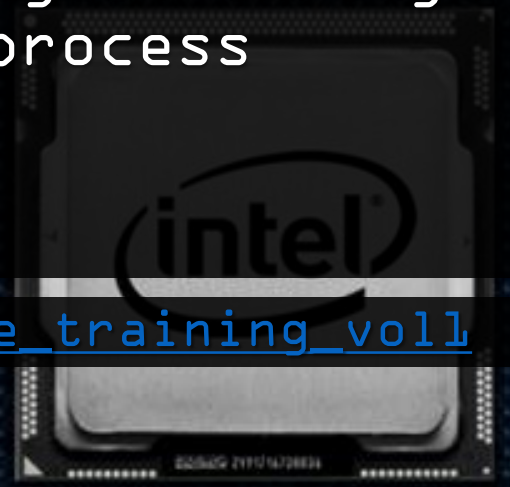
Module 1

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



https://github.com/hasherezade/malware_training_vol1

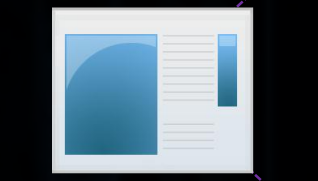
Basics of PE (Portable Executable)

Basics of a PE file

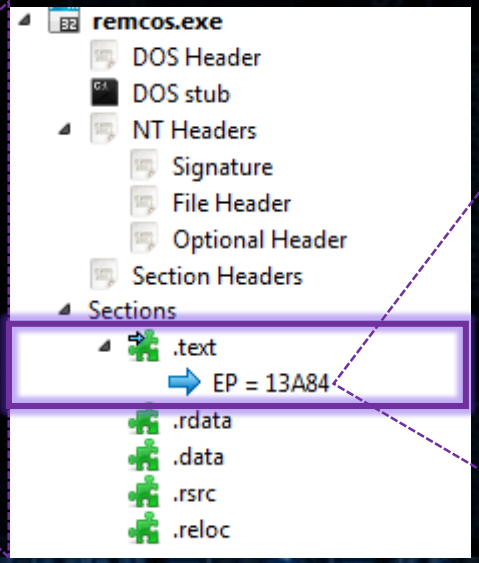
- PE (Portable Executable) is a native executable format on Windows
- PE files:
  - user mode: EXE, DLL
  - kernel mode: driver (.sys), kernel image (ntoskrnl.exe)
  - UEFI (run in SMM – System Managemant Mode)
  - Also OBJ files have structures similar to PE

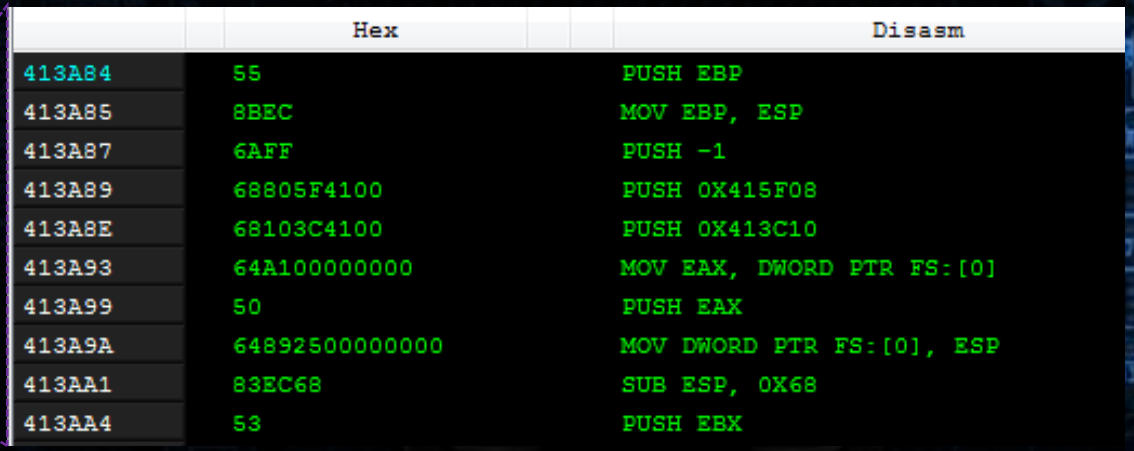
Basics of a PE file

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



remcos.exe





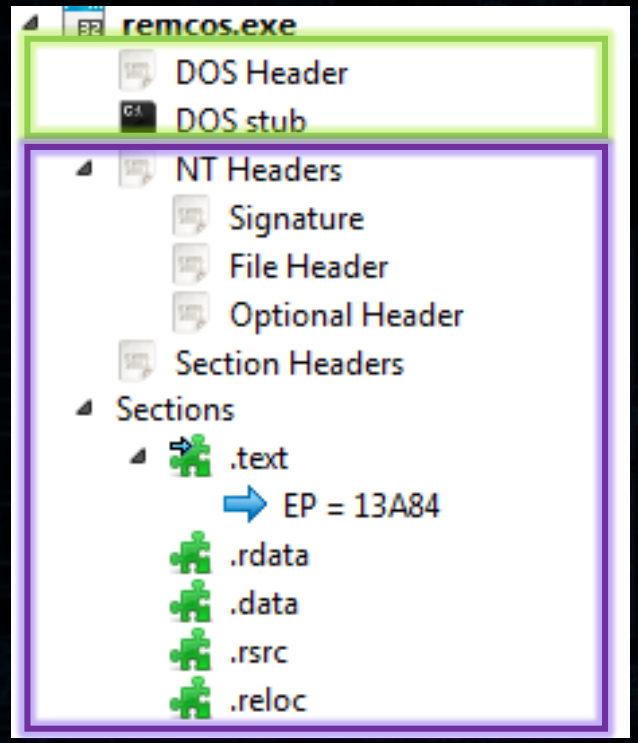
	Hex	Disasm
413A84	55	PUSH EBP
413A85	8BEC	MOV EBP, ESP
413A87	6AFF	PUSH -1
413A89	68805F4100	PUSH 0X415F08
413A8E	68103C4100	PUSH 0X413C10
413A93	64A100000000	MOV EAX, DWORD PTR FS:[0]
413A99	50	PUSH EAX
413A9A	64892500000000	MOV DWORD PTR FS:[0], ESP
413AA1	83EC68	SUB ESP, 0X68
413AA4	53	PUSH EBX

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



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

- OptionaHeader: 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;
```

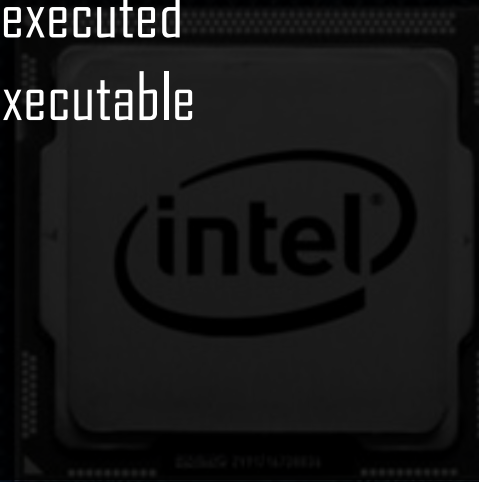
Let's have a look in PE-bear...

