CS-501

Introduction to Malware, Threat Hunting & Offensive Capabilities Development

PE Loaders

Agenda

- PE File Format (review)
- PE Loading

PE Loading

1) Memory Mapping headers and sections
2) Building the Import Address Table
3) Handling Base Relocations
4) Executing TLS Callbacks
5) Passing Execution

Note 2 & 3 can be be performed interchangeably

Memory Mapping a PE

Review

- File Address: the offset from the start of the file as the PE appears on Disk.
- PEs are composed of Headers and sections
- Headers tell you where data is
- Sections contain data

Tools

In this lecture, we will use x64dbg, and PE-Bear to explore the PE file format.

As a sample, lets use Calc.exe (64 bit)

Run $path = Get-Command calc.exe to find the path to calc.exe on your machine

Run PE-Bear.exe $path.Source (in powershell)

Memory Mapping a PE: Step 1

Load the **File bytes** of the PE into a contiguous chunk of memory

Note this can be loading a PE from disk, downloading it from the internet, retrieving it from a section of a PE…etc

Python pseudo code:

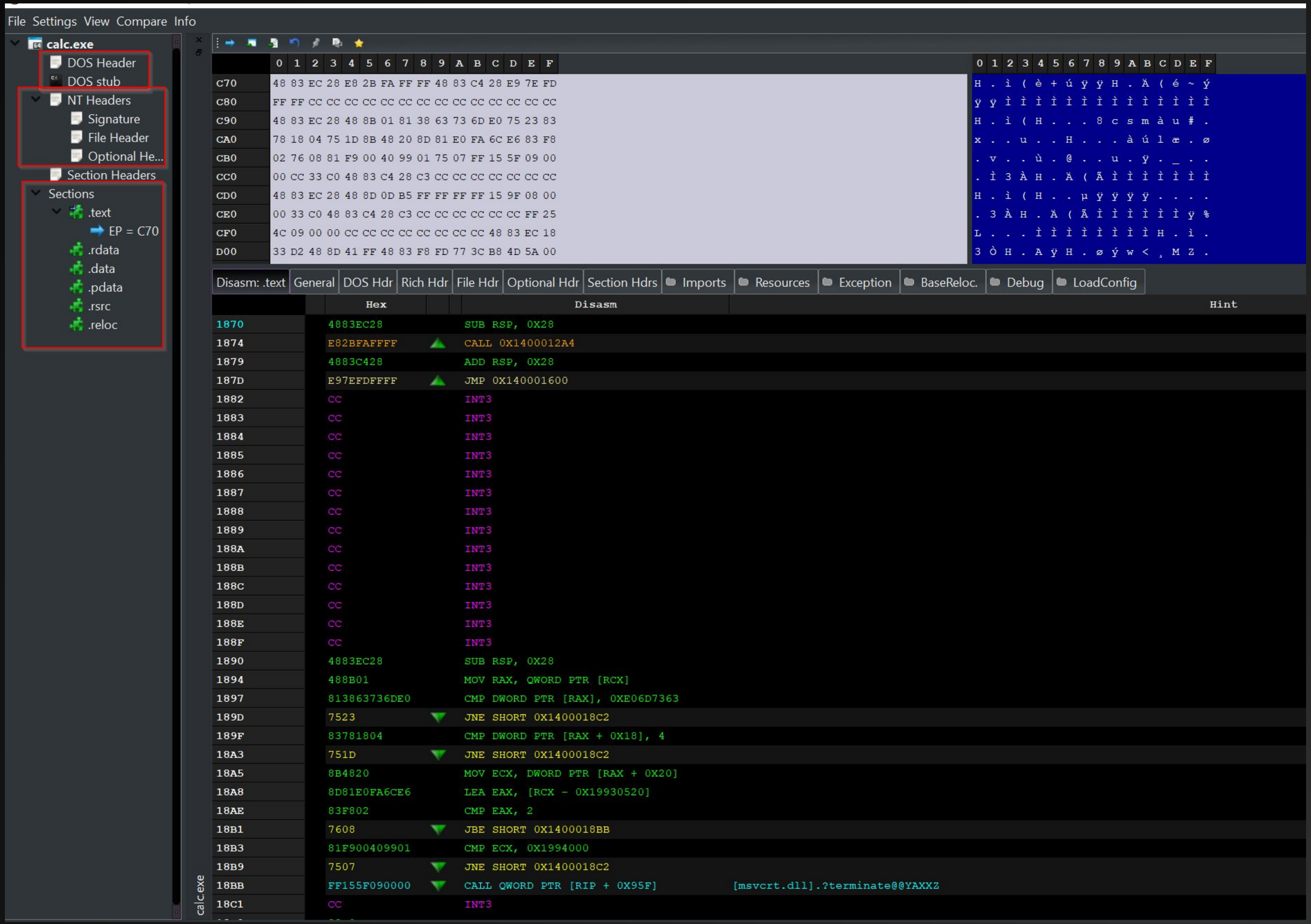
```
with open("foo.exe", "rb") as f:
    file_bytes = f.read()
```

Memory Mapping a PE: Step 2

Parse the Headers: this will tell you how to parse the rest of the PE!

