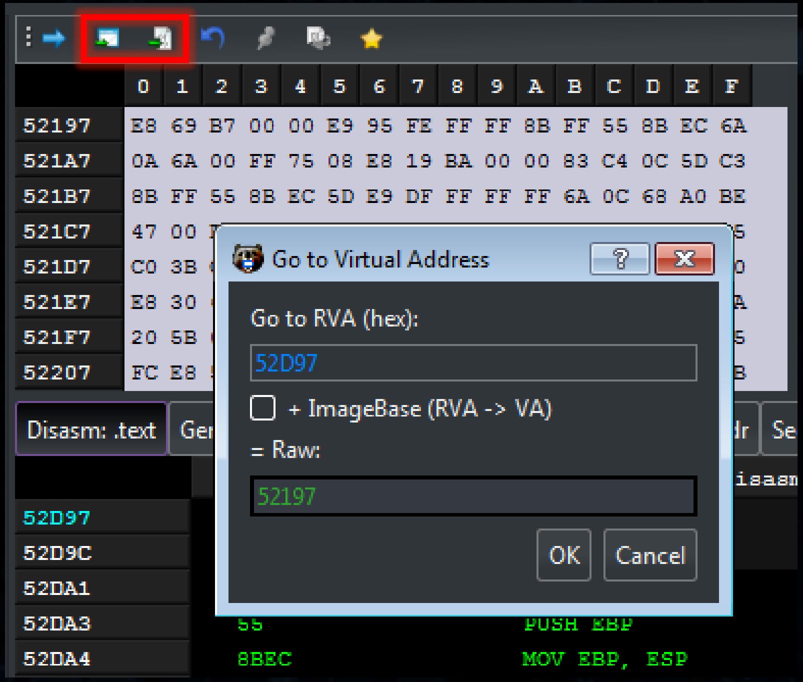
- Raw addresses (in file) *usually* correspond to virtual addresses (in memory) and vice versa
  - However:
    - Some sections can be unpacked in memory and not filled in the file
    - Some addresses may not be mapped (present in the file, but not in the memory image)



| Name | Raw Addr. | Raw size | Virtual Addr. | Virtual Size | Characteristics | Ptr to Reloc. | Num. of Reloc. | Num. of Linenum. |
|---|---|---|---|---|---|---|---|---|
| UPX0 | 400 | 0 | 1000 | 17000 | E0000080 | 0 | 0 | 0 |
| UPX1 | 400 | A000 | 18000 | A000 | E0000040 | 0 | 0 | 0 |
| .rsrc | A400 | 7000 | 22000 | 7000 | C0000040 | 0 | 0 | 0 |

# Basics of a PE file: addresses

- Let's open one of our sample PEs in PE-bear and see the section table
- Try converting various addresses from Raw format to Virtual, follow and observe



```
        0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
52197   E8 69 B7 00 00 E9 95 FE FF FF 8B FF 55 8B EC 6A
521A7   0A 6A 00 FF 75 08 E8 19 BA 00 00 83 C4 0C 5D C3
521B7   8B FF 55 8B EC 5D E9 DF FF FF FF 6A 0C 68 A0 BE
521C7   47 00                                         5
521D7   C0 3B                                         0
521E7   E8 30                                         A
521F7   20 5B                                         5
52207   FC E8                                         B
```

Go to Virtual Address

Go to RVA (hex): 52D97

☐ + ImageBase (RVA -> VA)

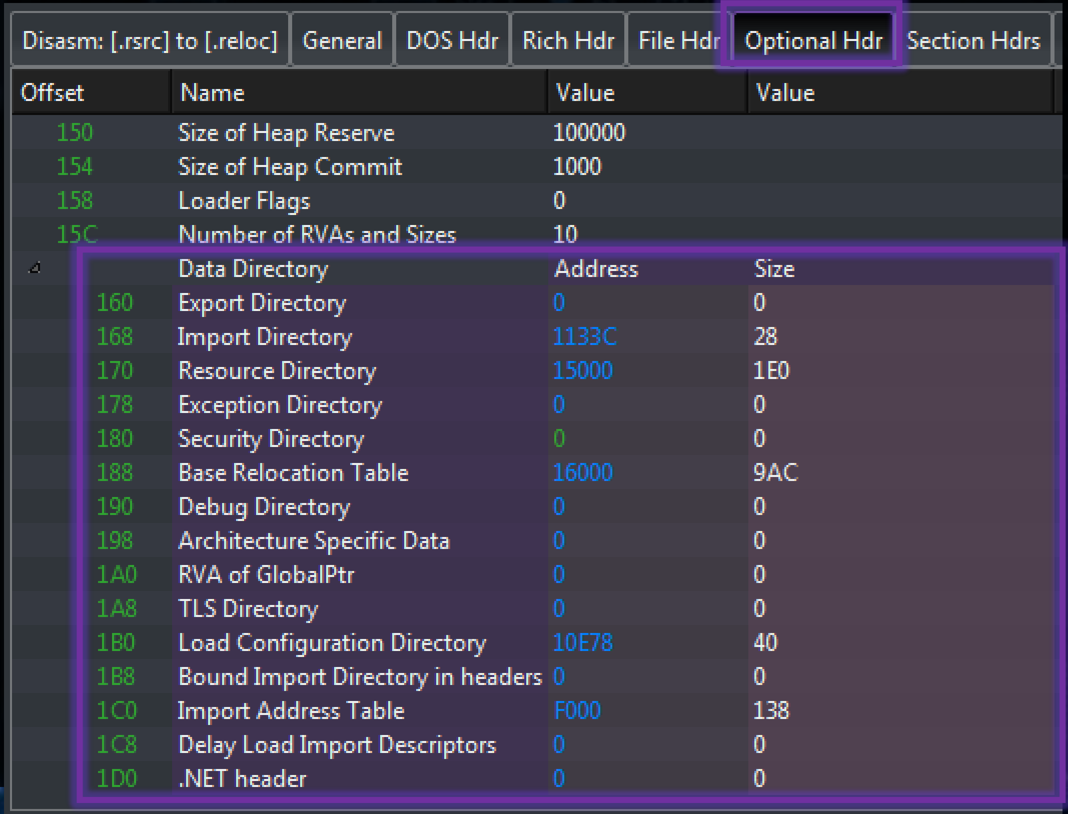
= Raw: 52197

```
52D97
52D9C
52DA1
52DA3   55       PUSH EBP
52DA4   8BEC     MOV EBP, ESP
```

Exercise time...

# Basics of a PE file

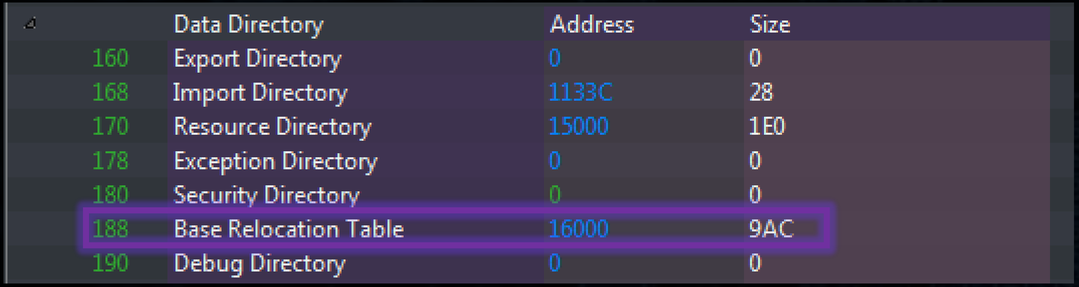
- The most information lies in data directories