```
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[IMAGE_DIRECTORY_ENTRIES_NUM];
} IMAGE_OPTIONAL_HEADER64;
```

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

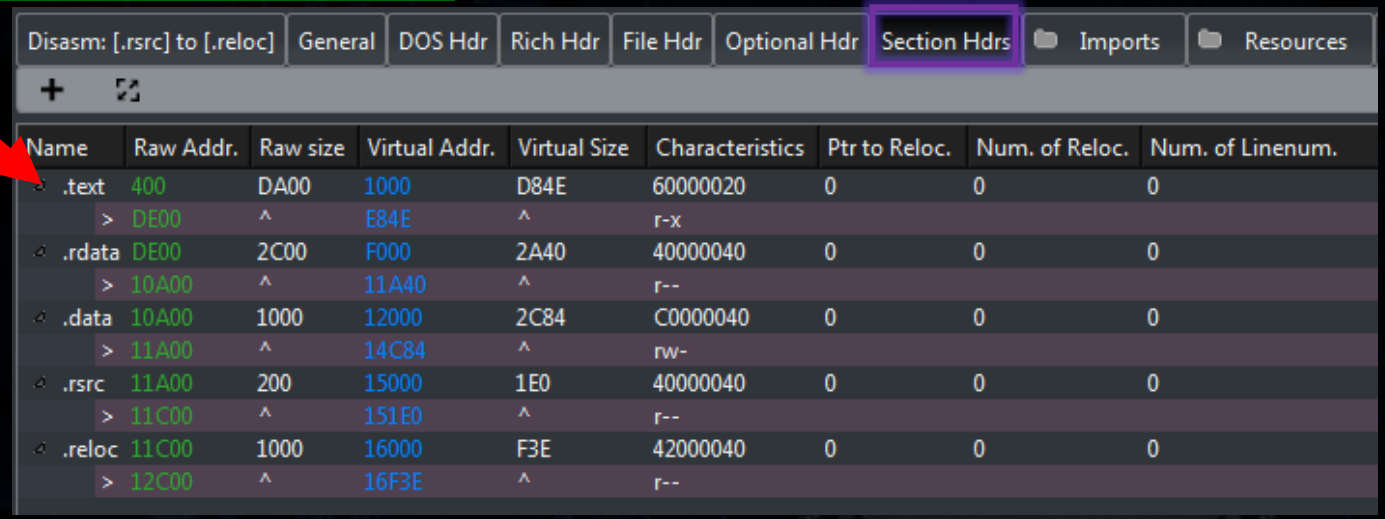


Basics of a PE file: sections

- 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

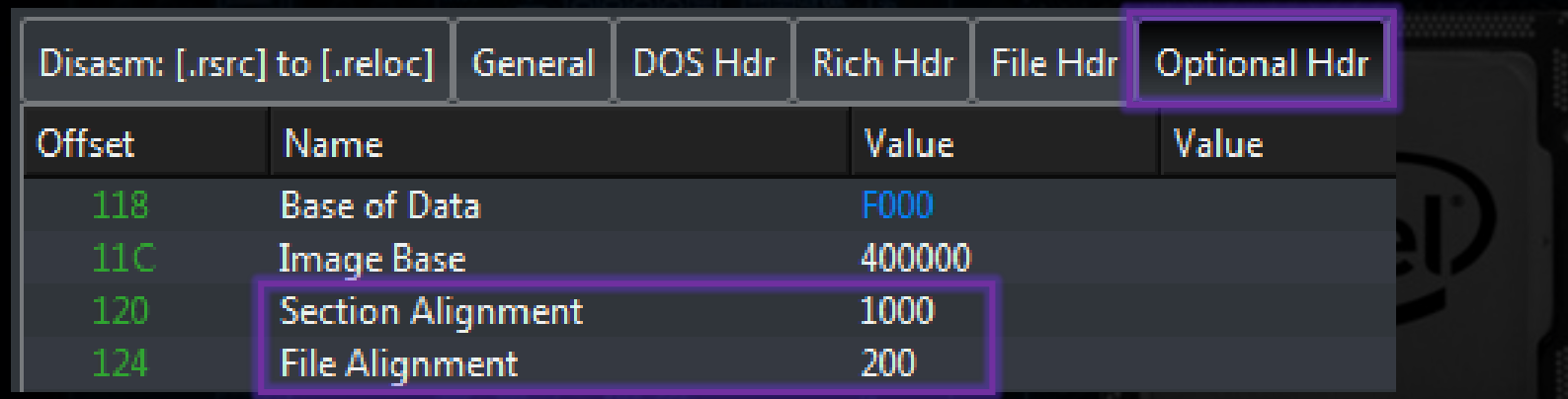


Name	Raw Addr.	Raw size	Virtual Addr.	Virtual Size	Characteristics	Ptr to Reloc.	Num. of Reloc.	Num. of Linenum.
.text	400	DA00	1000	D84E	60000020	0	0	0
>	DE00	^	E84E	^	r-x			
.rdata	DE00	2C00	F000	2A40	40000040	0	0	0
>	10A00	^	11A40	^	r--			
.data	10A00	1000	12000	2C84	C0000040	0	0	0
>	11A00	^	14C84	^	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

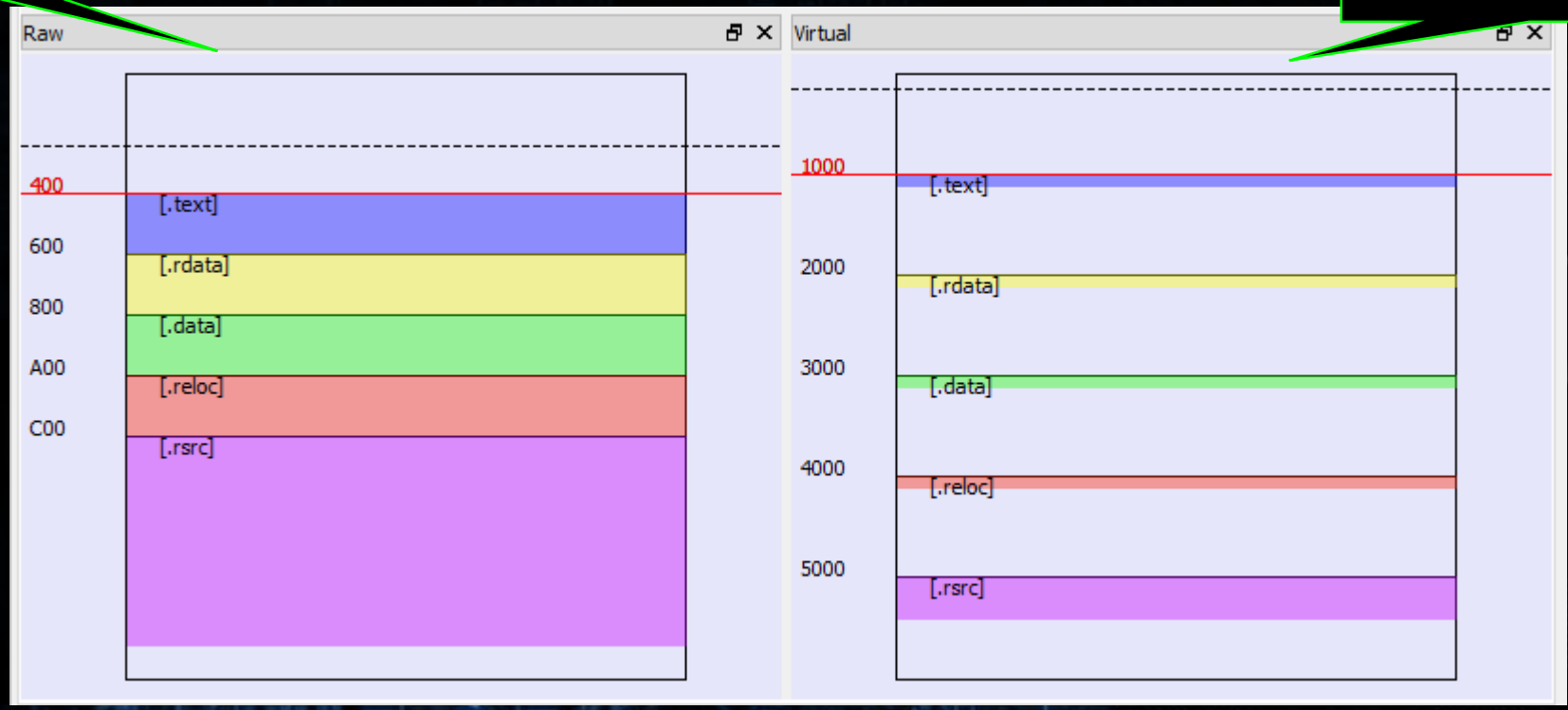
- on the disk PE is stored in a raw format (the unit is defined by File Alignment)
