STATIC MALWARE ANALYSIS TOOLS AND TECHNIQUES

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SCHOOL OF ECE

CREATING THE NEXT®

PLEASE CONSIDER THE ENVIRONMENT, AVOID PRINTING SLIDES!

MANY THANKS TO GOLDEN RICHARD AND MATHIAS PAYER FOR THEIR CONTRIBUTIONS TO THESE SLIDES

STATIC MALWARE ANALYSIS

- Study code of malware sample without executing
- Advantages
  - No danger of executing payload
  - Discovery of otherwise hidden behaviors
- Disadvantages
  - Encryption / packing
  - Complexity
  - Compilation obfuscates high level language structures

TOOLS OF THE TRADE

- EXE manipulation tools (e.g., dumpbin/PEView/PE Explorer)
  - Analyze structure of EXE
  - Dump code, data, import tables, export tables, resources, …
- Disassemblers (e.g., IDA, Ghidra)
  - Analyze code (generally in assembler)
  - Annotate code and data to increase understanding
- Decompilers (e.g., Hex-Rays decompiler plugin for IDA)
  - Attempt to translate into high level languages/pseudocode

ANALYZING EXECUTABLE FILE FORMATS

- The goal of analyzing executable files is to understand:
  - Sections
  - Entry point
  - Dependencies
    - Imported functions
    - Exported functions
  - Symbol table
  - Code
  - Initialized data
  - Relocation information
  - …
- e.g., dumpbin (Windows), PEView (Windows), readelf (Linux), otool (Mac OS X)
- Tools are NOT a replacement for a deep understanding of the executable formats
  - Read, study, Google, learn everything you can about the format of the file you're analyzing

MUST I?

- Short answer: Yes

- For many old DOS viruses, firmware, etc. and some Windows malware, it may be possible to do reverse engineering without caring about executable file formats

- In general, nearly all modern malware heavily abuse executable file formats to infect and propagate

- During reverse engineering, code may be opaque (to you) unless you understand executable file formats in detail
- Reverse engineering is often all about the nasty details…sorry!
  - Google, Google, Google! E.g., “What is offset 0x65 in PE Header?”

EXECUTABLE FORMATS

- Executable format allows a loader to instantiate a new program execution
  - Loader may be a program or part of the operating system
- Compiler may even insert some “set up” code before your main(…) function
  - Helps handle transition from the loader to the program
  - Initializes data, calls initialization functions in libraries
  - Read about: __tmainCRTStartup
- Programs then execute machine code directly and interface with the runtime system (libraries & OS)
- Executable formats have evolved, many different formats exist
- DOS/Windows executables evolved from COM files that were restricted to 64KB to EXE files executing in 16-bit mode to 32-bit and 64-bit Windows executables
- On Unix, ELF (Executable and Linkable Format) is most common, by far