- Use the DOS Header to find the NT Headers
- Use the NT headers to find the optional headers

Calc.exe



File Settings View Compare Info
calc.exe
DOS Header
DOS stub
NT Headers
Signature
File Header
Optional He...
Section Headers
Sections
.text
EP = C70
.rdata
.data
.pdata
.rsrc
.reloc
Disasm: .text
General
DOS Hdr
Rich Hdr
File Hdr
Optional Hdr
Section Hdrs
Imports
Resources
Exception
BaseReloc.
Debug
LoadConfig

DOS Header

- The DOS header contains the magic bytes MZ that identify it as a PE
- The final entry (referenced as ->e_lfanew) is the address of NT Headers
- The next block of bytes contain the DOS stub

Offset	Name	Value
0	Magic number	5A4D
2	Bytes on last page of file	90
4	Pages in file	3
6	Relocations	0
8	Size of header in paragraphs	4
A	Minimum extra paragraphs needed	0
C	Maximum extra paragraphs needed	FFFF
E	Initial (relative) SS value	0
10	Initial SP value	B8
12	Checksum	0
14	Initial IP value	0
16	Initial (relative) CS value	0
18	File address of relocation table	40
1A	Overlay number	0
1C	Reserved words[4]	0, 0, 0, 0
24	OEM identifier (for OEM information)	0
26	OEM information; OEM identifier specific	0
28	Reserved words[10]	0, 0, 0, 0, 0, 0, 0, 0, 0, 0
3C	File address of new exe header	E8

MZ magic Bytes

Address of NT Headers

Working with C/C++

There are several structures we can use to parse the bytes

We will assume that the Executables are all 64bit, but with a little bit of care, we can make our code work for 32bit and 64 bit PEs. (Note that we need a 32 bit exes to launch 32 bit applications. Same for 64 bit)

DOS Header:

```c
typedef struct _IMAGE_DOS_HEADER {          // DOS .EXE header
    WORD   e_magic;                         // Magic number
    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

  } IMAGE_DOS_HEADER, *PIMAGE_DOS_HEADER;
```