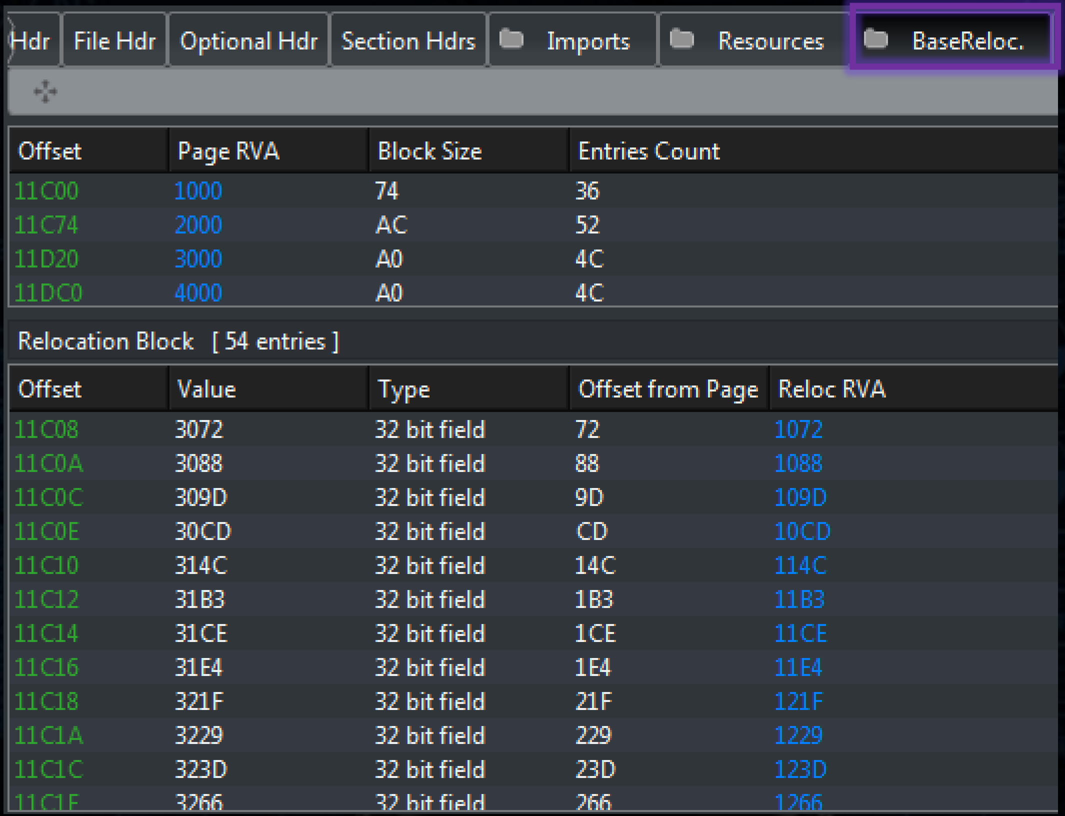
| Offset | Name | Value | Value |
|---|---|---|---|
| 150 | Size of Heap Reserve | 100000 | |
| 154 | Size of Heap Commit | 1000 | |
| 158 | Loader Flags | 0 | |
| 15C | Number of RVAs and Sizes | 10 | |
| | Data Directory | Address | Size |
| 160 | Export Directory | 0 | 0 |
| 168 | Import Directory | 1133C | 28 |
| 170 | Resource Directory | 15000 | 1E0 |
| 178 | Exception Directory | 0 | 0 |
| 180 | Security Directory | 0 | 0 |
| 188 | Base Relocation Table | 16000 | 9AC |
| 190 | Debug Directory | 0 | 0 |
| 198 | Architecture Specific Data | 0 | 0 |
| 1A0 | RVA of GlobalPtr | 0 | 0 |
| 1A8 | TLS Directory | 0 | 0 |
| 1B0 | Load Configuration Directory | 10E78 | 40 |
| 1B8 | Bound Import Directory in headers | 0 | 0 |
| 1C0 | Import Address Table | F000 | 138 |
| 1C8 | Delay Load Import Descriptors | 0 | 0 |
| 1D0 | .NET header | 0 | 0 |

# Basics of a PE file: Relocation

- Relocation Table



| | Data Directory | Address | Size |
|---|---|---|---|
| 160 | Export Directory | 0 | 0 |
| 168 | Import Directory | 1133C | 28 |
| 170 | Resource Directory | 15000 | 1E0 |
| 178 | Exception Directory | 0 | 0 |
| 180 | Security Directory | 0 | 0 |
| 188 | Base Relocation Table | 16000 | 9AC |
| 190 | Debug Directory | 0 | 0 |



| Offset | Page RVA | Block Size | Entries Count |
|---|---|---|---|
| 11C00 | 1000 | 74 | 36 |
| 11C74 | 2000 | AC | 52 |
| 11D20 | 3000 | A0 | 4C |
| 11DC0 | 4000 | A0 | 4C |

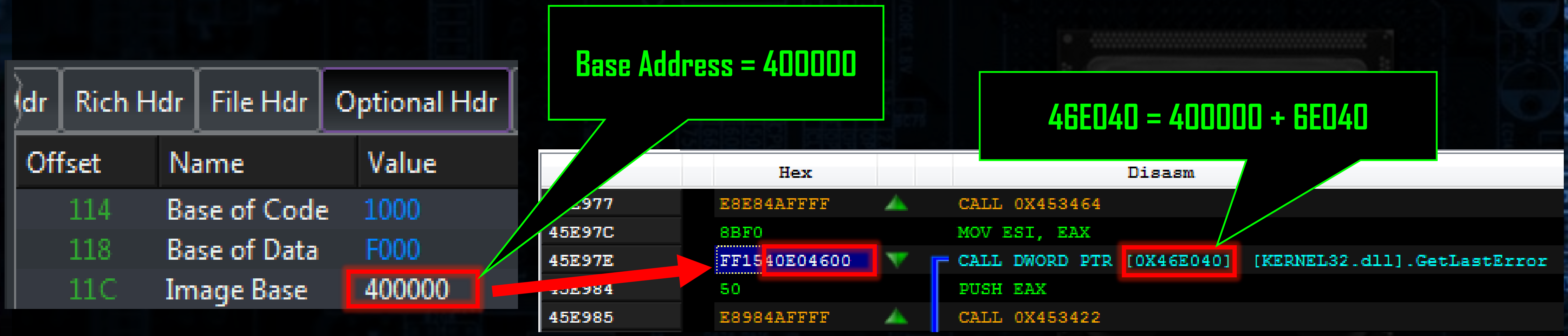
Relocation Block [ 54 entries ]

| Offset | Value | Type | Offset from Page | Reloc RVA |
|---|---|---|---|---|
| 11C08 | 3072 | 32 bit field | 72 | 1072 |
| 11C0A | 3088 | 32 bit field | 88 | 1088 |
| 11C0C | 309D | 32 bit field | 9D | 109D |
| 11C0E | 30CD | 32 bit field | CD | 10CD |
| 11C10 | 314C | 32 bit field | 14C | 114C |
| 11C12 | 31B3 | 32 bit field | 1B3 | 11B3 |
| 11C14 | 31CE | 32 bit field | 1CE | 11CE |
| 11C16 | 31E4 | 32 bit field | 1E4 | 11E4 |
| 11C18 | 321F | 32 bit field | 21F | 121F |
| 11C1A | 3229 | 32 bit field | 229 | 1229 |
| 11C1C | 323D | 32 bit field | 23D | 123D |
| 11C1E | 3266 | 32 bit field | 266 | 1266 |

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/relocate.h

# Basics of a PE file: Relocation

1. PE comes with some default base address in the header
2. All the absolute addresses inside the PE assume that it was loaded at this base



| Offset | Name | Value |
|---|---|---|
| 114 | Base of Code | 1000 |
| 118 | Base of Data | F000 |
| 11C | Image Base | 400000 |

Base Address = 400000

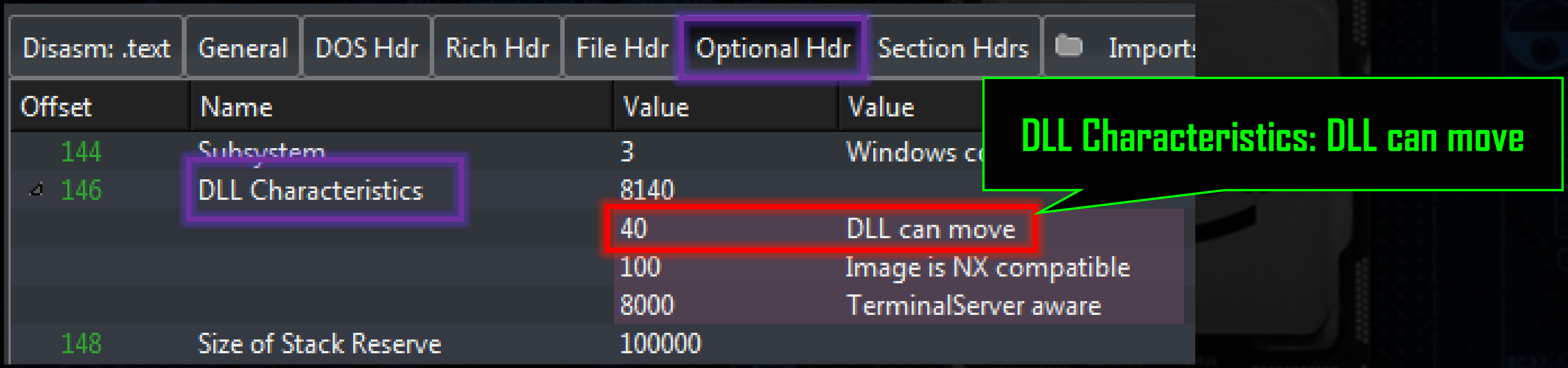
46E040 = 400000 + 6E040

```
         Hex                   Disasm
E977     E8E84AFFFF            CALL 0X453464
45E97C   8BF0                  MOV ESI, EAX
45E97E   FF1540E04600          CALL DWORD PTR [0X46E040]  [KERNEL32.dll].GetLastError
45E984   50                    PUSH EAX
45E985   E8984AFFFF            CALL 0X453422
```

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/relocate.h

# Basics of a PE file: Relocation

- In the past EXEs were usually loaded at their default base (only DLLs didn't have to)
- Nowadays most PEs load at a dynamic base (due to ASLR)
- A flag in the header determines if a dynamic base will be used