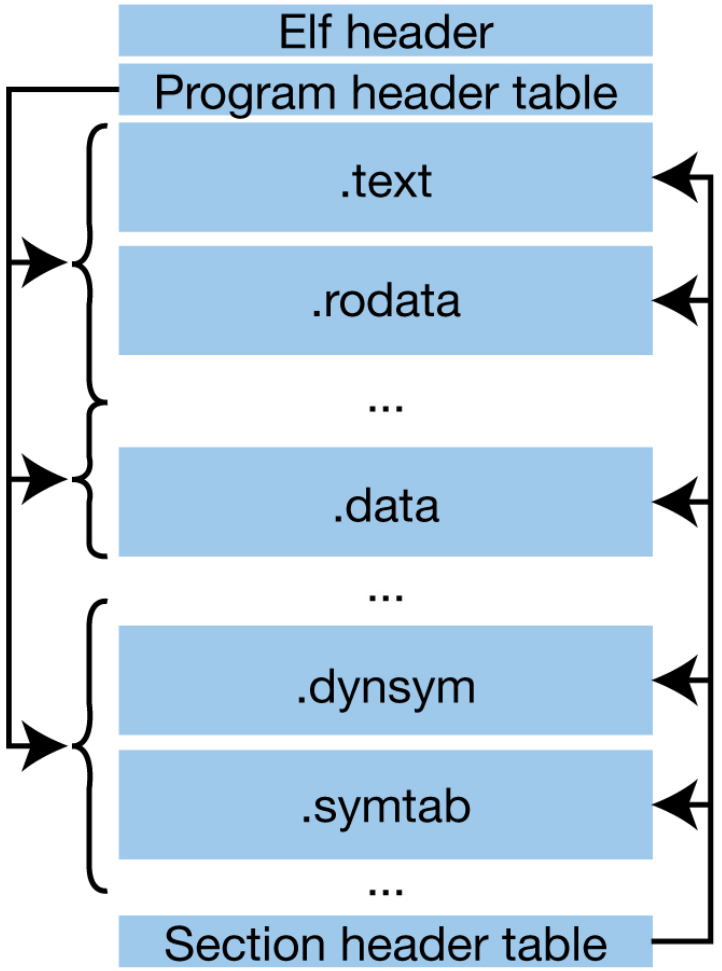
ELF FORMAT (LINUX)

- ELF allows two interpretations of each file:
- **Segments** contain permissions and mapped regions
- **Sections** enable linking and relocation

- The loader:

1) Reads the ELF header
2) Maps segments into a new virtual address space
3) Resolves relocations
4) Starts executing from the entry point

- If .interp section is present, the interpreter loads the interpreter executable (and resolves relocations)
  - This section holds the literal path name of the interpreter