DOS Header

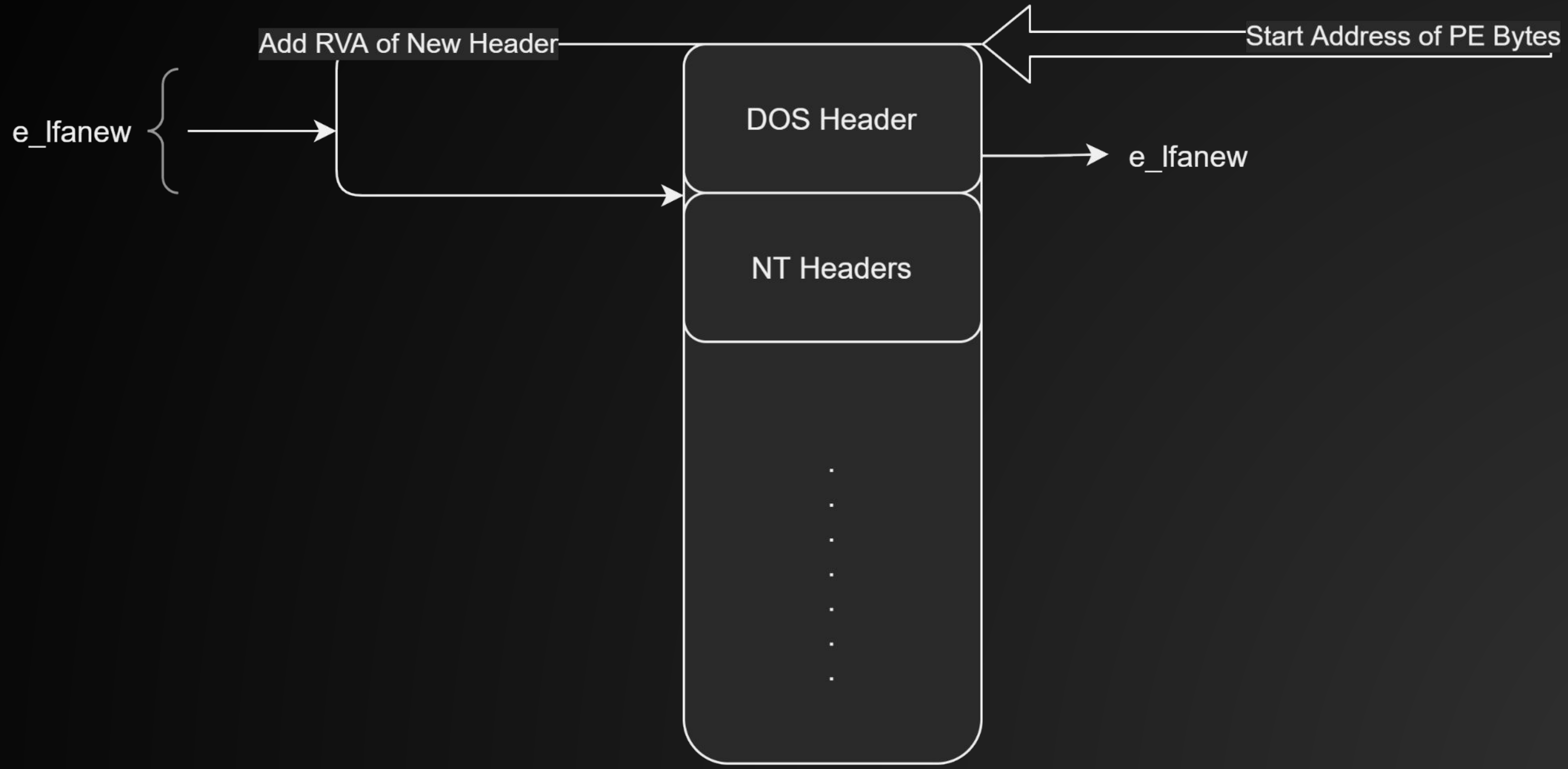
- If we have a pointer to the start of our PE Bytes, we can simply set the start of a DOS_HEADER struct to our PE bytes
-
- Defined in <winnt.h>
- ```
      LONG   e_lfanew;                    // File address of new exe header
  ```
- The offset above gives us the start address of the NT Headers
  ```

NT Headers

To calculate the **file address* of the NT Headers, we add the offset e_lfanew to the base file address

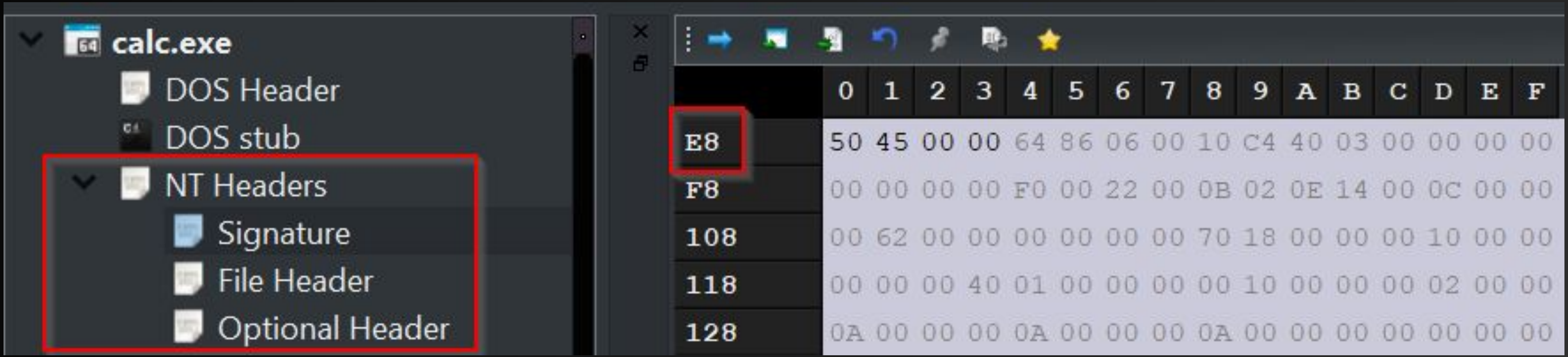
- I.e. if the value of e_lfanew is X, and the start memory address of our PE buffer is Y, then the address of the beginning of the NT Headers struct is Y + X

NT Headers


Add RVA of New Header
Start Address of PE Bytes
e_lfanew
DOS Header
e_lfanew
NT Headers
.
.
.
.
.
.
.

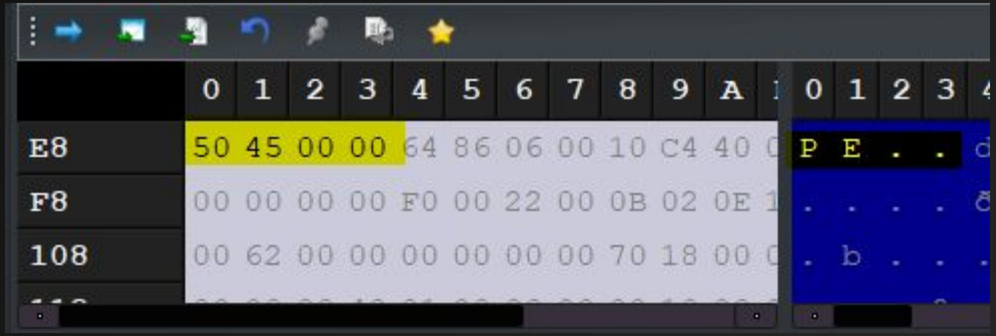
NT Headers

- Signatures
- File Header
- Optional Header



Signature

- Usually 4 bytes containing
- “PE\0\0”
- For our purposes, it is only used to verify the file format.



File Headers

Following the Signature, we have the File Headers. This gives us

- The number of sections (NumberOfSections)
- Whether or not we have a DLL/EXE (Characteristics)
- The Compilation timestamp

Disasm | General | DOS Hdr | Rich Hdr | File Hdr | Optional Hdr | Section Hdrs | Imports

Offset	Name	Value	Meaning
EC	Machine	8664	AMD64 (K8)
EE	Sections Count	6	6
F0	Time Date Stamp	340c410	Friday, 24.09.1971 16:02:24 UTC
F4	Ptr to Symbol Table	0	0
F8	Num. of Symbols	0	0
FC	Size of OptionalHeader	f0	240
FE	Characteristics	22	

Optional Headers

I don’t know why it is listed as optional. I don’t think a PE can run without this section (but I could be wrong?)

The optional headers will contain the data required to load the PE

Specifically, we will use values found here to build the IAT, and perform Base Relocations

Offset	Name	Value	Value
100	Magic	20B	NT64
102	Linker Ver. (Major)	E	
103	Linker Ver. (Minor)	14	
104	Size of Code	C00	
108	Size of Initialized Data	6200	
10C	Size of Uninitialized Data	0	
110	Entry Point	1870	
114	Base of Code	1000	
118	Image Base	140000000	
120	Section Alignment	1000	
124	File Alignment	200	
128	OS Ver. (Major)	A	
12A	OS Ver. (Minor)	0	
12C	Image Ver. (Major)	A	
12E	Image Ver. (Minor)	0	
130	Subsystem Ver. (Major)	A	
132	Subsystem Ver. Minor)	0	
134	Win32 Version Value	0	
138	Size of Image	B000	
13C	Size of Headers	400	
140	Checksum	14163	
144	Subsystem	2	Windows GUI
146	DLL Characteristics	C160	
		40	DLL can move
		100	Image is NX compatible
		4000	Guard
		8000	TerminalServer aware
148	Size of Stack Reserve	80000	
150	Size of Stack Commit	2000	
158	Size of Heap Reserve	100000	
160	Size of Heap Commit	1000	

Optional Headers (pt 1)

- Magic: Architecture of image
- Entry Point: Relative virtual address (RVA) from the Base Address
- Image Base: (prefered) Base address: Where in memory the PE “prefers” to be loaded. If the location is unavailable, the Image needs to be relocated

Offset	Name	Value	Value
100	Magic	20B	NT64
102	Linker Ver. (Major)	E	
103	Linker Ver. (Minor)	14	
104	Size of Code	C00	
108	Size of Initialized Data	6200	
10C	Size of Uninitialized Data	0	
110	Entry Point	1870	
114	Base of Code	1000	
118	Image Base	140000000	
120	Section Alignment	1000	
124	File Alignment	200	
128	OS Ver. (Major)	A	
12A	OS Ver. (Minor)	0	
12C	Image Ver. (Major)	A	
12E	Image Ver. (Minor)	0	
130	Subsystem Ver. (Major)	A	
132	Subsystem Ver. Minor)	0	
134	Win32 Version Value	0	
138	Size of Image	B000	
13C	Size of Headers	400	
140	Checksum	14163	
144	Subsystem	2	Windows GUI
146	DLL Characteristics	C160	
		40	DLL can move
		100	Image is NX compatible
		4000	Guard
		8000	TerminalServer aware
148	Size of Stack Reserve	80000	
150	Size of Stack Commit	2000	
158	Size of Heap Reserve	100000	
160	Size of Heap Commit	1000	

Arch

RVA from Base Address

Prefered Base address of loaded image

Optional Headers (pt 2)

- SizeOfImage: the virtual size of the image
- SizeOfHeaders: the size of the headers
- DLLCharacteristics: flags including knowledge of hardening features such as ASLR/ CFG...etc. Not super important for us other than assuming knowledge of ASLR.

Offset	Name	Value	Value
100	Magic	20B	NT64
102	Linker Ver. (Major)	E	
103	Linker Ver. (Minor)	14	
104	Size of Code	C00	
108	Size of Initialized Data	6200	
10C	Size of Uninitialized Data	0	
110	Entry Point	1870	
114	Base of Code	1000	
118	Image Base	140000000	
120	Section Alignment	1000	
124	File Alignment	200	
128	OS Ver. (Major)	A	
12A	OS Ver. (Minor)	0	
12C	Image Ver. (Major)	A	
12E	Image Ver. (Minor)	0	
130	Subsystem Ver. (Major)	A	
132	Subsystem Ver. Minor)	0	
134	Win32 Version Value	0	
138	Size of Image	B000	
13C	Size of Headers	400	
140	Checksum	14163	
144	Subsystem	2	Windows GUI
146	DLL Characteristics	C160	
		40	DLL can move
		100	Image is NX compatible
		4000	Guard
		8000	TerminalServer aware
148	Size of Stack Reserve	80000	
150	Size of Stack Commit	2000	
158	Size of Heap Reserve	100000	
160	Size of Heap Commit	1000	

Size of the Image in bytes, as well as the headers

Subsystem (are we a console application or GUI?)

NT Headers

IMAGE_NT_HEADERS is actually a macro that expands to the relevant Struct for 32bit PEs and 64bit PEs respectively

32 bit: IMAGE_NT_HEADERS32

64 bit: IMAGE_NT_HEADERS64

NT Headers 64 bit