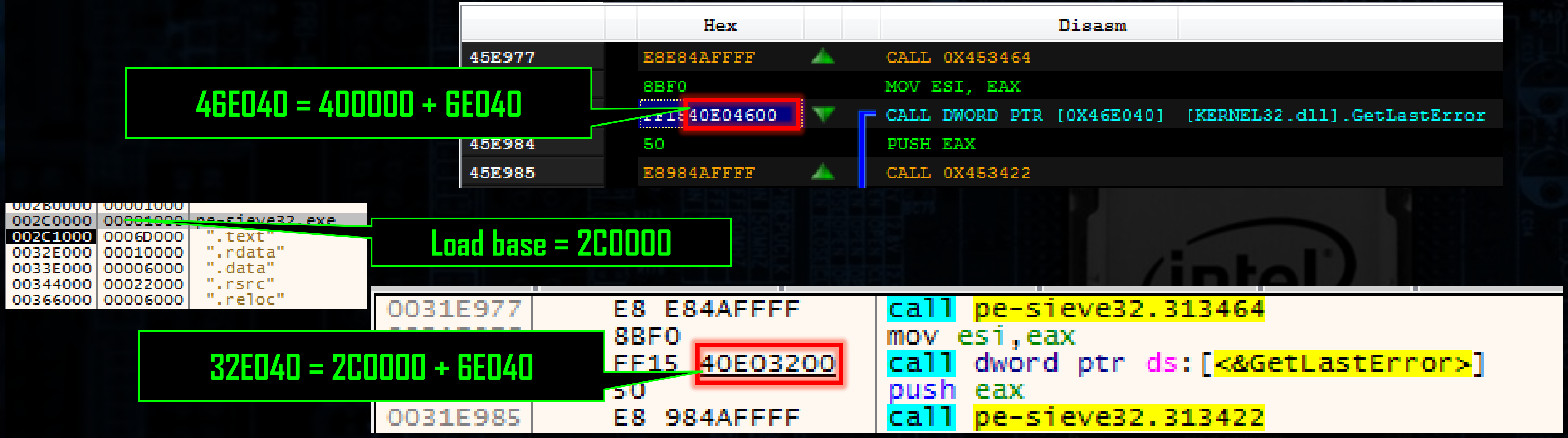
| Offset | Name | Value | Value |
|---|---|---|---|
| 144 | Subsystem | 3 | Windows c |
| 146 | DLL Characteristics | 8140 | |
| | | 40 | DLL can move |
| | | 100 | Image is NX compatible |
| | | 8000 | TerminalServer aware |
| 148 | Size of Stack Reserve | 100000 | |

DLL Characteristics: DLL can move

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/relocate.h

# Basics of a PE file: Relocation

- If the PE was loaded at a different base than the one defined in the header, all its fields using absolute addresses must be recalculated (rebased)



```
              Hex                        Disasm
45E977        E8E84AFFFF                 CALL 0X453464
              8BF0                       MOV ESI, EAX
              FF15 40E04600              CALL DWORD PTR [0X46E040]  [KERNEL32.dll].GetLastError
45E984        50                         PUSH EAX
45E985        E8984AFFFF                 CALL 0X453422
```

46E040 = 400000 + 6E040

```
002B0000  00001000
002C0000  00001000  pe-sieve32.exe
002C1000  0006D000   ".text"
0032E000  00010000   ".rdata"
0033E000  00006000   ".data"
00344000  00022000   ".rsrc"
00366000  00006000   ".reloc"
```

Load base = 2C0000

```
0031E977   E8 E84AFFFF     call pe-sieve32.313464
           8BF0            mov esi,eax
           FF15 40E03200   call dword ptr ds:[<&GetLastError>]
           50              push eax
0031E985   E8 984AFFFF     call pe-sieve32.313422
```

32E040 = 2C0000 + 6E040

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/relocate.h

# Basics of a PE file: Relocation

- How does PE know **where** are the fields that needs to be **rebased**?

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/relocate.h

# Basics of a PE file: Relocation

- How does PE know **where** are the fields that needs to be **rebased**?
- They are listed in the Relocation Table!

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/relocate.h

# Basics of a PE file: Relocation

- Let's open one of our sample PEs in PE-bear and see the relocation table
- Check the code snippet to see how the relocation table is processed

Exercise time...

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/relocate.h

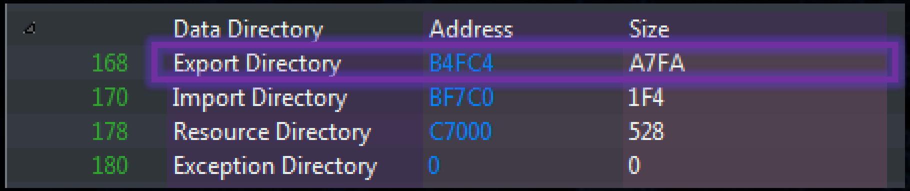
# Basics of a PE file:
# Imports & Exports

Most executables use some functions exported by other modules (external libraries)

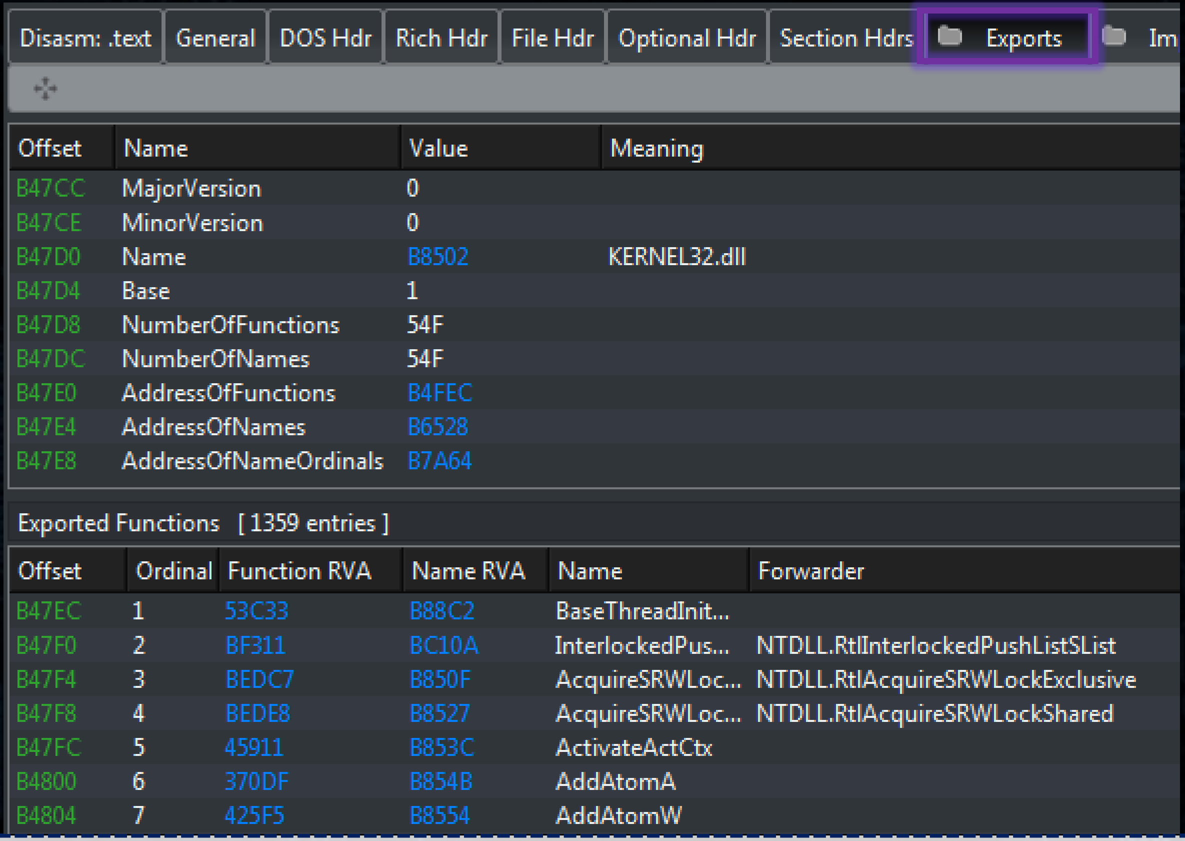
1. If we use a static library, the linker will automatically add the external code into our PE
2. If we use a dynamic library (DLL), the used functions will be listed in the Import Table of our PE, and dynamic linking will be done when the PE is loaded
3. Alternatively, we can load a DLL by ourselves using `LoadLibrary` and fetch the exported function via `GetProcessAddress`

# Basics of a PE file: Exports

- Export Table



| | Data Directory | Address | Size |
|---|---|---|---|
| 168 | Export Directory | B4FC4 | A7FA |
| 170 | Import Directory | BF7C0 | 1F4 |
| 178 | Resource Directory | C7000 | 528 |
| 180 | Exception Directory | 0 | 0 |



| Offset | Name | Value | Meaning |
|---|---|---|---|
| B47CC | MajorVersion | 0 | |
| B47CE | MinorVersion | 0 | |
| B47D0 | Name | B8502 | KERNEL32.dll |
| B47D4 | Base | 1 | |
| B47D8 | NumberOfFunctions | 54F | |
| B47DC | NumberOfNames | 54F | |
| B47E0 | AddressOfFunctions | B4FEC | |
| B47E4 | AddressOfNames | B6528 | |
| B47E8 | AddressOfNameOrdinals | B7A64 | |