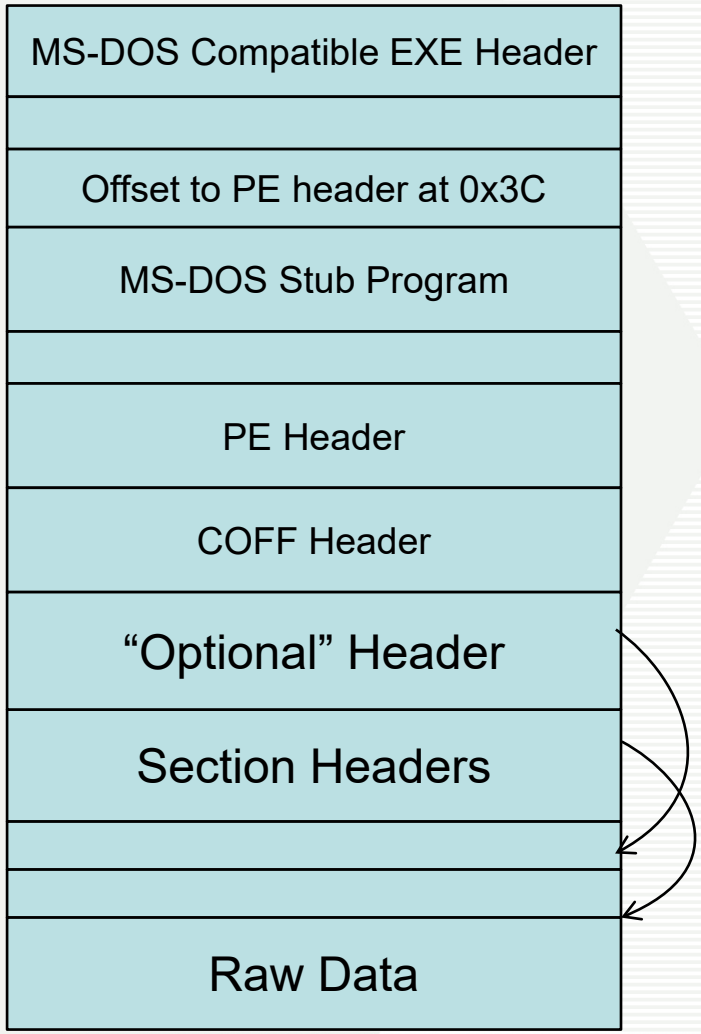
TOOLS FOR INSPECTING ELF EXECUTABLES

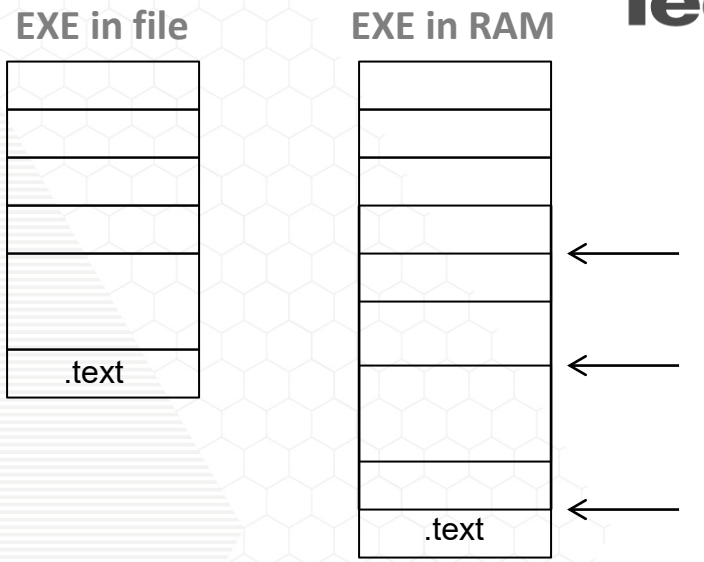
- readelf and objdump can display information about ELF files
  - Executables, shared objects, archives, object files, …
- Your brain is better than those
  - Many different ELF specifications for different platforms
  - https://en.wikipedia.org/wiki/Executable_and_Linkable_Format#Specifications
- readelf -h <filename> displays basic information about ELF header
- readelf -l <filename> displays program headers used by loader to map program into memory
- readelf -S <filename> displays sections, used by loader to relocate and connect different parts of the executable

WINDOWS PE FORMAT

- Portable Executable (PE) format for .EXE, .SCR, .DLL et al.
  - No particular distinction between these
    - EXEs contain a startup entry point/DLLs export functions
- File format consists of a number of sections, including a section for “backwards compatibility” with MS-DOS
  - Backwards compatibility is typically limited to a small embedded application that indicates Windows is required
- Complete specification available from Microsoft:
  - “Microsoft Portable Executable and Common Object File Format Specification”
  - We will also use “Peering Inside the PE”
    - Online at: https://msdn.microsoft.com/en-us/library/ms809762(d=printer).aspx
    - PDF also on Canvas!
- Very important to be familiar with all the details!

PE SECTION ALIGNMENT IN FILE VS. MEMORY





- Typical file alignment: 512 bytes
- Typical section alignment: 4K (page size)

- These pointers are RVAs!

- Relative Virtual Addresses
- Offsets from **base address once loaded in memory**

- https://en.wikipedia.org/wiki/COFF#Relative_virtual_address

COFF FILE HEADER

Offset	Size	Field	Description
0	2	Machine	The number that identifies the type of target machine. For more information, see section 3.3.1, “Machine Types.”
2	2	NumberOfSections	The number of sections. This indicates the size of the section table, which immediately follows the headers.
4	4	TimeDateStamp	The low 32 bits of the number of seconds since 00:00 January 1, 1970 (a C run-time time_t value), that indicates when the file was created.
8	4	PointerToSymbolTable	The file offset of the COFF symbol table, or zero if no COFF symbol table is present. This value should be zero for an image because COFF debugging information is deprecated.
12	4	NumberOfSymbols	The number of entries in the symbol table. This data can be used to locate the string table, which immediately follows the symbol table. This value should be zero for an image because COFF debugging information is deprecated.
16	2	SizeOfOptionalHeader	The size of the optional header, which is required for executable files but not for object files. This value should be zero for an object file. For a description of the header format, see section 3.4, “Optional Header (Image Only).”
18	2	Characteristics	The flags that indicate the attributes of the file. For specific flag values, see section 3.3.2, “Characteristics.”