```
typedef struct _IMAGE_NT_HEADERS64 {
  DWORD                   Signature;
  IMAGE_FILE_HEADER       FileHeader;
  IMAGE_OPTIONAL_HEADER64 OptionalHeader;
} IMAGE_NT_HEADERS64, *PIMAGE_NT_HEADERS64;
```

NT Header → FileHeader

```
typedef struct _IMAGE_FILE_HEADER {
  WORD  Machine;
  WORD  NumberOfSections;
  DWORD TimeDateStamp;
  DWORD PointerToSymbolTable;
  DWORD NumberOfSymbols;
  WORD  SizeOfOptionalHeader;
  WORD  Characteristics;
} IMAGE_FILE_HEADER, *PIMAGE_FILE_HEADER;
```

NT Header → FileHeader

We need to Parse the

- **Machine** to ensure we have the correct Arch
- **NumberOfSections**: this allows us to iterate through all sections of the PE

NT Headers → OptionalHeaders

```
typedef struct _IMAGE_OPTIONAL_HEADER64 {
  WORD                 Magic;
  BYTE                 MajorLinkerVersion;
  BYTE                 MinorLinkerVersion;
  DWORD                SizeOfCode;
  DWORD                SizeOfInitializedData;
  DWORD                SizeOfUninitializedData;
  DWORD                AddressOfEntryPoint;
  DWORD                BaseOfCode;
  ULONGLONG            ImageBase;
  DWORD                SectionAlignment;
  DWORD                FileAlignment;
  WORD                 MajorOperatingSystemVersion;
  WORD                 MinorOperatingSystemVersion;
  WORD                 MajorImageVersion;
  WORD                 MinorImageVersion;
  WORD                 MajorSubsystemVersion;
  WORD                 MinorSubsystemVersion;
  DWORD                Win32VersionValue;
  DWORD                SizeOfImage;
  DWORD                SizeOfHeaders;
  DWORD                CheckSum;
  WORD                 Subsystem;
  WORD                 DllCharacteristics;
  ULONGLONG            SizeOfStackReserve;
  ULONGLONG            SizeOfStackCommit;
  ULONGLONG            SizeOfHeapReserve;
  ULONGLONG            SizeOfHeapCommit;
  DWORD                LoaderFlags;
  DWORD                NumberOfRvaAndSizes;
  IMAGE_DATA_DIRECTORY DataDirectory[IMAGE_NUMBEROF_DIRECTORY_ENTRIES];
} IMAGE_OPTIONAL_HEADER64, *PIMAGE_OPTIONAL_HEADER64;
```

Optional Headers → ___

There is a lot going on in this structure but lets gleam a few important values from it that will come in handy:

1) ImageBase: a memory address (preferred) to load the image at. If we can’t load the PE here, we should load it somewhere else.
2) AddressOfEntryPoint: the RVA of the PE’s entry function. (I.e., ImageBase + AddressOfEntryPoint → Virtual Address of the entry point
3) SizeOfHeaders: the size of the PE’s headers

Steps to Load a PE

1) Get a pointer to the start of your PE Bytes.
2) Parse the DOS Header, and the NT Header
3) Map the PE into Memory
4) Resolve Imports
5) Perform Base Relocations
6) Fix Section Memory Protections (technically optional but you shouldn’t mark everything as R/W/X)
7) Pass execution to the entrypoint

Note steps 2 and 3 can be interchanged.

Mapping the PE into Memory

From the optional Headers, we know the size of the PE is ntHeader--> OptionalHeader-->SizeOfHeaders

We can use this to Allocate enough memory to hold all of the sections of our PE