- In memory PE is mapped to its virtual format (the unit is defined by Section Alignment) – usually of the granularity of one page (0x1000)



Basics of a PE file: sections

Raw
(file on the disk)

Virtual
(mapped in the process memory)



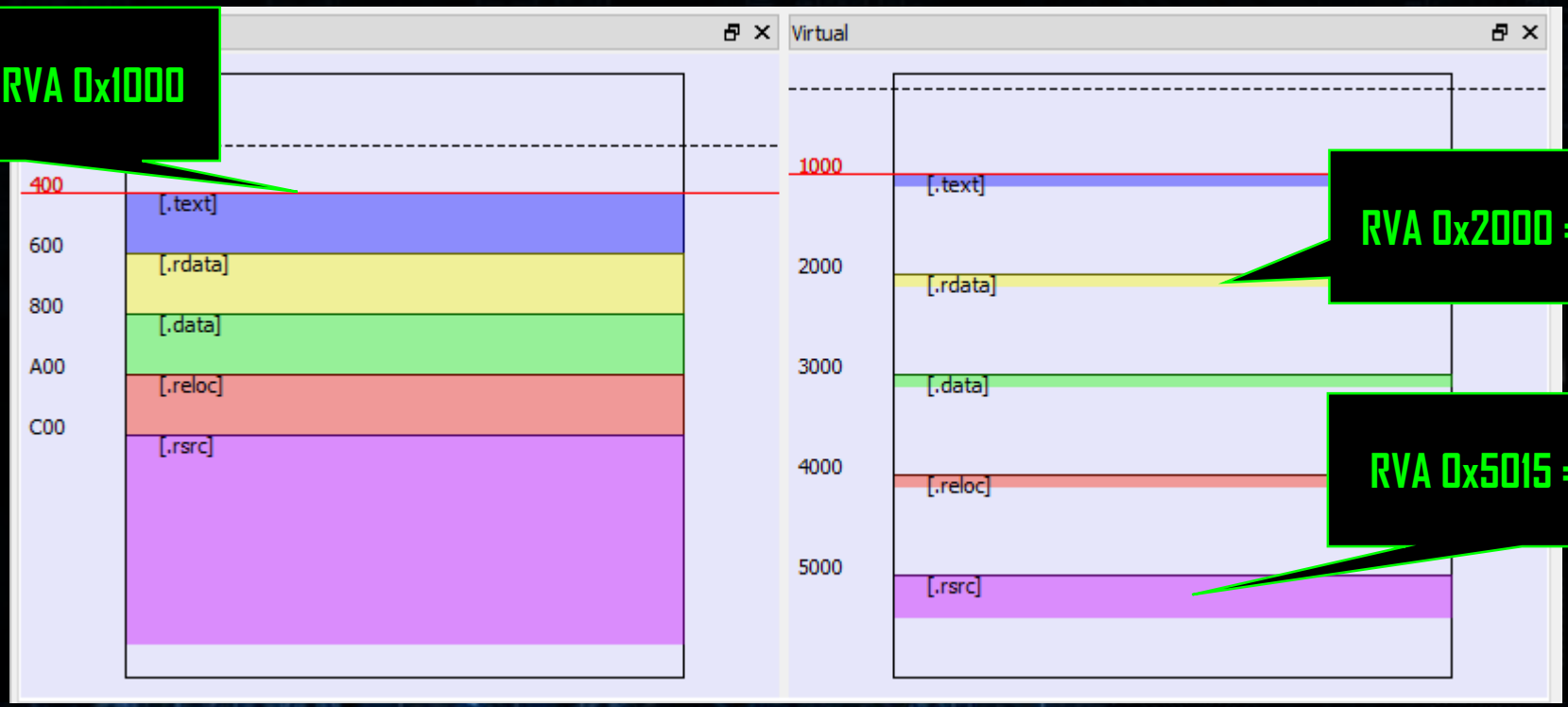
https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/remap.h

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.
- Caves may be virtual or raw
- Sometimes they may be used for installing code implants

Basics of a PE file: addresses

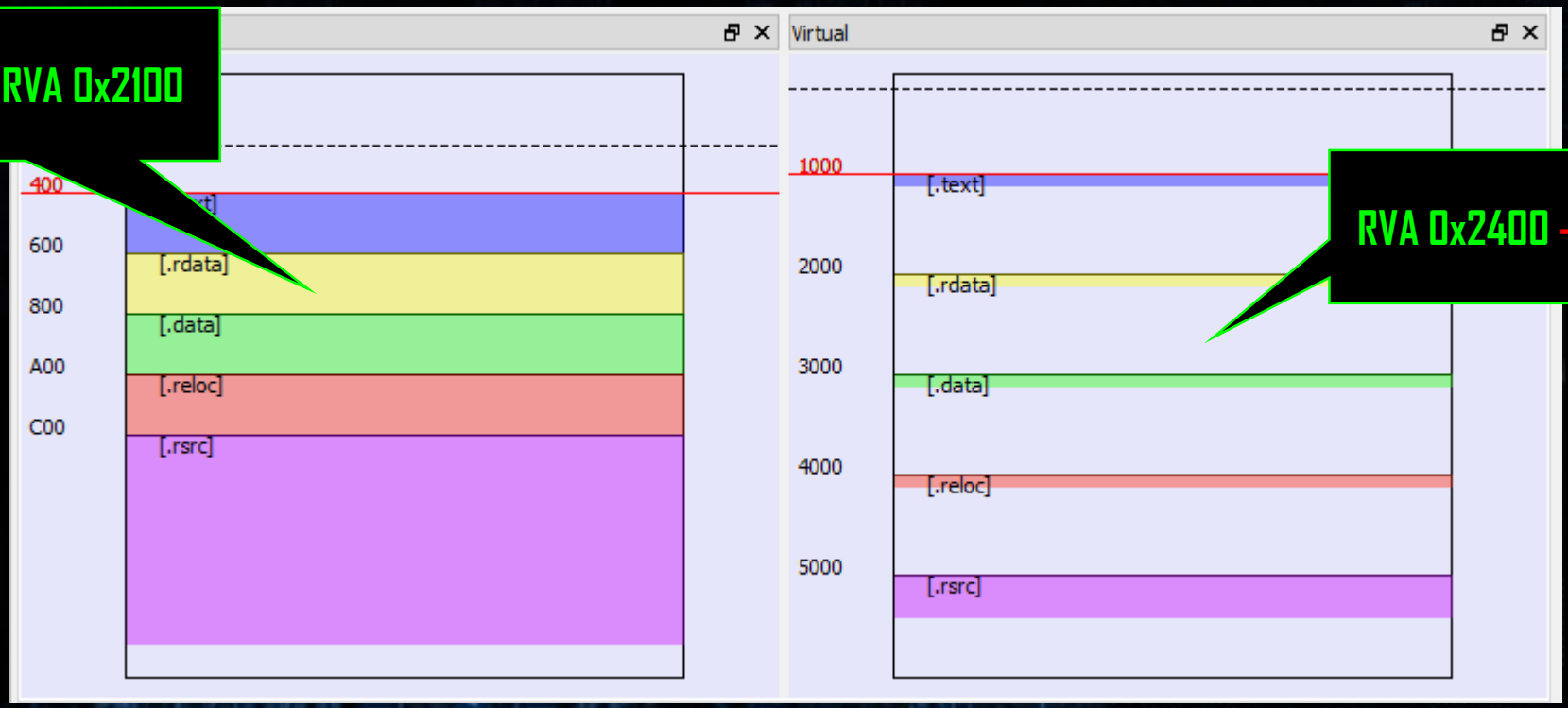
- Raw addresses (in file) usually correspond to virtual addresses (in memory) and vice versa



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

Basics of a PE file: addresses

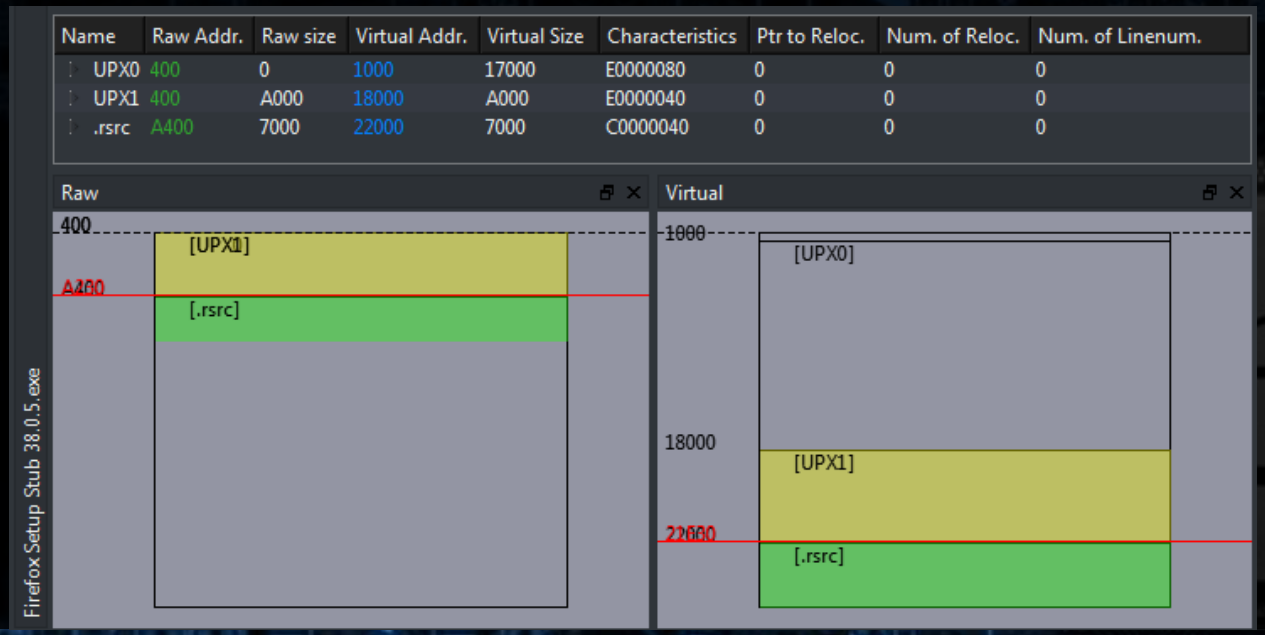