"OPTIONAL" HEADER

- Not optional at all for executables…optional only for object files
- Contains information that helps the loader
- PE32 is 32-bit, PE32+ is 64-bit

Offset (PE32/PE32+)	Size (PE32/PE32+)	Header part	Description
0	28/24	Standard fields	Fields that are defined for all implementations of COFF, including UNIX.
28/24	68/88	Windows-specific fields	Additional fields to support specific features of Windows (for example, subsystems).
96/112	Variable	Data directories	Address/size pairs for special tables that are found in the image file and are used by the operating system (for example, the import table and the export table).

"OPTIONAL" HEADER (2)

Offset	Size	Field	Description
0	2	Magic	The unsigned integer that identifies the state of the image file. The most common number is 0x10B, which identifies it as a normal executable file. 0x107 identifies it as a ROM image, and 0x20B identifies it as a PE32+ executable.
2	1	MajorLinkerVersion	The linker major version number.
3	1	MinorLinkerVersion	The linker minor version number.
4	4	SizeOfCode	The size of the code (text) section, or the sum of all code sections if there are multiple sections.
8	4	SizeOfInitializedData	The size of the initialized data section, or the sum of all such sections if there are multiple data sections.
12	4	SizeOfUninitializedData	The size of the uninitialized data section (BSS), or the sum of all such sections if there are multiple BSS sections.
16	4	AddressOfEntryPoint	The address of the entry point relative to the image base when the executable file is loaded into memory. For program images, this is the starting address. For device drivers, this is the address of the initialization function. An entry point is optional for DLLs. When no entry point is present, this field must be zero.
20	4	BaseOfCode	The address that is relative to the image base of the beginning-of-code section when it is loaded into memory.

"OPTIONAL" HEADER (3)

PE32 contains this additional field, which is absent in PE32+, following BaseOfCode.

Offset	Size	Field	Description
24	4	BaseOfData	The address that is relative to the image base of the beginning-of-data section when it is loaded into memory.

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Windows-specific fields

Offset (PE32/ PE32+)	Size (PE32/ PE32+)	Field	Description
28/24	4/8	ImageBase	The preferred address of the first byte of image when loaded into memory; must be a multiple of 64 K. The default for DLLs is 0x10000000. The default for Windows CE EXEs is 0x00010000. The default for Windows NT, Windows 2000, Windows XP, Windows 95, Windows 98, and Windows Me is 0x00400000.
32/32	4	SectionAlignment	The alignment (in bytes) of sections when they are loaded into memory. It must be greater than or equal to FileAlignment. The default is the page size for the architecture.
36/36	4	FileAlignment	The alignment factor (in bytes) that is used to align the raw data of sections in the image file. The value should be a power of 2 between 512 and 64 K, inclusive. The default is 512. If the SectionAlignment is less than the architecture's page size, then FileAlignment must match SectionAlignment.

Impacts Relative Virtual Addresses (RVAs)

"OPTIONAL" HEADER (5)

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More Windows-specific fields

40/40	2	MajorOperatingSystemVersion	The major version number of the required operating system.
42/42	2	MinorOperatingSystemVersion	The minor version number of the required operating system.
44/44	2	MajorImageVersion	The major version number of the image.
46/46	2	MinorImageVersion	The minor version number of the image.
48/48	2	MajorSubsystemVersion	The major version number of the subsystem.
50/50	2	MinorSubsystemVersion	The minor version number of the subsystem.
52/52	4	Win32VersionValue	Reserved, must be zero.
56/56	4	SizeOfImage	The size (in bytes) of the image, including all headers, as the image is loaded in memory. It must be a multiple of SectionAlignment.