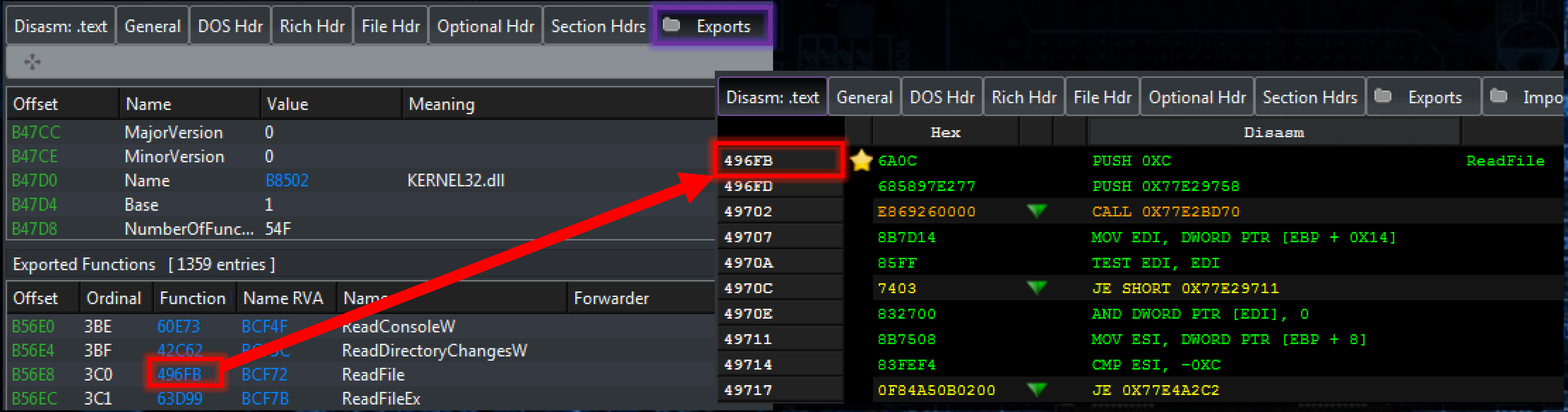
Exported Functions [ 1359 entries ]

| Offset | Ordinal | Function RVA | Name RVA | Name | Forwarder |
|---|---|---|---|---|---|
| B47EC | 1 | 53C33 | B88C2 | BaseThreadInit... | |
| B47F0 | 2 | BF311 | BC10A | InterlockedPus... | NTDLL.RtlInterlockedPushListSList |
| B47F4 | 3 | BEDC7 | B850F | AcquireSRWLoc... | NTDLL.RtlAcquireSRWLockExclusive |
| B47F8 | 4 | BEDE8 | B8527 | AcquireSRWLoc... | NTDLL.RtlAcquireSRWLockShared |
| B47FC | 5 | 45911 | B853C | ActivateActCtx | |
| B4800 | 6 | 370DF | B854B | AddAtomA | |
| B4804 | 7 | 425F5 | B8554 | AddAtomW | |

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/export_lookup.h

# Basics of a PE file: Exports

1. DLLs are libraries of functions for other PEs to use
2. An Export Table is a catalogue allowing to find and use a particular function



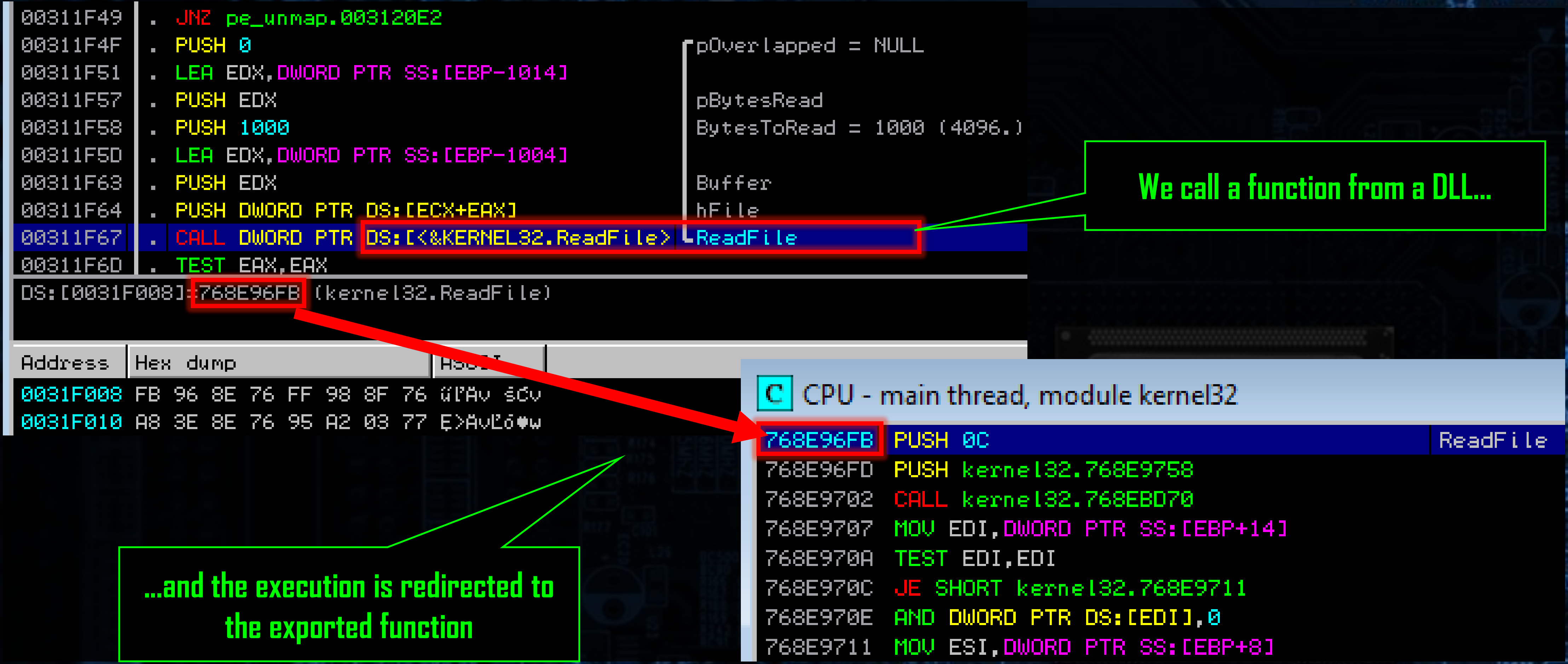
| Offset | Name | Value | Meaning |
|---|---|---|---|
| B47CC | MajorVersion | 0 | |
| B47CE | MinorVersion | 0 | |
| B47D0 | Name | B8502 | KERNEL32.dll |
| B47D4 | Base | 1 | |
| B47D8 | NumberOfFunc... | 54F | |

Exported Functions [ 1359 entries ]

| Offset | Ordinal | Function | Name RVA | Name | Forwarder |
|---|---|---|---|---|---|
| B56E0 | 3BE | 60E73 | BCF4F | ReadConsoleW | |
| B56E4 | 3BF | 42C62 | [illegible] | ReadDirectoryChangesW | |
| B56E8 | 3C0 | 496FB | BCF72 | ReadFile | |
| B56EC | 3C1 | 63D99 | BCF7B | ReadFileEx | |

```
        Hex                  Disasm
496FB   6A0C                 PUSH 0XC                              ReadFile
496FD   685897E277           PUSH 0X77E29758
49702   E869260000           CALL 0X77E2BD70
49707   8B7D14               MOV EDI, DWORD PTR [EBP + 0X14]
4970A   85FF                 TEST EDI, EDI
4970C   7403                 JE SHORT 0X77E29711
4970E   832700               AND DWORD PTR [EDI], 0
49711   8B7508               MOV ESI, DWORD PTR [EBP + 8]
49714   83FEF4               CMP ESI, -0XC
49717   0F84A50B0200         JE 0X77E4A2C2
```

# Basics of a PE file: Exports



```
00311F49 . JNZ pe_unmap.003120E2
00311F4F . PUSH 0                                  ┌pOverlapped = NULL
00311F51 . LEA EDX,DWORD PTR SS:[EBP-1014]         │
00311F57 . PUSH EDX                                │pBytesRead
00311F58 . PUSH 1000                               │BytesToRead = 1000 (4096.)
00311F5D . LEA EDX,DWORD PTR SS:[EBP-1004]         │
00311F63 . PUSH EDX                                │Buffer
00311F64 . PUSH DWORD PTR DS:[ECX+EAX]             │hFile
00311F67 . CALL DWORD PTR DS:[<&KERNEL32.ReadFile> └ReadFile
00311F6D . TEST EAX,EAX
DS:[0031F008]=768E96FB (kernel32.ReadFile)

Address  Hex dump                 ASCII
0031F008 FB 96 8E 76 FF 98 8F 76  űľÄv šĆv
0031F010 A8 3E 8E 76 95 A2 03 77  Ę>ÄvĽó♥w
```

We call a function from a DLL...

CPU - main thread, module kernel32

```
768E96FB PUSH 0C                              ReadFile
768E96FD PUSH kernel32.768E9758
768E9702 CALL kernel32.768EBD70
768E9707 MOV EDI,DWORD PTR SS:[EBP+14]
768E970A TEST EDI,EDI
768E970C JE SHORT kernel32.768E9711
768E970E AND DWORD PTR DS:[EDI],0
768E9711 MOV ESI,DWORD PTR SS:[EBP+8]
```

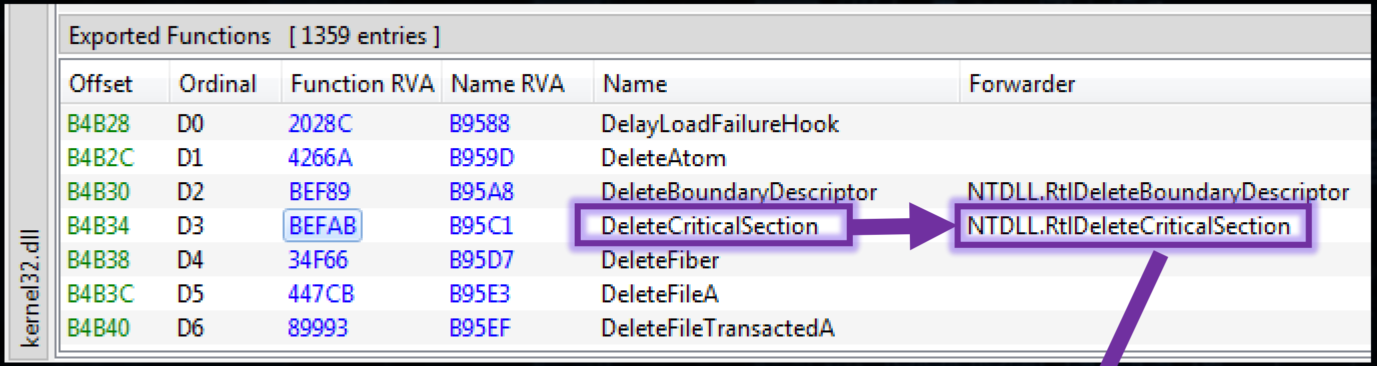
...and the execution is redirected to the exported function