```
BYTE* ImageBase =  (BYTE*)::VirtualAlloc(NULL,
    sizeOfImage,
    MEM_RESERVE | MEM_COMMIT,
    PAGE_READWRITE
    );
```

This gives us a pointer to a buffer in memory that we can read from and write to.

Breaking down the VirtualAlloc Args

NULL: I want the OS to figure out where in virtual memory to give me space. Alternatively, we could pass in a specific address.

sizeOfImage: how many bytes I want

MEM_RESERVE | MEM_COMMIT: reserve the contiguous memory, and ensure it is filled with 0s. Distinction between reserving and committing is a bit technical, so we omit details. But these are usually the parameters you want when calling VirtualAlloc

PAGE_READWRITE: I want to be able to read from and write to this block of memory

Mapping Sections

Recall that our PE has a preferred base address.

Since ASLR is enabled on most systems, there is a chance the address is unavailable.

We could make a call to VirtualAlloc with the preferred base address, check if it fails than set the parameter to NULL but in my experiment, we rarely get our desired address.

For simplicity, I skip this extra step, but just know we are deviating from what the actual PE loader does.

Mapping the PE into Memory

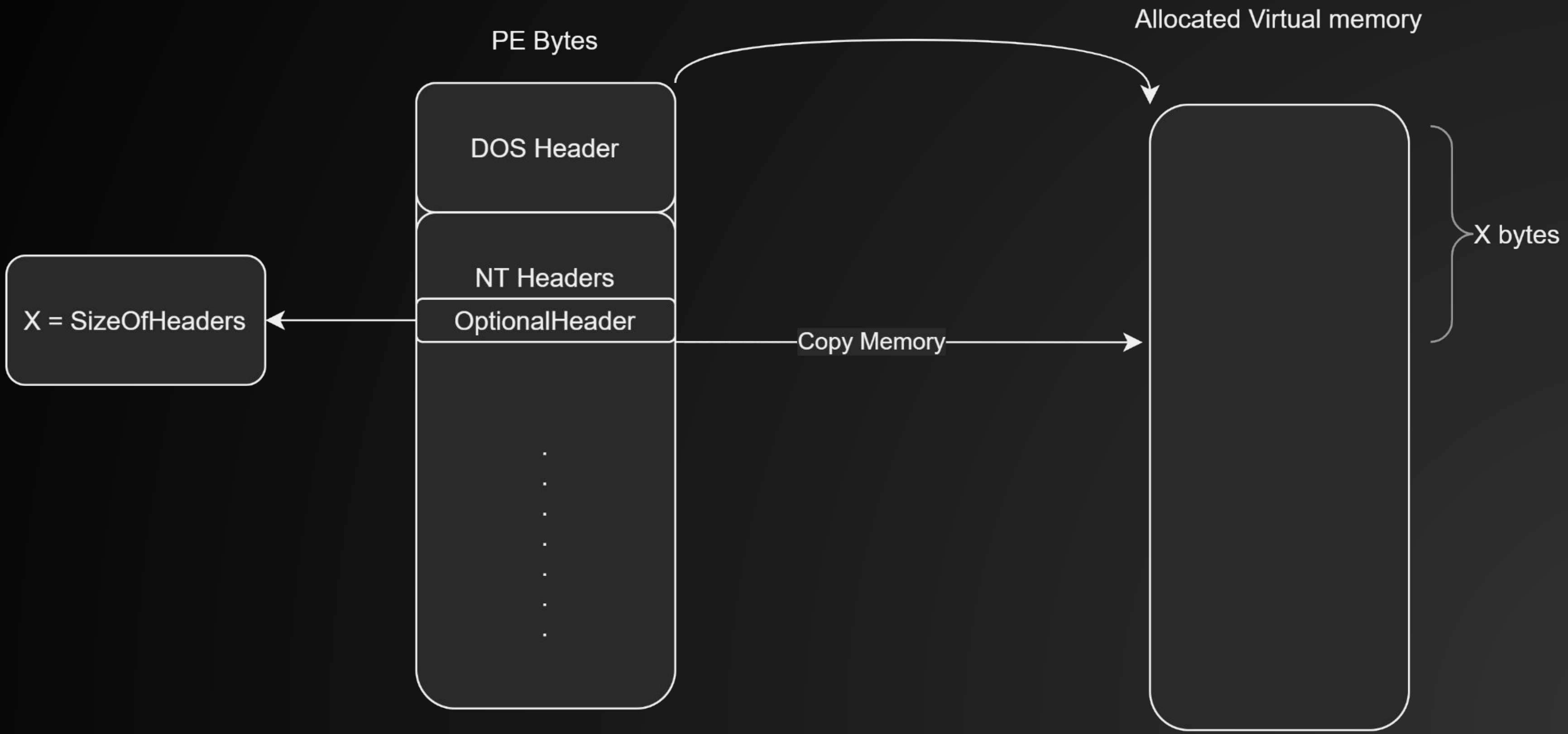
First, we need to copy the headers of the PE.

The first X bytes of the PE are the PE headers

X is located in the optional Header under SizeOfHeaders

To map the headers into memory, we simply copy X bytes starting at the beginning of the PE bytes, into the first X bytes of the newly allocated Buffer

Copying The Headers into Memory



PE Sections

PE Sections Struct