"OPTIONAL" HEADER (6)

More more Windows-specific fields

60/60	4	SizeOfHeaders	The combined size of an MS-DOS stub, PE header, and section headers rounded up to a multiple of FileAlignment.
64/64	4	CheckSum	The image file checksum. The algorithm for computing the checksum is incorporated into IMAGHELP.DLL. The following are checked for validation at load time: all drivers, any DLL loaded at boot time, and any DLL that is loaded into a critical Windows process.
68/68	2	Subsystem	The subsystem that is required to run this image. For more information, see "Windows Subsystem" later in this specification.
70/70	2	DllCharacteristics	For more information, see "DLL Characteristics" later in this specification.
72/72	4/8	SizeOfStackReserve	The size of the stack to reserve. Only SizeOfStackCommit is committed; the rest is made available one page at a time until the reserve size is reached.
76/80	4/8	SizeOfStackCommit	The size of the stack to commit.

"OPTIONAL" HEADER (7)

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More more more Windows-specific fields

80/88	4/8	SizeOfHeapReserve	The size of the local heap space to reserve. Only SizeOfHeapCommit is committed; the rest is made available one page at a time until the reserve size is reached.
84/96	4/8	SizeOfHeapCommit	The size of the local heap space to commit.
88/104	4	LoaderFlags	Reserved, must be zero.
92/108	4	NumberOfRvaAndSizes	The number of data-directory entries in the remainder of the optional header. Each describes a location and size.

"OPTIONAL" HEADER: DATA DIRECTORIES

```
typedef struct _IMAGE_DATA_DIRECTORY {
    // relative virtual address (RVA) of table
    DWORD   VirtualAddress;
    DWORD   Size; // size of table in bytes
} IMAGE_DATA_DIRECTORY, *PIMAGE_DATA_DIRECTORY;
```

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These are important in RE:

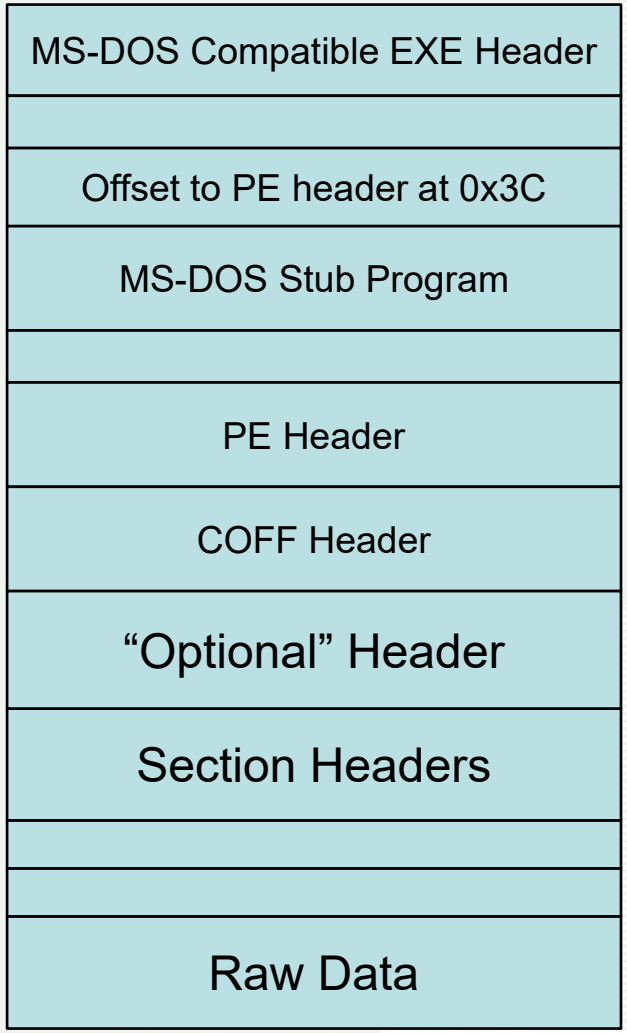
Offset (PE/PE32+)	Size	Field	Description
96/112	8	Export Table	The export table address and size. For more information see section 6.3, "The .edata Section (Image Only)."
104/120	8	Import Table	The import table address and size. For more information, see section 6.4, "The .idata Section."
112/128	8	Resource Table	The resource table address and size. For more information, see section 6.9, "The .rsrc Section."
120/136	8	Exception Table	The exception table address and size. For more information, see section 6.5, "The .pdata Section."
128/144	8	Certificate Table	The attribute certificate table address and size. For more information, see section 5.7, "The attribute certificate table (Image Only)."
136/152	8	Base Relocation Table	The base relocation table address and size. For more information, see section 6.6, "The **.reloc** Section (Image Only)."
144/160	8	Debug	The debug data starting address and size. For more information, see section 6.1, "The .debug Section."
152/168	8	Architecture	Reserved, must be 0