# Basics of a PE file: Exports

1. Functions can be exported by a name or by ordinal (a number)
2. Some exports can be forwarded (pointing to other functions, in other DLLs)

# Basics of a PE file: Exports

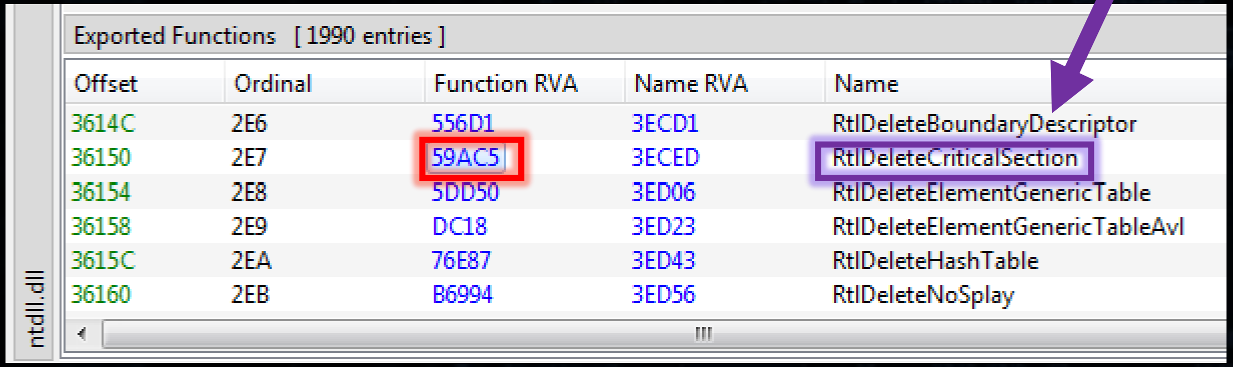
- Forwarded functions



kernel32.dll

Exported Functions [ 1359 entries ]

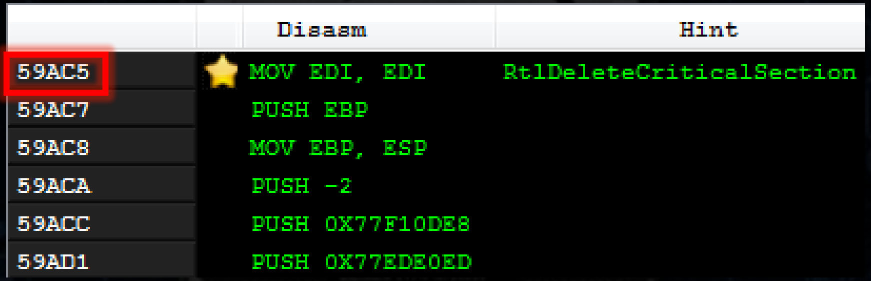
| Offset | Ordinal | Function RVA | Name RVA | Name | Forwarder |
|---|---|---|---|---|---|
| B4B28 | D0 | 2028C | B9588 | DelayLoadFailureHook | |
| B4B2C | D1 | 4266A | B959D | DeleteAtom | |
| B4B30 | D2 | BEF89 | B95A8 | DeleteBoundaryDescriptor | NTDLL.RtlDeleteBoundaryDescriptor |
| B4B34 | D3 | BEFAB | B95C1 | DeleteCriticalSection | NTDLL.RtlDeleteCriticalSection |
| B4B38 | D4 | 34F66 | B95D7 | DeleteFiber | |
| B4B3C | D5 | 447CB | B95E3 | DeleteFileA | |
| B4B40 | D6 | 89993 | B95EF | DeleteFileTransactedA | |



ntdll.dll

Exported Functions [ 1990 entries ]

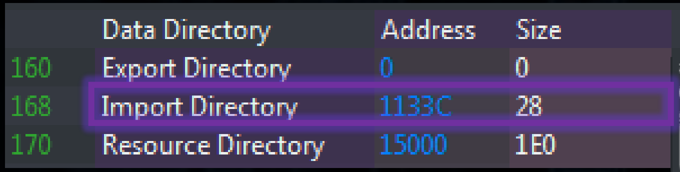
| Offset | Ordinal | Function RVA | Name RVA | Name |
|---|---|---|---|---|
| 3614C | 2E6 | 556D1 | 3ECD1 | RtlDeleteBoundaryDescriptor |
| 36150 | 2E7 | 59AC5 | 3ECED | RtlDeleteCriticalSection |
| 36154 | 2E8 | 5DD50 | 3ED06 | RtlDeleteElementGenericTable |
| 36158 | 2E9 | DC18 | 3ED23 | RtlDeleteElementGenericTableAvl |
| 3615C | 2EA | 76E87 | 3ED43 | RtlDeleteHashTable |
| 36160 | 2EB | B6994 | 3ED56 | RtlDeleteNoSplay |



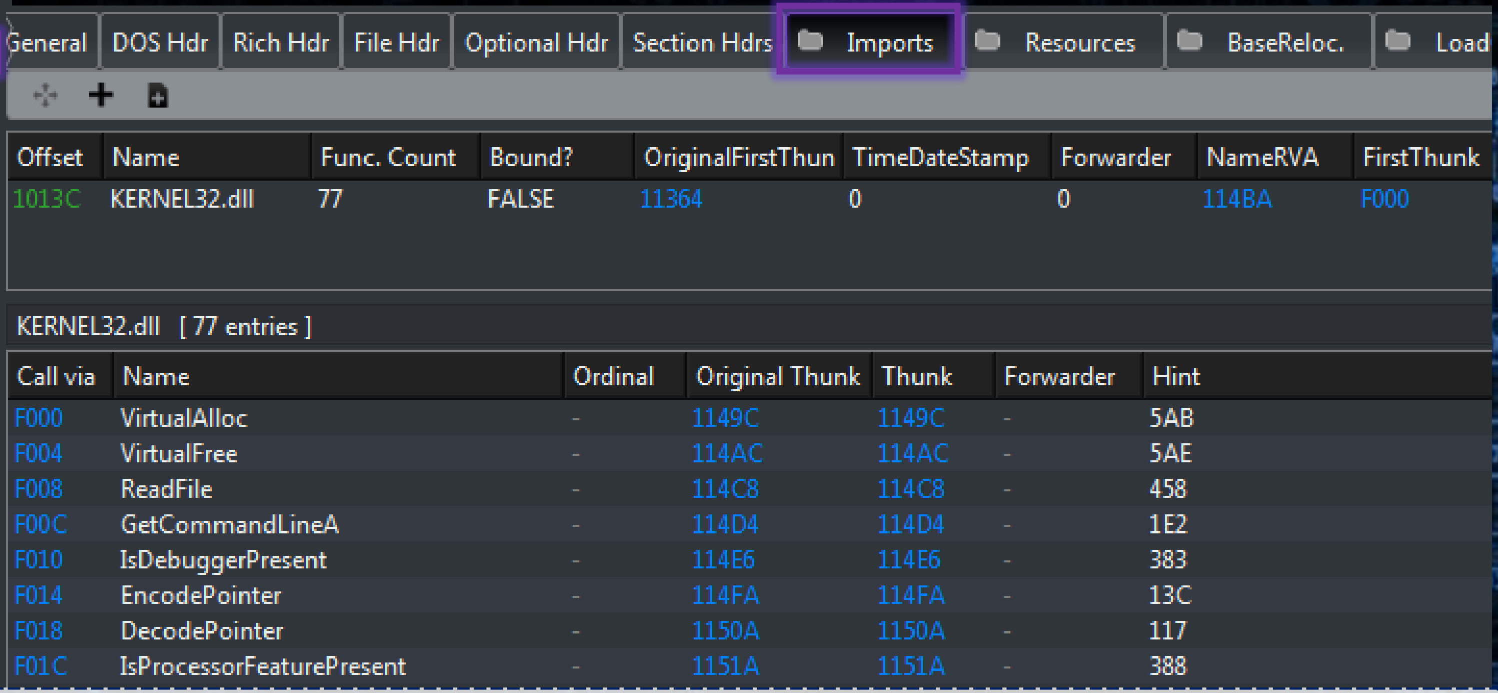
| | Disasm | Hint |
|---|---|---|
| 59AC5 | ⭐ MOV EDI, EDI | RtlDeleteCriticalSection |
| 59AC7 | PUSH EBP | |
| 59AC8 | MOV EBP, ESP | |
| 59ACA | PUSH -2 | |
| 59ACC | PUSH 0X77F10DE8 | |
| 59AD1 | PUSH 0X77EDE0ED | |

# Basics of a PE file: Imports

- Import Table



| | Data Directory | Address | Size |
|---|---|---|---|
| 160 | Export Directory | 0 | 0 |
| 168 | Import Directory | 1133C | 28 |
| 170 | Resource Directory | 15000 | 1E0 |



| Offset | Name | Func. Count | Bound? | OriginalFirstThun | TimeDateStamp | Forwarder | NameRVA | FirstThunk |
|---|---|---|---|---|---|---|---|---|
| 1013C | KERNEL32.dll | 77 | FALSE | 11364 | 0 | 0 | 114BA | F000 |