- Raw addresses (in file) *usually* correspond to virtual addresses (in memory) and vice versa



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

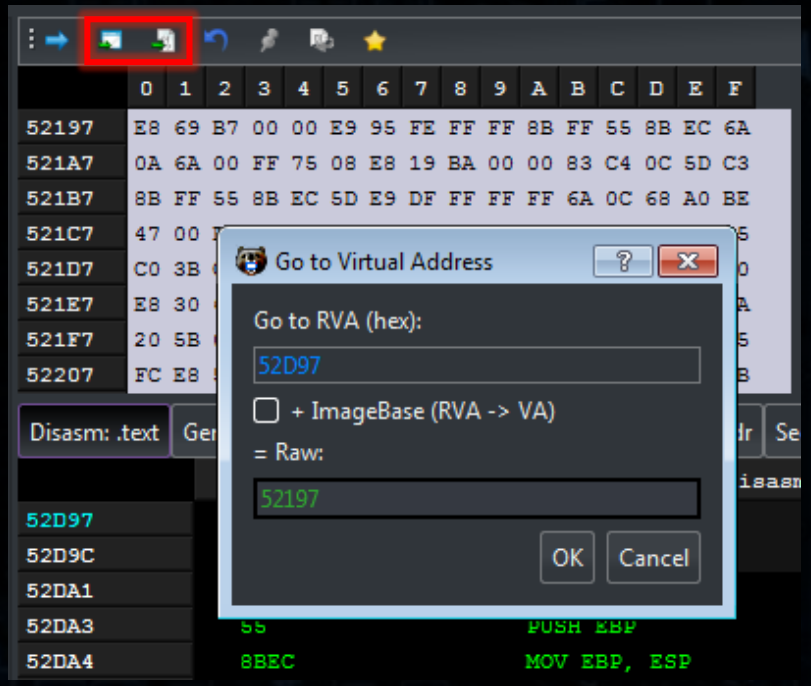
Basics of a PE file: addresses

- 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)



Basics of a PE file: addresses

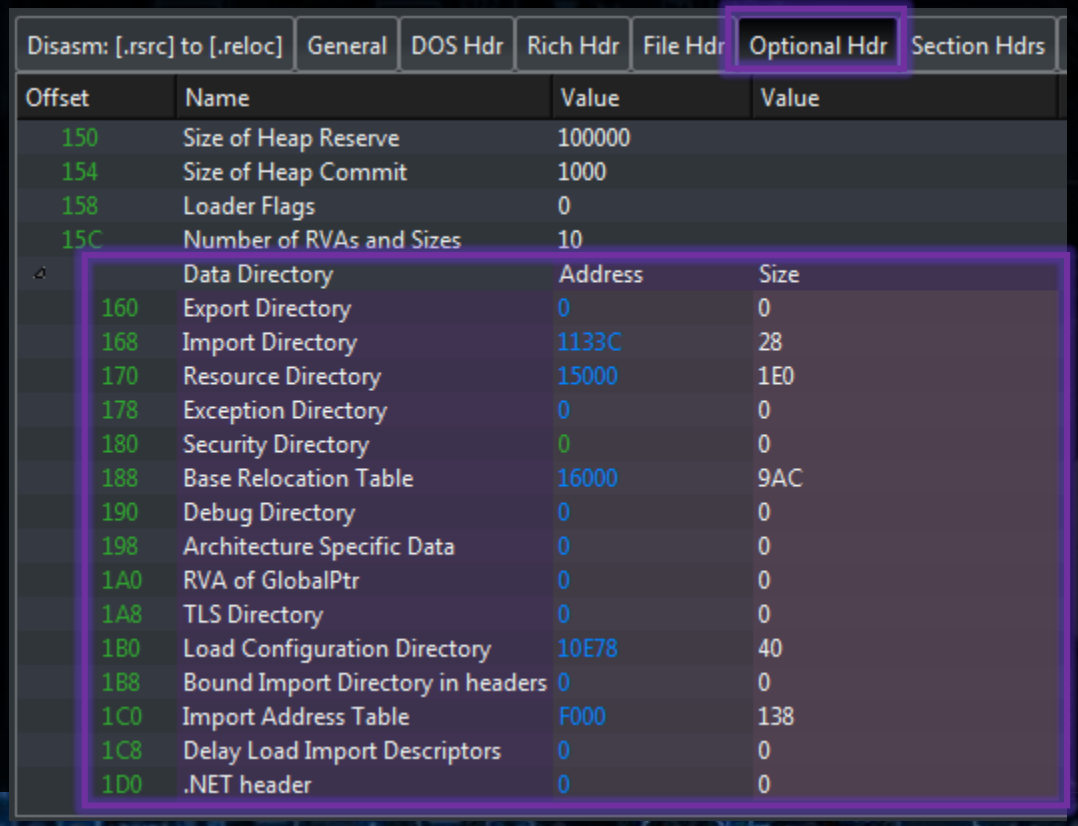
- Let's open one of our sample PEs in PE-bear and see the section table
- Try converting various addresses from Raw format to Virtual, follow and observe



Exercise time...

Basics of a PE file

- The most information lies in data directories



Disasm: [.rsrc] to [.reloc] | General | DOS Hdr | Rich Hdr | File Hdr | Optional Hdr | Section Hdrs

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

Hdr | File Hdr | Optional Hdr | Section Hdrs | Imports | Resources | BaseReloc.