```
typedef struct _IMAGE_SECTION_HEADER {
  BYTE  Name[IMAGE_SIZEOF_SHORT_NAME];
  union {
    DWORD PhysicalAddress;
    DWORD VirtualSize;
  } Misc;
  DWORD VirtualAddress;
  DWORD SizeOfRawData;
  DWORD PointerToRawData;
  DWORD PointerToRelocations;
  DWORD PointerToLinenumbers;
  WORD  NumberOfRelocations;
  WORD  NumberOfLinenumbers;
  DWORD Characteristics;
} IMAGE_SECTION_HEADER, *PIMAGE_SECTION_HEADER;
```

Copying The Sections into Memory

We must now iterate over each section (i.e. .text .data .rdata ...etc) and map it into memory at the correct offset in our newly allocated buffer

The sections should come after the header

Sections are also structs whos definitions can be found in winnt.h

Iterating over Sections

- There is a handy macro that will give us the address of the first section: `IMAGE_FIRST_SECTION()`
- This macro returns a pointer to an array of Image sections
- We retrieved the number of sections in the previous step, and we can now iterate

Copying Sections

For each section struct, we need to get

- The VirtualAddress: RVA of the section
- PointerToRawData: a pointer to the section bytes
- SizeOfRawData: the number of bytes in the section

Add the RVA to the base address of the PE to get a pointer to the start of this section.

Copy SizeOfRawData bytes from PointertoRawData to BaseAddress + RVA

The Characteristic value also tells us what memory protection is required for the section

Handling Imports

Now that we have all of our sections mapped into memory, it is time to build the IAT

The Imports are described in the PE Header inside of the Optional Header

The Data Directories is struct corresponding to a table

Data Directory	Address	Size
Export Directory	0	0
Import Directory	2794	A0
Resource Directory	5000	4710
Exception Directory	4000	F0
Security Directory	0	0
Base Relocation Table	A000	2C
Debug Directory	2320	54
Architecture Specific Data	0	0
RVA of GlobalPtr	0	0
TLS Directory	0	0
Load Configuration Directory	2010	118
Bound Import Directory in headers	0	0
Import Address Table	2128	140
Delay Load Import Descriptors	0	0
.NET header	0	0

Building the IAT

IAT

Recall that the Import Address Table (IAT) is a table of function pointers

These function pointers are references to functions from loaded Libraries

The notation we use to reference a function from a DLL is with a $

I.e. user32.dll$MessageBoxA

Building up the IAT

We locate the Import Address Table by parsing the optional headers, which contains the data directory

The DataDirectory is an array of IMAGE_DATA_DIRECTORY structure

```
typedef struct _IMAGE_DATA_DIRECTORY {
    DWORD   VirtualAddress;
    DWORD   Size;
} IMAGE_DATA_DIRECTORY, *PIMAGE_DATA_DIRECTORY;
```

Data Directory	Address	Size
Export Directory	0	0
Import Directory	2794	A0
Resource Directory	5000	4710
Exception Directory	4000	F0
Security Directory	0	0
Base Relocation Table	A000	2C
Debug Directory	2320	54
Architecture Specific Data	0	0
RVA of GlobalPtr	0	0
TLS Directory	0	0
Load Configuration Directory	2010	118
Bound Import Directory in headers	0	0
Import Address Table	2128	140
Delay Load Import Descriptors	0	0
.NET header	0	0

Getting the Import Address table

- Given the start address of the DataDirectory (cast as the correct type), we can reference the start of the Import Address Table
    - `ntHeaders->OptionalHeader.DataDirectory[IMAGE_DIRECTORY_ENTRY_IAT];`
- The IAT contains the functions address, but we don’t know which entry the function pointer belongs to
- This information is contained elsewhere

Import Directory Table

- The IDT is a null terminated array of IMAGE_IMPORT_DESCRIPTOR structs
- I sometimes absent mindedly call this the Import Descriptor Table (which is NOT a thing), because it contains the descriptions of required modules
- The Import Directory table, contains entries for modules loaded by the image
- The Loader uses this table to build the IAT with function pointers to absolute Virtual Addresses.
- Recall these entries should point to the correct offset in a loaded DLL

TLDR: this is where we find our null terminated array of DLLs required by our PE

Import Lookup Table

The ILT is also a null terminated array of IMAGE_THUNK_DATA structs

IMAGE_THUNK_DATA expands to IMAGE_THUNK_DATA32/64 depending on the architecture.

These structs contain the functions within the DLL that we need to load.