KERNEL32.dll [ 77 entries ]

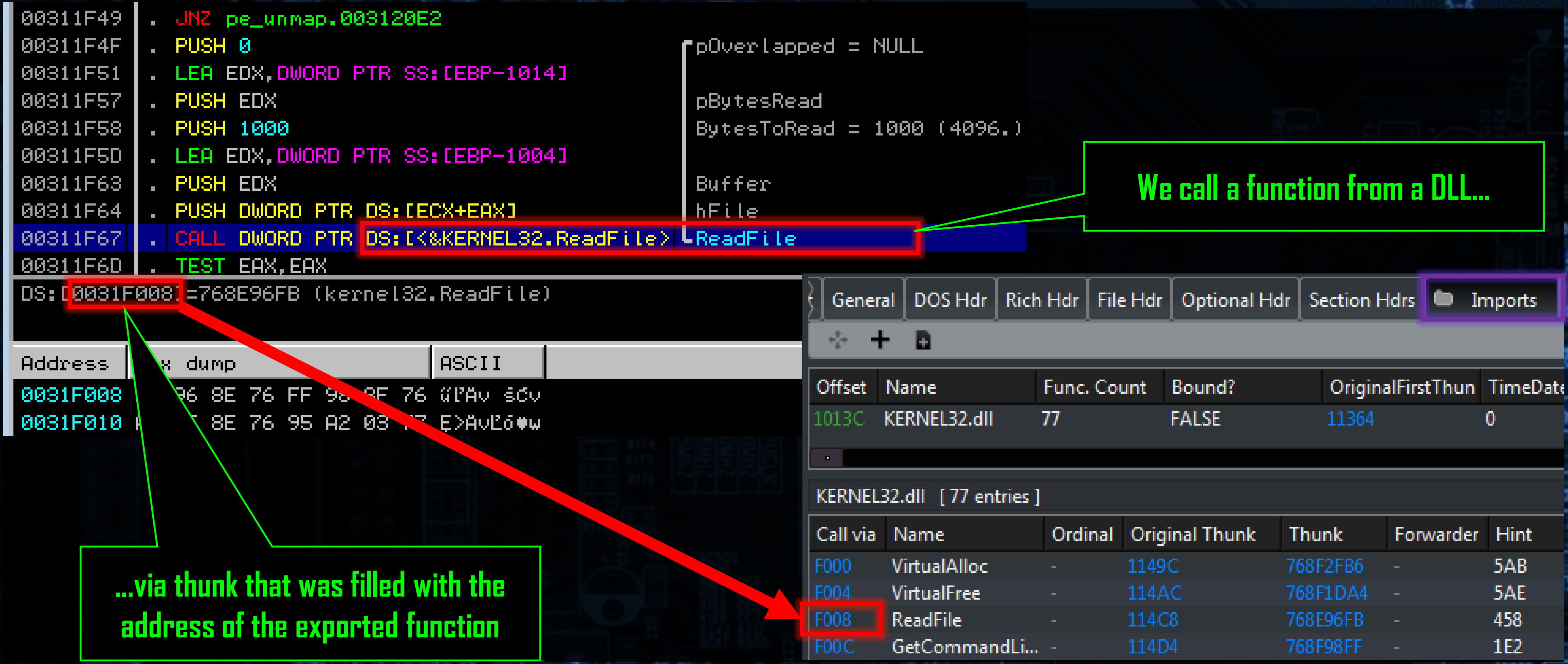
| Call via | Name | Ordinal | Original Thunk | Thunk | Forwarder | Hint |
|---|---|---|---|---|---|---|
| F000 | VirtualAlloc | - | 1149C | 1149C | - | 5AB |
| F004 | VirtualFree | - | 114AC | 114AC | - | 5AE |
| F008 | ReadFile | - | 114C8 | 114C8 | - | 458 |
| F00C | GetCommandLineA | - | 114D4 | 114D4 | - | 1E2 |
| F010 | IsDebuggerPresent | - | 114E6 | 114E6 | - | 383 |
| F014 | EncodePointer | - | 114FA | 114FA | - | 13C |
| F018 | DecodePointer | - | 1150A | 1150A | - | 117 |
| F01C | IsProcessorFeaturePresent | - | 1151A | 1151A | - | 388 |

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/imports_load.h

# Basics of a PE file: Imports

- Dynamic linking is done when a PE is loaded
- The loader walks through the Import Table of the PE
  - loads needed DLLs
  - searches the imported functions in the export table of the DLL
  - fills the thunks via which the PE is going to make calls to the exported functions with appropriate addresses

# Basics of a PE file: Imports



```
00311F49  .  JNZ pe_unmap.003120E2
00311F4F  .  PUSH 0                                    ┌pOverlapped = NULL
00311F51  .  LEA EDX,DWORD PTR SS:[EBP-1014]           │
00311F57  .  PUSH EDX                                  │pBytesRead
00311F58  .  PUSH 1000                                 │BytesToRead = 1000 (4096.)
00311F5D  .  LEA EDX,DWORD PTR SS:[EBP-1004]           │
00311F63  .  PUSH EDX                                  │Buffer
00311F64  .  PUSH DWORD PTR DS:[ECX+EAX]               │hFile
00311F67  .  CALL DWORD PTR DS:[<&KERNEL32.ReadFile>   └ReadFile
00311F6D  .  TEST EAX,EAX
DS:[0031F008]=768E96FB (kernel32.ReadFile)

Address   x dump                    ASCII
0031F008     96 8E 76 FF 9   F 76   űľAv šČv
0031F010       8E 76 95 A2 03       Ę>AvĽó●w
```

| Offset | Name | Func. Count | Bound? | OriginalFirstThun | TimeDate |
|---|---|---|---|---|---|
| 1013C | KERNEL32.dll | 77 | FALSE | 11364 | 0 |

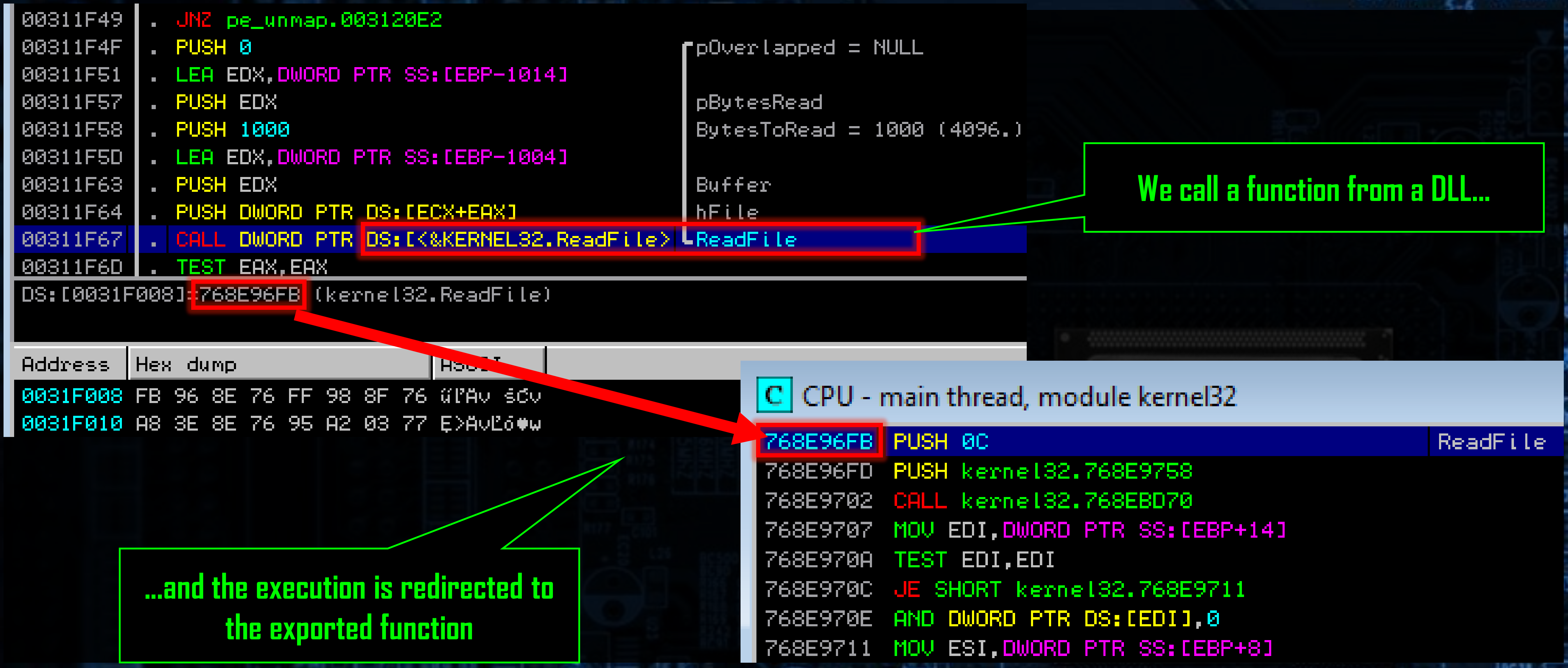
KERNEL32.dll [ 77 entries ]

| Call via | Name | Ordinal | Original Thunk | Thunk | Forwarder | Hint |
|---|---|---|---|---|---|---|
| F000 | VirtualAlloc | - | 1149C | 768F2FB6 | - | 5AB |
| F004 | VirtualFree | - | 114AC | 768F1DA4 | - | 5AE |
| F008 | ReadFile | - | 114C8 | 768E96FB | - | 458 |
| F00C | GetCommandLi... | - | 114D4 | 768F98FF | - | 1E2 |

We call a function from a DLL...