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

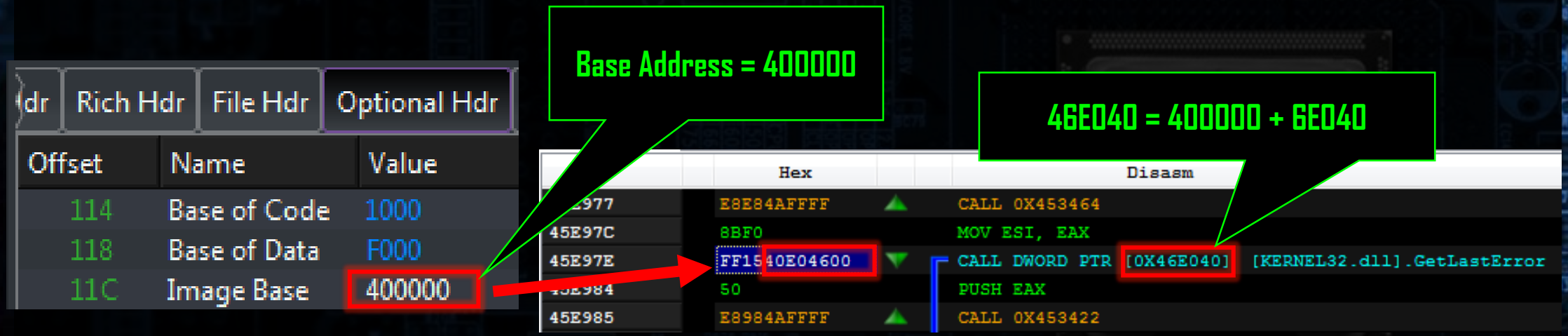
Relocation Block [54 entries]

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

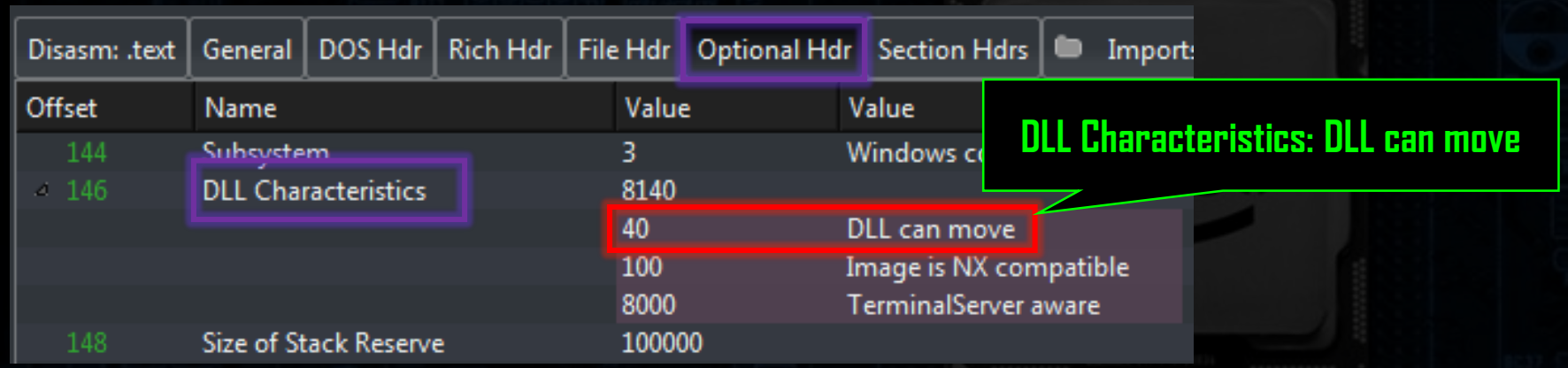
1. PE comes with some default base address in the header
2. All the absolute addresses inside the PE assume that it was loaded at this base



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

Basics of a PE file: Relocation

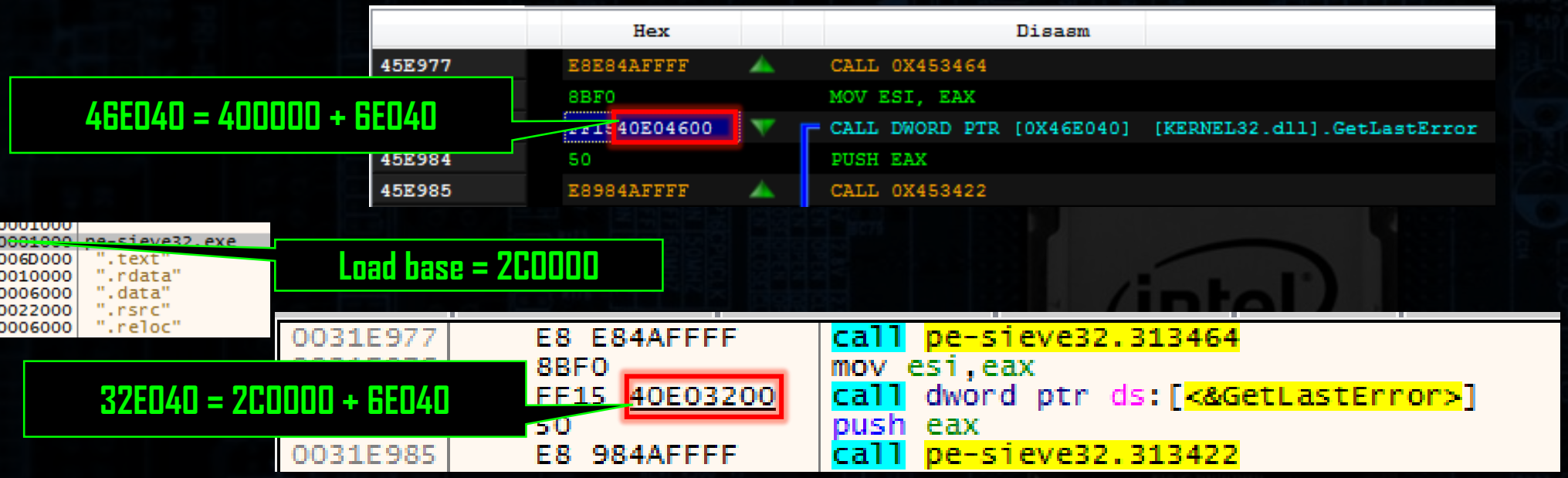
- In the past EXEs were usually loaded at their default base (only DLLs didn't have to)
- Nowadays most PEs load at a dynamic base (due to ASLR)
- A flag in the header determines if a dynamic base will be used