```
typedef struct _IMAGE_THUNK_DATA64 {
    union {
        ULONGLONG ForwarderString;  // PBYTE
        ULONGLONG Function;         // PDWORD
        ULONGLONG Ordinal;
        ULONGLONG AddressOfData;    // PIMAGE_IMPORT_BY_NAME
    } u1;
} IMAGE_THUNK_DATA64;
typedef IMAGE_THUNK_DATA64 * PIMAGE_THUNK_DATA64;
```

ILT Parsing

- The ILT can specify imported functions by either Name or Ordinal value
- For ordinal fields, the union in IMAGE_THUNK_DATA will have the most significant bit set to 1
  - In the above case, we can extract the the ordinal name from the least significant bytes
- If the bit is not set, the name of the function is contained in an IMAGE_IMPORT_BY_NAME struct

Data Directories

The directories appear in a fixed order, (Export Directory <*> followed by Import Directory <*> followed by Resource Directory <*>...etc)

The values in the Data directory that we need to read/modify are

1) The import directory
2) Import Address Directory Table (IDT)
3) Import Address Table (IAT)

Data Directories

The IDT gives us information about what imports are required for the PE to load

The IAT provides the programer an interface to reference an RVA that will contain a trampoline to the actual address of the imported function at run time.

The Import Directory RVA points to a NULL terminated array of IMAGE_IMPORT_DESCRIPTOR structs

IMAGE_IMPORT_DESCRIPTOR

```
typedef struct _IMAGE_IMPORT_DESCRIPTOR {
    union {
        DWORD   Characteristics;            // 0 for terminating null import descriptor
        DWORD   OriginalFirstThunk;         // RVA to original unbound IAT (PIMAGE_THUNK_DATA)
    } DUMMYUNIONNAME;
    DWORD   TimeDateStamp;                  // 0 if not bound,
                                            // -1 if bound, and real date\time stamp
                                            //     in IMAGE_DIRECTORY_ENTRY_BOUND_IMPORT (new BIND)
                                            // O.W. date/time stamp of DLL bound to (Old BIND)

    DWORD   ForwarderChain;                 // -1 if no forwarders
    DWORD   Name;
    DWORD   FirstThunk;                     // RVA to IAT (if bound this IAT has actual addresses)
} IMAGE_IMPORT_DESCRIPTOR;
```

Iterating over Libraries

- For each Image import descriptor, attempt to get a handle to the library. If this fails, panic.
- Add the data directories IMAGE_DIRECTORY_ENTRY_IMPORT RVA to the base address to get the start of the NULL terminated array of IMAGE_IMPORT_DESCRIPTOR structs
- We must now walk this array.
- Each Image Descriptor will have a
- → Name (the DLL to load)
- → IMAGE_THUNK_DATA* which points to “THUNK” (functions resolved at a later date)
- Call LoadLibraryA on → Name
- For each image descriptor, we must now iterate through the list of functions required for that library

Iterating over Functions in a Module

- Parse the OriginalFirstThunk and FirstThunk entry points for this library
- These entries are both null terminated `IMAGE_THUNK_DATA` structs.
- The OriginalFirstThunk entry points to an array of references to the functions to import from the external library. This is exactly the Import Lookup Table.
- FirstThunk points to a list of addresses that gets filled with pointers to the imported symbols. This is exactly the import Address table.

IMAGE_THUNK_DATA

Also a macro that expands to the 32bit/64bit version

```
typedef struct _IMAGE_THUNK_DATA64 {
    union {
        ULONGLONG ForwarderString;  // PBYTE
        ULONGLONG Function;         // PDWORD
        ULONGLONG Ordinal;
        ULONGLONG AddressOfData;    // PIMAGE_IMPORT_BY_NAME
    } u1;
} IMAGE_THUNK_DATA64;
typedef IMAGE_THUNK_DATA64 * PIMAGE_THUNK_DATA64;
```

Image thunk Data

We recover the function name either via Ordinal or via Name.

We read the function name from our lookup table, as well as the RVA

The Function field needs to be patched with the functions address

We call GetProcAddress (eiter on the ordinal or the Name) and set the value of the lookup table to the address of the loaded function

Repeat this for each function, and each library!

Debugging

Tips for Debugging:

- Look at the entry point of the PE you are loading.
- Notice the symbols you see for functions are actually references to the IAT
- Break at the entrypoint of the manually loaded PE and compare it to the legitimately loaded PE
- If these symbols differ, the IAT was not created properly
- Example: detecting (an actual bug) that ate my Wednesday night.

Tips

- Breakpoint at VirtualAlloc
- MessageBoxA ← just put these wherever you want to break at. Or you can compile with symbols/Configure VSCode.
- Breakpoint at CreateThread/However you pass execution.
  - Set a breakpoint at the entry point (in this case, register R8 should have the address of the entry point)
- Ctrl-f9 (execute until function return) is your friend!
- F8 step over a function call (run until return then call ret)
- F7 step into (follow RIP into the function)

Tips Continued

- Debugging ACCESS_VIOLATION:
    - This error means you
        - Tried to read memory you are not allowed to read
        - Tried to write to memory your are not allowed to write to
        - Tied to execute memory you are not allowed to execute
- For the PE loader, you either
    - Messed up the memory protections
    - Have invalud function pointers in your IAT
    - Did not perform relocations properly
    - *Other PE stuff (TLS callbacks)

Relocations

- Recall that the ImageBase is the preferred base address of the PE once it is mapped into memory
- If we were able to give the PE its preferred address, then we are done! Pass execution off the the entry point.
- If not, we have more work to do.
- If the PE has acknowledge the existence of ASLR, we can map it into a different location. If not, panic.

Dealing with Absolute Addresses

Our PE, while aware of ASLR, might still references addresses that are absolute addresses.

In this case, we need to find all of them, calculate their offset from the preferred address, and patch them

The PE file format makes this easy for us with a structure called the relocation table

IMAGE_BASE_RELOCATION

The VirtualAddress is a relative Virtual address, where we can relocate a block

The SizeOfBlock is...well the size of the block