...via thunk that was filled with the address of the exported function

# Basics of a PE file: Imports



```
00311F49 | . JNZ pe_unmap.003120E2
00311F4F | . PUSH 0                                 ┌pOverlapped = NULL
00311F51 | . LEA EDX,DWORD PTR SS:[EBP-1014]        │
00311F57 | . PUSH EDX                               │pBytesRead
00311F58 | . PUSH 1000                              │BytesToRead = 1000 (4096.)
00311F5D | . LEA EDX,DWORD PTR SS:[EBP-1004]        │
00311F63 | . PUSH EDX                               │Buffer
00311F64 | . PUSH DWORD PTR DS:[ECX+EAX]            │hFile
00311F67 | . CALL DWORD PTR DS:[<&KERNEL32.ReadFile> └ReadFile
00311F6D | . TEST EAX,EAX
DS:[0031F008]=768E96FB (kernel32.ReadFile)

Address  Hex dump                 ASCII
0031F008 FB 96 8E 76 FF 98 8F 76 ûľAv śCv
0031F010 A8 3E 8E 76 95 A2 03 77 Ę>AvĽó♥w
```

We call a function from a DLL…

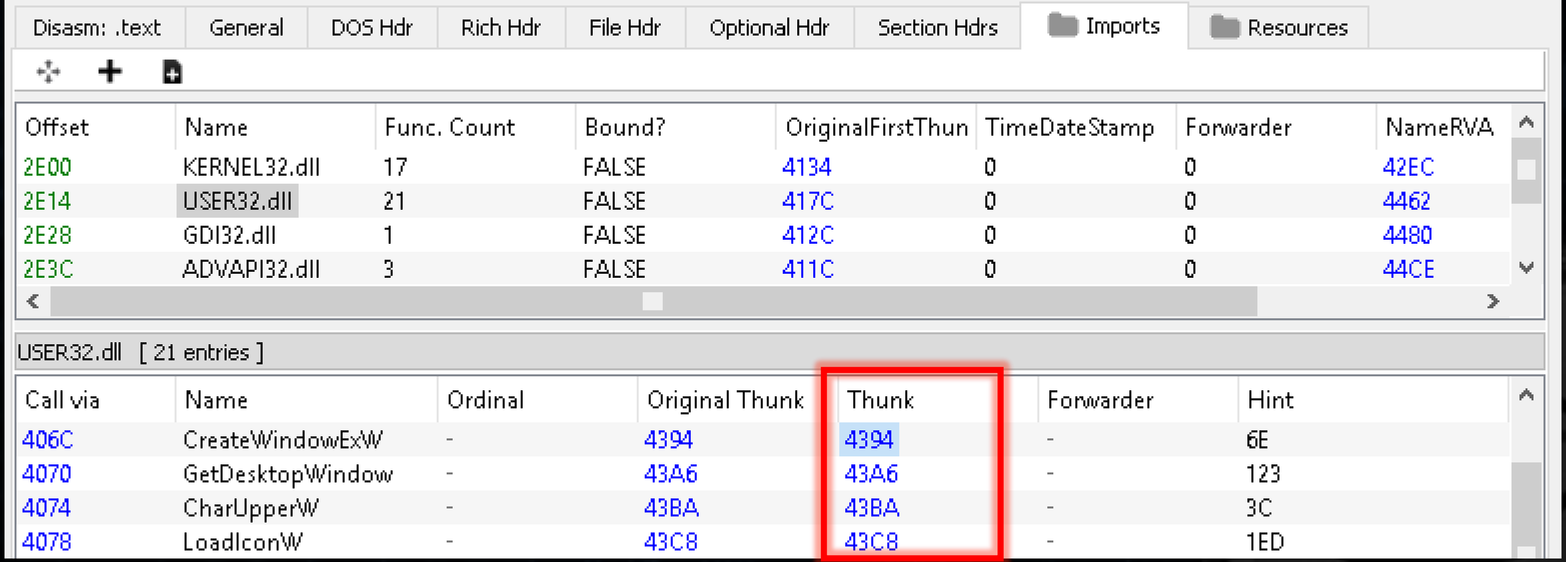
CPU - main thread, module kernel32

```
768E96FB  PUSH 0C                             ReadFile
768E96FD  PUSH kernel32.768E9758
768E9702  CALL kernel32.768EBD70
768E9707  MOV EDI,DWORD PTR SS:[EBP+14]
768E970A  TEST EDI,EDI
768E970C  JE SHORT kernel32.768E9711
768E970E  AND DWORD PTR DS:[EDI],0
768E9711  MOV ESI,DWORD PTR SS:[EBP+8]
```

…and the execution is redirected to the exported function

# Basics of a PE file: Imports

- Raw: before filling imports



| Offset | Name | Func. Count | Bound? | OriginalFirstThun | TimeDateStamp | Forwarder | NameRVA |
|---|---|---|---|---|---|---|---|
| 2E00 | KERNEL32.dll | 17 | FALSE | 4134 | 0 | 0 | 42EC |
| 2E14 | USER32.dll | 21 | FALSE | 417C | 0 | 0 | 4462 |
| 2E28 | GDI32.dll | 1 | FALSE | 412C | 0 | 0 | 4480 |
| 2E3C | ADVAPI32.dll | 3 | FALSE | 411C | 0 | 0 | 44CE |

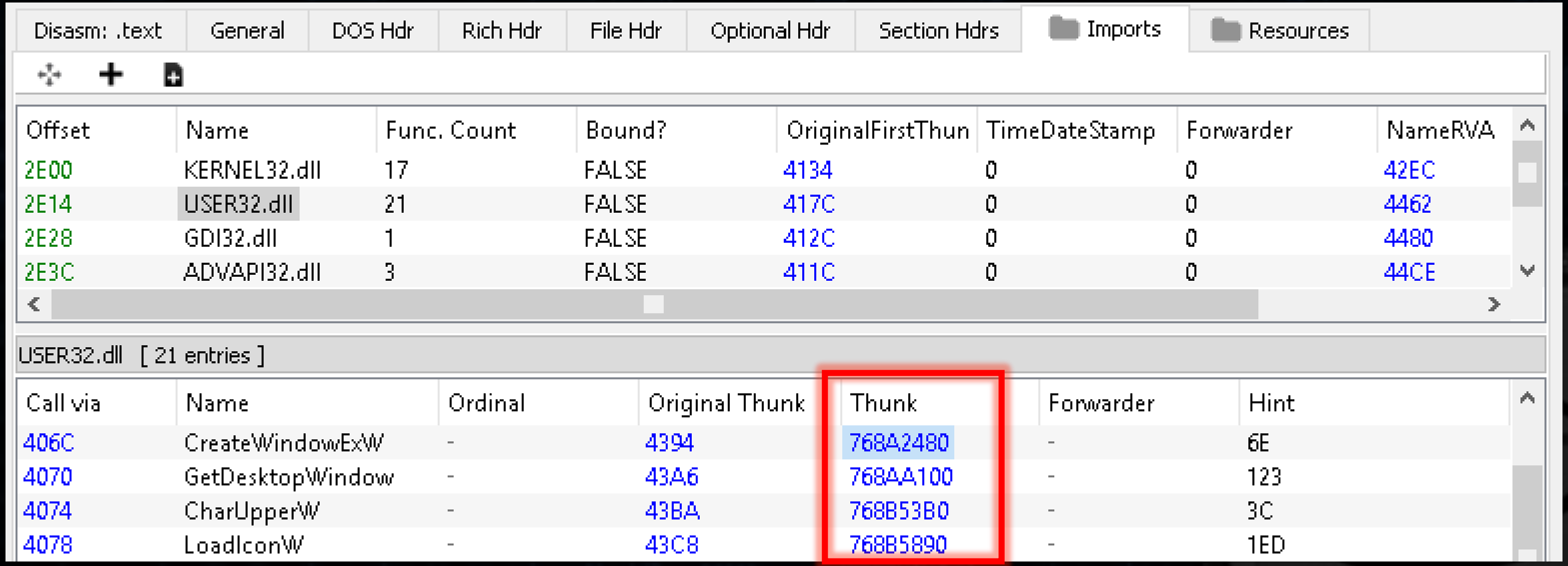
USER32.dll [ 21 entries ]

| Call via | Name | Ordinal | Original Thunk | Thunk | Forwarder | Hint |
|---|---|---|---|---|---|---|
| 406C | CreateWindowExW | - | 4394 | 4394 | - | 6E |
| 4070 | GetDesktopWindow | - | 43A6 | 43A6 | - | 123 |
| 4074 | CharUpperW | - | 43BA | 43BA | - | 3C |
| 4078 | LoadIconW | - | 43C8 | 43C8 | - | 1ED |

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/imports_load.h

# Basics of a PE file: Imports

- Loaded: after filling imports – thunks are filled with addresses of exported functions