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)



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

Disasm: .text | General | DOS Hdr | Rich Hdr | File Hdr | Optional Hdr | Section Hdrs | Exports | Im

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	

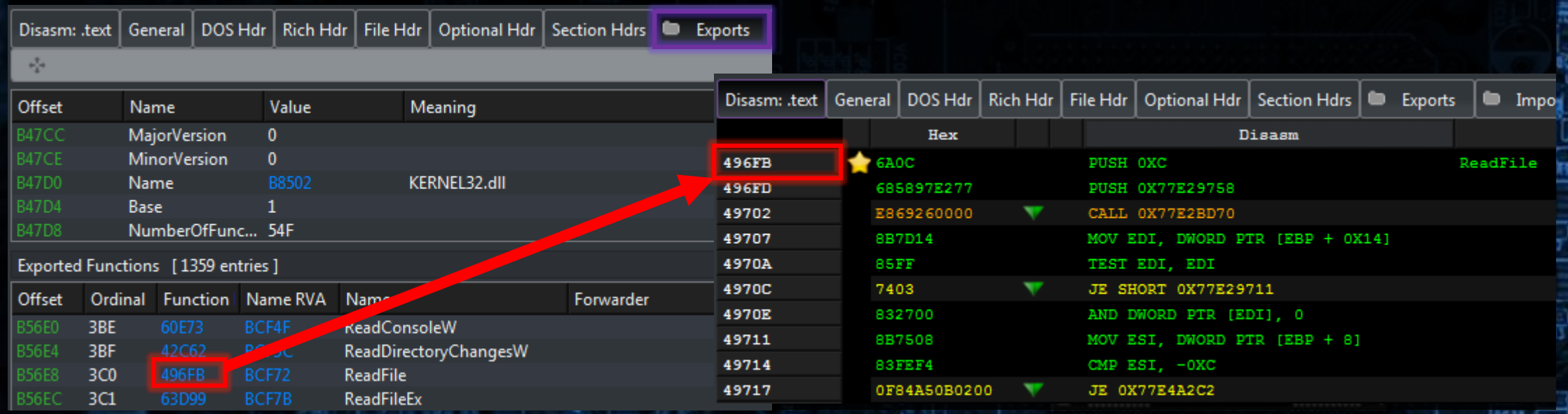
Exported Functions [1359 entries]

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	

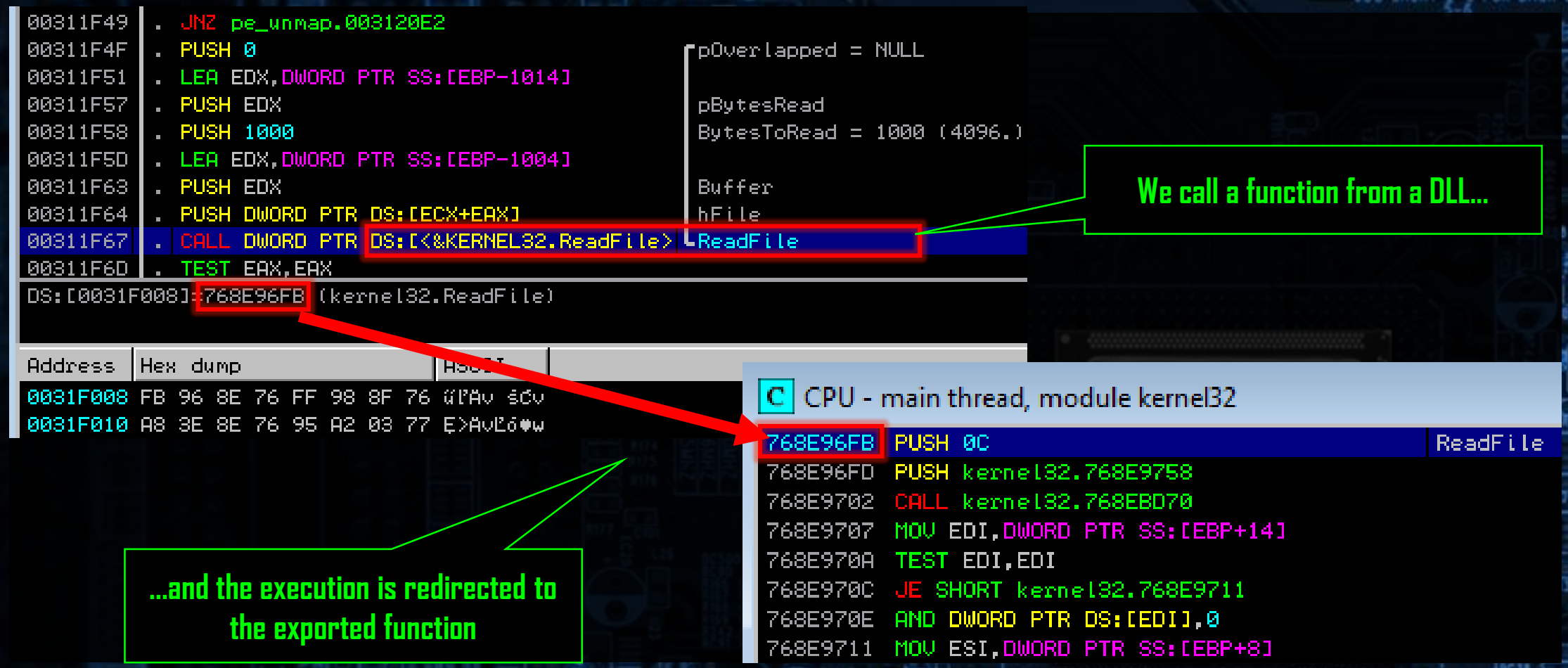
https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/export_lookup.h

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



Basics of a PE file: Exports



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