```
typedef struct _IMAGE_BASE_RELOCATION
{  DWORD      VirtualAddress;
   DWORD      SizeOfBlock;
}  IMAGE_BASE_RELOCATION, *PIMAGE_BASE_RELOCATION;
```

Data Directory	Address	Size
Export Directory	0	0
Import Directory	2794	A0
Resource Directory	5000	4710
Exception Directory	4000	F0
Security Directory	0	0
Base Relocation Table	A000	2C
Debug Directory	2320	54
Architecture Specific Data	0	0
RVA of GlobalPtr	0	0
TLS Directory	0	0
Load Configuration Directory	2010	118
Bound Import Directory in headers	0	0
Import Address Table	2128	140
Delay Load Import Descriptors	0	0
.NET header	0	0

Relocations

If the Base Address of the allocated memory matches the preferred base address of the PE, there is nothing to be done!

Else, we might need to patch some values.

We can parse the relocation table from the option headers inside of the Data Directory

We can also compute the “delta” in base addresses by taking the preferred base address and subtracting it from the mapped address.

Base Relocation

All memory addresses in the code and data sections are stored relative to the address defined by ImageBase in the OptionalHeader.

If the PE can't be loaded at its preferred memory address, the references must reflect this!

The PE stores informations about all these references in the base relocation table inside of the Data Directory

Relocation

Each entry has (SizeOfBlock - IMAGE_SIZEOF_BASE_RELOCATION) / 2 entries where each entry is a word.

The first 4 bits define the type of relocation

the lower 12 bits define the offset relative to the VirtualAddress.

```
typedef struct _IMAGE_BASE_RELOCATION {
    DWORD   VirtualAddress;
    DWORD   SizeOfBlock;
} IMAGE_BASE_RELOCATION;
```

It’s just a switch case

IMAGE_REL_BASED_ABSOLUTE : nothing to be done

IMAGE_REL_BASED_HIGHLOW: Add the delta between the preferred base address and the allocated memory block to the 32 bits found at the offset.

IMAGE_REL_BASED_DIR64: Same as above, but addresses are 64 bit.

TLS Callbacks

I am just going to give you this one.

If you want to use multiple threads, you need to run TLS callbacks that prepare Thread Local Storage. Run this right before passing off execution

```
void HandleTLSCallbacks(void* lpImageBase, IMAGE_NT_HEADERS* ntHeaders){
    if(ntHeaders->OptionalHeader.DataDirectory[IMAGE_DIRECTORY_ENTRY_TLS].Size)
    {
        PIMAGE_TLS_DIRECTORY tls = (PIMAGE_TLS_DIRECTORY)( (UINT_PTR)lpImageBase +
ntHeaders->OptionalHeader.DataDirectory[IMAGE_DIRECTORY_ENTRY_TLS].VirtualAddress);
        PIMAGE_TLS_CALLBACK *callback = (PIMAGE_TLS_CALLBACK *) tls->AddressOfCallBacks;

        while(*callback)
        {
            wprintf(L"[+] TLS callback at %p\n", (void*) callback);
            (*callback)((LPVOID) lpImageBase, DLL_PROCESS_ATTACH, NULL);
            callback++;
        }
    } else{
        wprintf(L"No Tls Callbacks!\n");
    }
}
```

Packers/Crypters

- Yara rules will help us identify static content in PEs.
- We can no longer fully rely on them to detect the malware
- Since we can run a PE from memory, we can embed a compressed, and encrypted PE inside of another PE
- We can, however, use it to detect the stub that unpacks the malware
- Usually though, we want to unpack the malware to identify not just the packer but also the final payload
- This also has implications in how First/second stage payloads work

UnPacking Malware

Let’s assume for now that the unpacked payload is a .exe PE.

Most stubs that unpack malware need to do the following

1) Recover the raw PE Bytes (decompress, decrypt...etc)
2) Allocate memory, some of which needs to be executable
3) Copy the PE into memory
4) Resolve Import Address Table
5) Handle Relocations
6) TLS callbacks
7) Pass execution to the entry point

Unpacking: Useful Breakpoints

- As always, look at the imports. There might, however, might not be any!
- If we can catch the loader/packer before it passes off execution, we can simply dump the PE from memory
  - Note that the PE we dump might be memory mapped, in which case we will need to perform the opposite of what our loader does!
- Set a Breakpoint at VirtualAlloc(Ex), or other functions used to allocate memory (HeapAlloc, NtAllocateVirtualMemory...etc)
  - Run until Return. The value in RAX will be the base address of the allocate memory
  - Follow this address in dump and keep an eye on this until you see the sections copied into memory

Matryoshka Dolls

- Malware authors will routinely Compose Packers
- This can get very annoying, very fast.
- You can actually run the same packer multiple times.
- For example, we can UPX pack our loader to load a UPX packed exe.
- First, we need to unpack the real loader, then we unpack the packed payload, then we can dump the actual payload

Building your own Packer

- Compile a stub to unpack your code that decrypts, and decompresses data embedded in the PE. An example of this could be a resource file
- Python pefile makes interacting with PE resources easy
- This way, you can use python to compress and encrypt your payload, and you can embed the result as a resource in a fixed place.
- The primary purpose of a packer is two fold:
- 1) Hash Busting: old signatures no longer work on the packed malware. You can (and should!) write yara rules for the stub-- but it is very easy to also hash bust the stub!
- 2) Frustrating the reverse engineer.

Automation

- Scripting a debugger : set breakpoints at common functions found in Packers and scan memory for the magic MZ
- Unpack.me: unpacking sandbox. Sadly for you all, it is 32bit only >:)
- PE-Sieve: incredible tool by Hasherezade that checks for injected PEs/Shellcode in a process
- Writing a static unpacker for a specific packer you see a lot can take time, but depending on the circumstances could also be worth it!