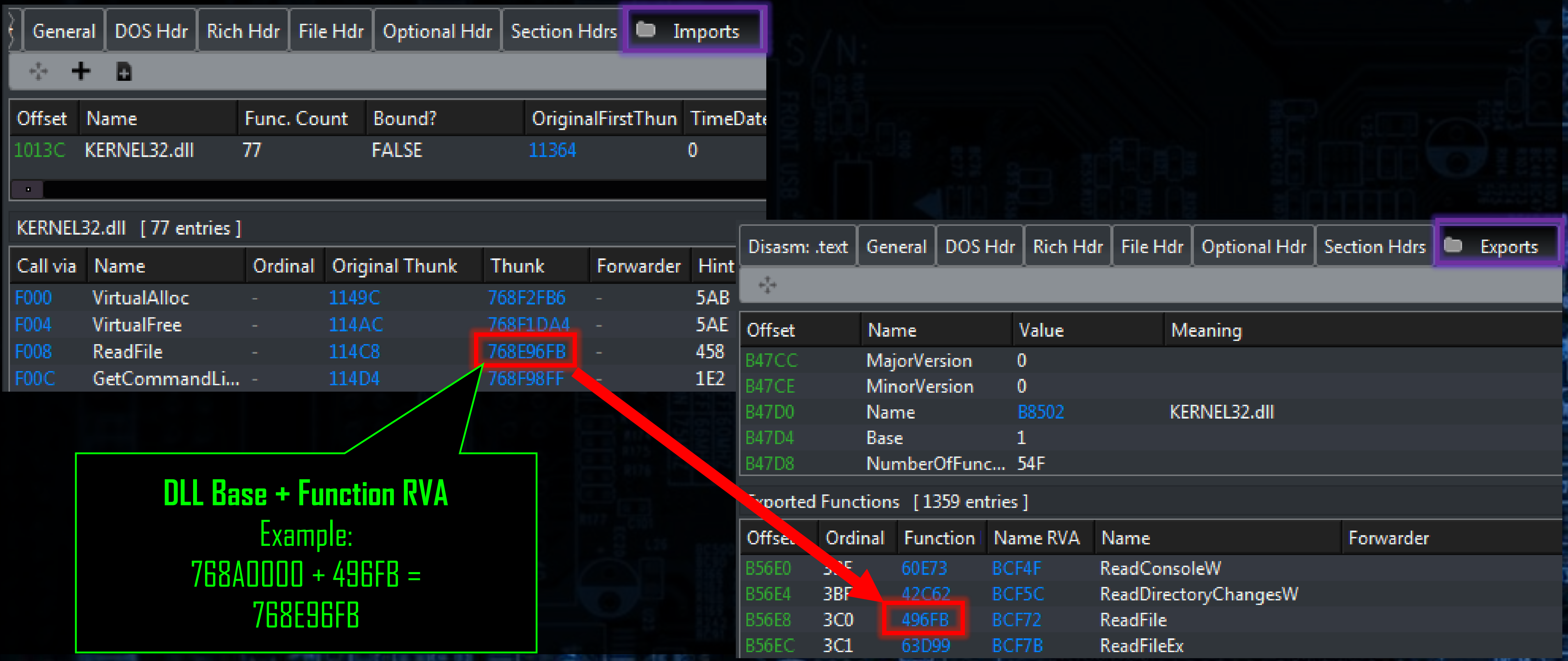
| Offset | Name | Func. Count | Bound? | OriginalFirstThun | TimeDateStamp | Forwarder | NameRVA |
|---|---|---|---|---|---|---|---|
| 2E00 | KERNEL32.dll | 17 | FALSE | 4134 | 0 | 0 | 42EC |
| 2E14 | USER32.dll | 21 | FALSE | 417C | 0 | 0 | 4462 |
| 2E28 | GDI32.dll | 1 | FALSE | 412C | 0 | 0 | 4480 |
| 2E3C | ADVAPI32.dll | 3 | FALSE | 411C | 0 | 0 | 44CE |

USER32.dll [ 21 entries ]

| Call via | Name | Ordinal | Original Thunk | Thunk | Forwarder | Hint |
|---|---|---|---|---|---|---|
| 406C | CreateWindowExW | - | 4394 | 768A2480 | - | 6E |
| 4070 | GetDesktopWindow | - | 43A6 | 768AA100 | - | 123 |
| 4074 | CharUpperW | - | 43BA | 768B53B0 | - | 3C |
| 4078 | LoadIconW | - | 43C8 | 768B5890 | - | 1ED |

https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/imports_load.h

# Basics of a PE file: Imports



| Offset | Name | Func. Count | Bound? | OriginalFirstThun | TimeDate |
|---|---|---|---|---|---|
| 1013C | KERNEL32.dll | 77 | FALSE | 11364 | 0 |

KERNEL32.dll [ 77 entries ]

| Call via | Name | Ordinal | Original Thunk | Thunk | Forwarder | Hint |
|---|---|---|---|---|---|---|
| F000 | VirtualAlloc | - | 1149C | 768F2FB6 | - | 5AB |
| F004 | VirtualFree | - | 114AC | 768F1DA4 | - | 5AE |
| F008 | ReadFile | - | 114C8 | 768E96FB | - | 458 |
| F00C | GetCommandLi... | - | 114D4 | 768F98FF | - | 1E2 |

| Offset | Name | Value | Meaning |
|---|---|---|---|
| B47CC | MajorVersion | 0 | |
| B47CE | MinorVersion | 0 | |
| B47D0 | Name | B8502 | KERNEL32.dll |
| B47D4 | Base | 1 | |
| B47D8 | NumberOfFunc... | 54F | |

Exported Functions [ 1359 entries ]

| Offset | Ordinal | Function | Name RVA | Name | Forwarder |
|---|---|---|---|---|---|
| B56E0 | 3BE | 60E73 | BCF4F | ReadConsoleW | |
| B56E4 | 3BF | 42C62 | BCF5C | ReadDirectoryChangesW | |
| B56E8 | 3C0 | 496FB | BCF72 | ReadFile | |
| B56EC | 3C1 | 63D99 | BCF7B | ReadFileEx | |

**DLL Base + Function RVA**

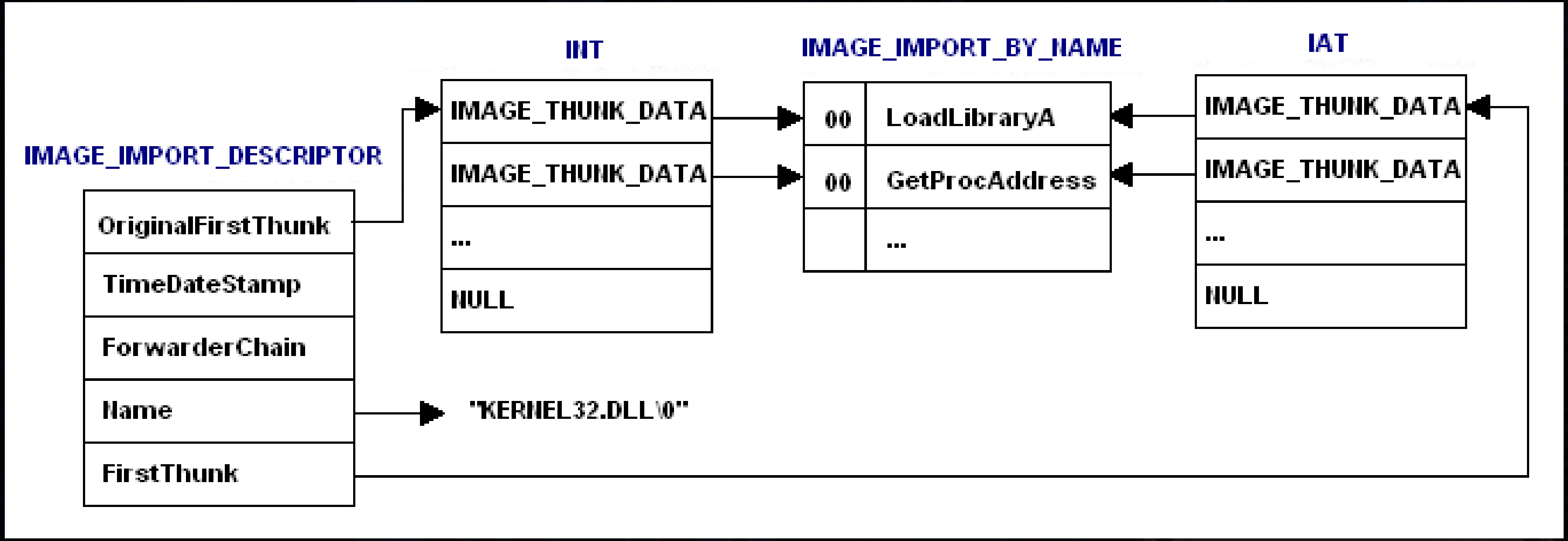
Example:

768A0000 + 496FB =

768E96FB

# Basics of a PE file: Imports

- Import Table: structure



https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/imports_load.h

# Basics of a PE file: Imports

- Let's open one of our sample PEs in PE-bear and see the import table. Find the corresponding DLLs and their exports.
- Check the code snippets to see how the import and export tables are processed

```
Exercise time...
```

# Exercise

- Compile the given code of a custom PE loader and get familiar with it
    - https://github.com/hasherezade/malware_training_vol1/tree/main/exercises/module1/lesson2_pe

# Further readings...

- MSDN documentation:
  - https://docs.microsoft.com/en-us/windows/win32/debug/pe-format
- Classic articles about PE by Matt Pietrek:
  - https://bytepointer.com/resources/pietrek_in_depth_look_into_pe_format_pt1.htm -
  - https://bytepointer.com/resources/pietrek_in_depth_look_into_pe_format_pt2.htm
  - https://docs.microsoft.com/en-us/previous-versions/ms809762(v=msdn.10)?redirectedfrom=MSDN