General | DOS Hdr | Rich Hdr | File Hdr | Optional Hdr | Section Hdrs | Imports | Resources | BaseReloc. | Load

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

KERNEL32.dll [77 entries]

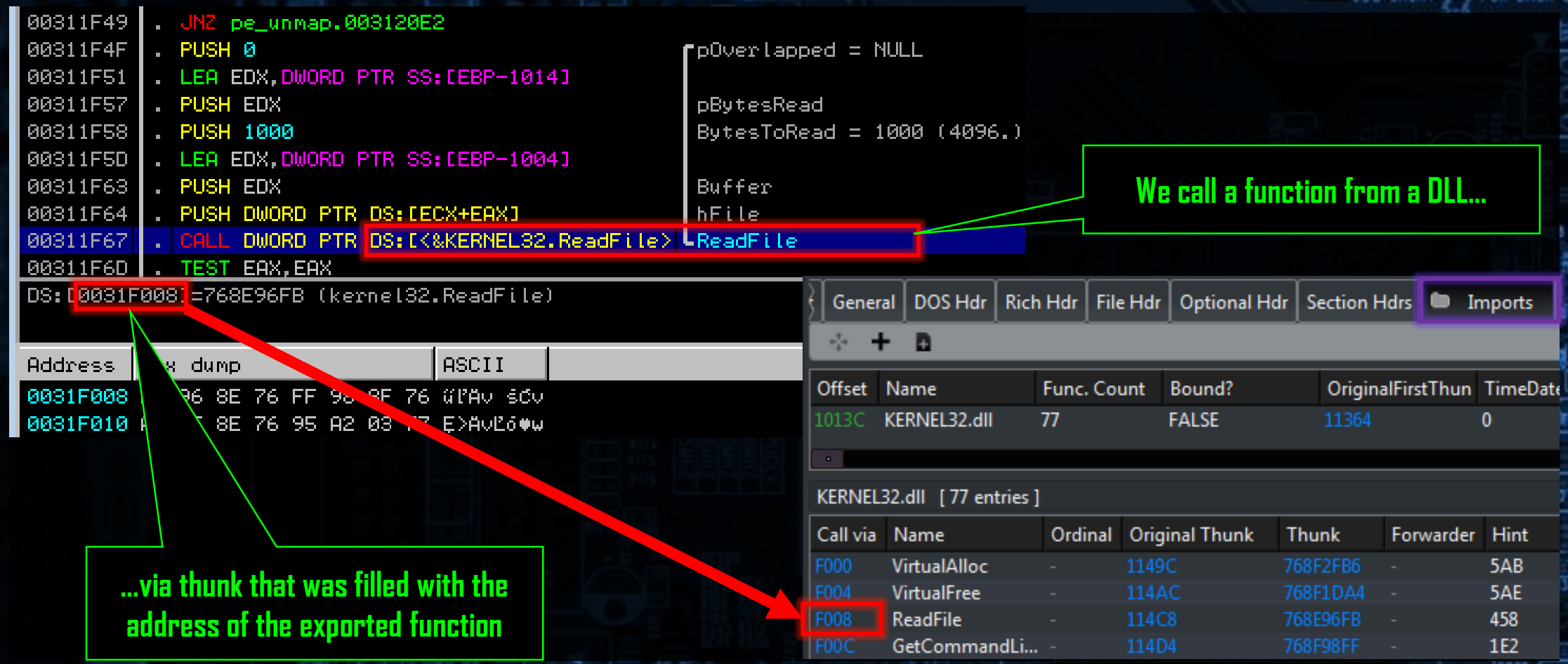
Call via	Name	Ordinal	Original Thunk	Thunk	Forwarder	Hint
F000	VirtualAlloc	-	1149C	1149C	-	5AB
F004	VirtualFree	-	114AC	114AC	-	5AE
F008	ReadFile	-	114C8	114C8	-	458
F00C	GetCommandLineA	-	114D4	114D4	-	1E2
F010	IsDebuggerPresent	-	114E6	114E6	-	383
F014	EncodePointer	-	114FA	114FA	-	13C
F018	DecodePointer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

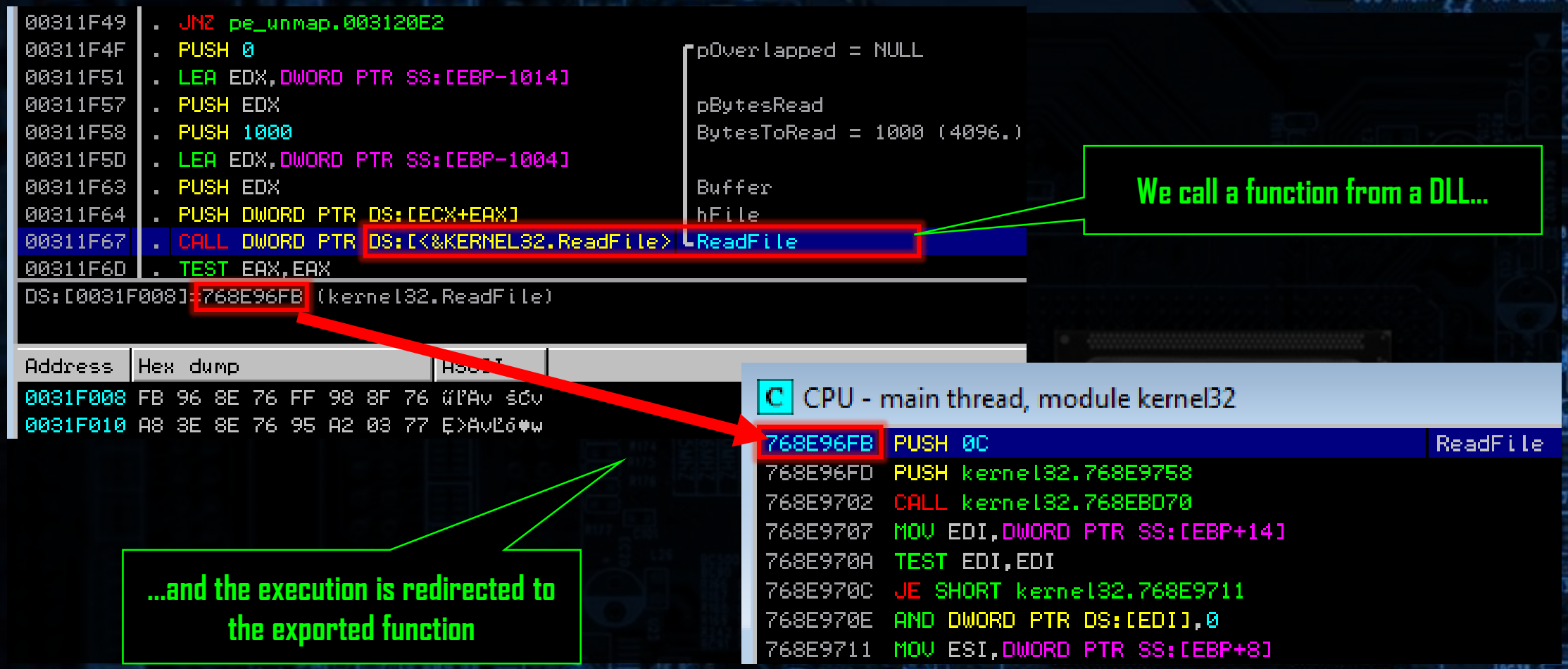
Basics of a PE file: Imports

- 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

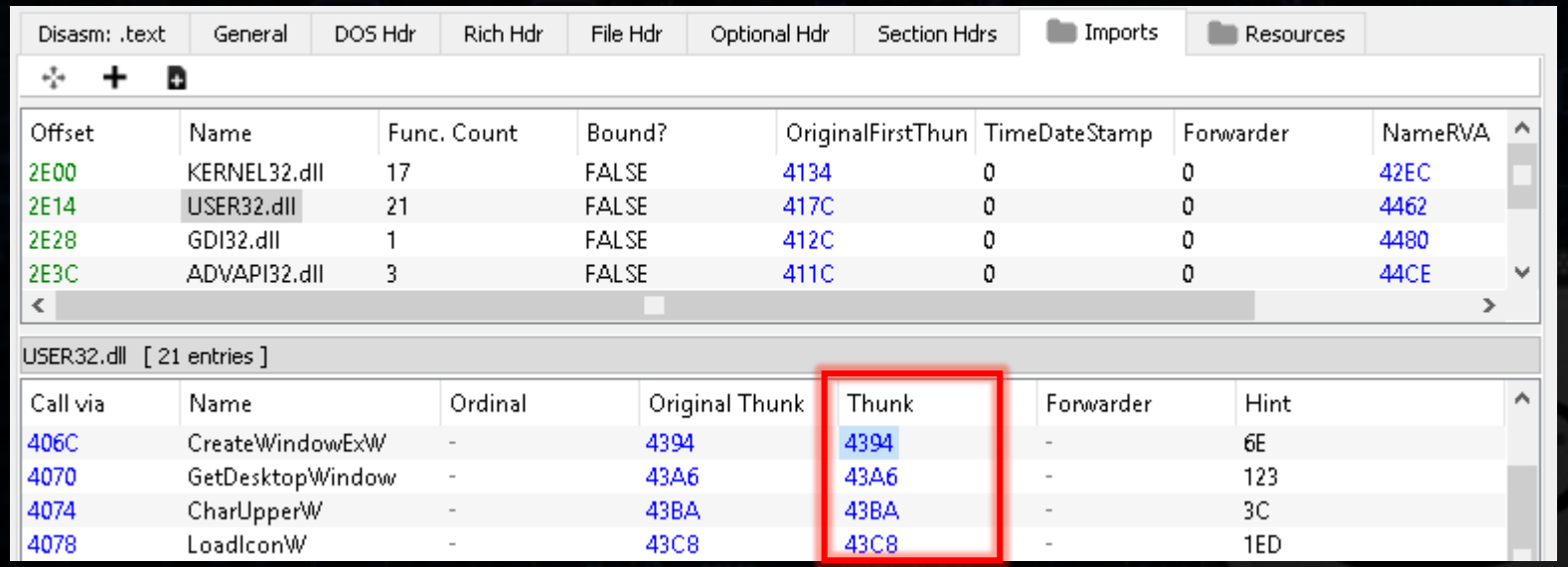


Basics of a PE file: Imports



Basics of a PE file: Imports

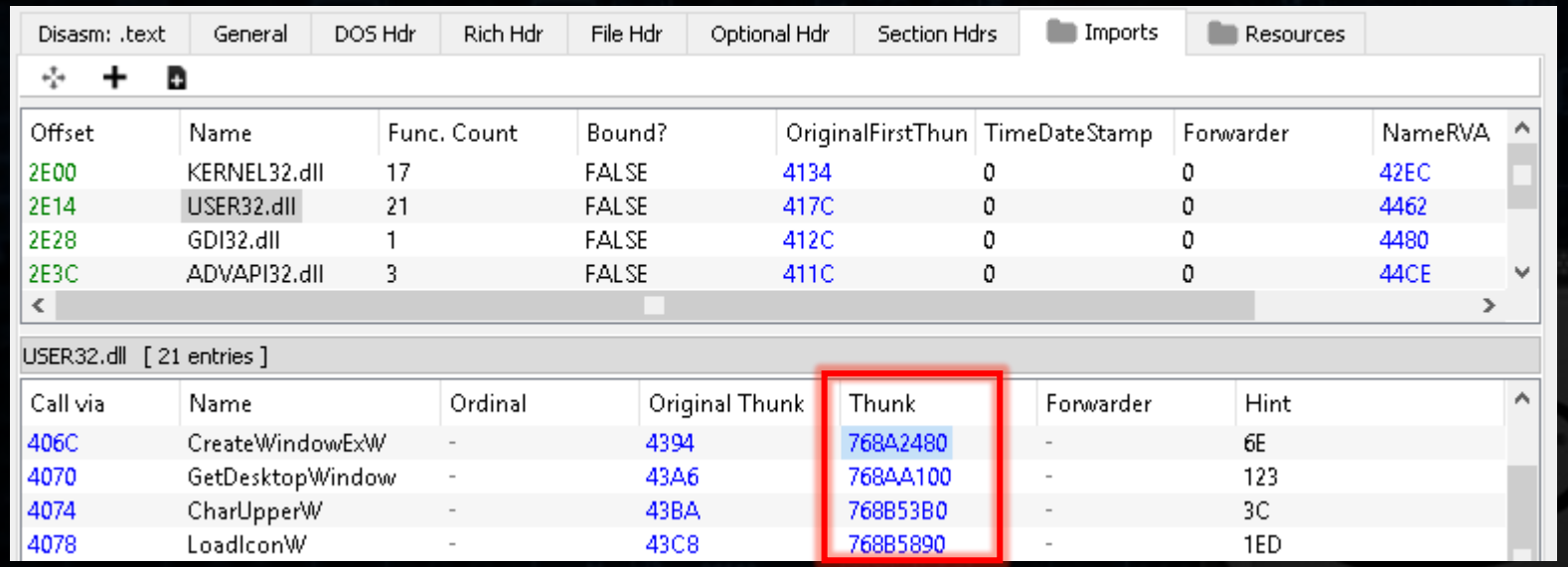
- Raw: before filling imports



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

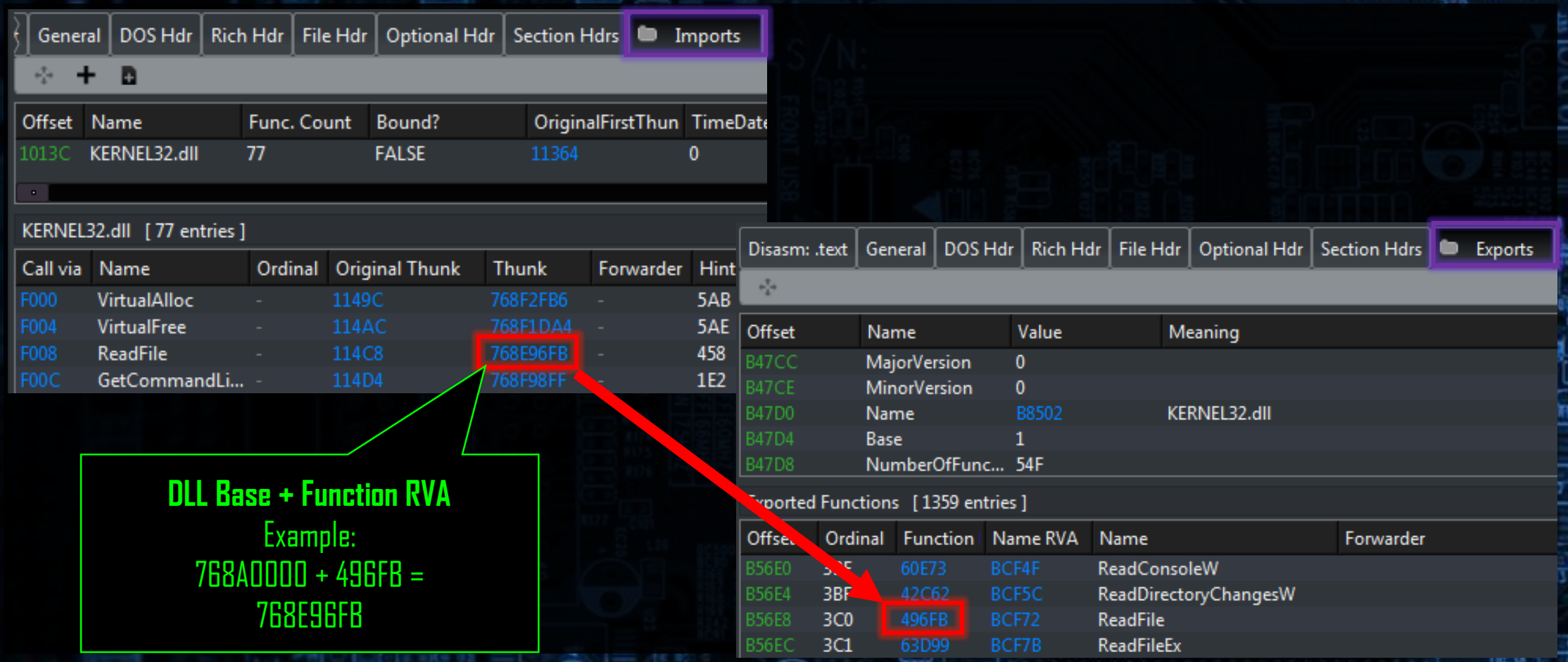
Basics of a PE file: Imports

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



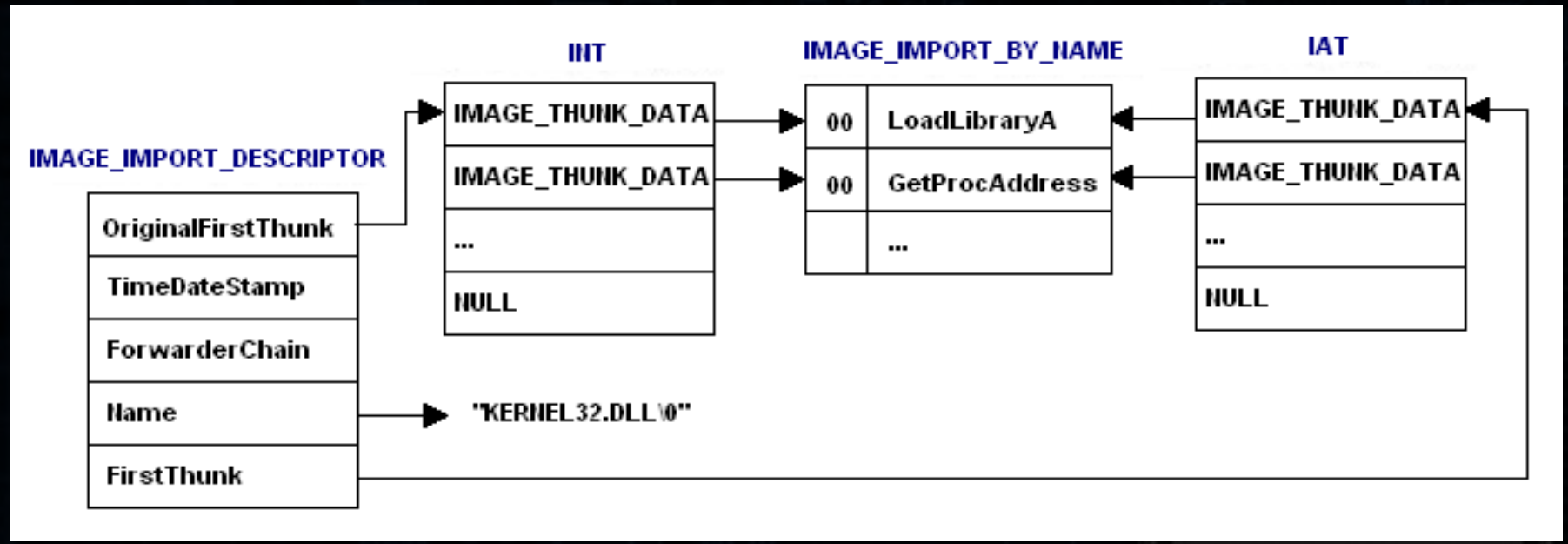
https://github.com/hasherezade/malware_training_vol1/blob/main/exercises/module1/lesson2_pe/pe_snippets/imports_load.h

Basics of a PE file: Imports



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