DATA DIRECTORIES (2)

These are important in RE:

160/176	8	Global Ptr	The RVA of the value to be stored in the global pointer register. The size member of this structure must be set to zero.
168/184	8	TLS Table	The thread local storage (TLS) table address and size. For more information, see section 6.7, “The .tls Section.”
176/192	8	Load Config Table	The load configuration table address and size. For more information, see section 6.8, “The Load Configuration Structure (Image Only).”
184/200	8	Bound Import	The bound import table address and size.
192/208	8	IAT	The import address table address and size. For more information, see section 6.4.4, “Import Address Table.”
200/216	8	Delay Import Descriptor	The delay import descriptor address and size. For more information, see section 5.8, “Delay-Load Import Tables (Image Only).”
208/224	8	CLR Runtime Header	The CLR runtime header address and size. For more information, see section 6.10, “The .cormeta Section (Object Only).”
216/232	8	Reserved, must be zero	

SECTION HEADERS



- Section headers area follows the “optional” header in the PE file
- Contains a series of 40 byte entries
- Each entry describes one of the sections in the file
- Section headers are followed by section data
  - .text, .bss, etc.

SECTION HEADERS

Offset	Size	Field	Description
0	8	Name	An 8-byte, null-padded UTF-8 encoded string. If the string is exactly 8 characters long, there is no terminating null. For longer names, this field contains a slash (/) that is followed by an ASCII representation of a decimal number that is an offset into the string table. Executable images do not use a string table and do not support section names longer than 8 characters. Long names in object files are truncated if they are emitted to an executable file.
8	4	VirtualSize	The total size of the section when loaded into memory. If this value is greater than SizeOfRawData, the section is zero-padded. This field is valid only for executable images and should be set to zero for object files.
12	4	VirtualAddress	For executable images, the address of the first byte of the section relative to the image base when the section is loaded into memory. For object files, this field is the address of the first byte before relocation is applied; for simplicity, compilers should set this to zero. Otherwise, it is an arbitrary value that is subtracted from offsets during relocation.
16	4	SizeOfRawData	The size of the section (for object files) or the size of the initialized data on disk (for image files). For executable images, this must be a multiple of FileAlignment from the optional header. If this is less than VirtualSize, the remainder of the section is zero-filled. Because the SizeOfRawData field is rounded but the VirtualSize field is not, it is possible for SizeOfRawData to be greater than VirtualSize as well. When a section contains only uninitialized data, this field should be zero.
20	4	PointerToRawData	The file pointer to the first page of the section within the COFF file. For executable images, this must be a multiple of FileAlignment from the optional header. For object files, the value should be aligned on a 4-byte boundary for best performance. When a section contains only uninitialized data, this field should be zero.

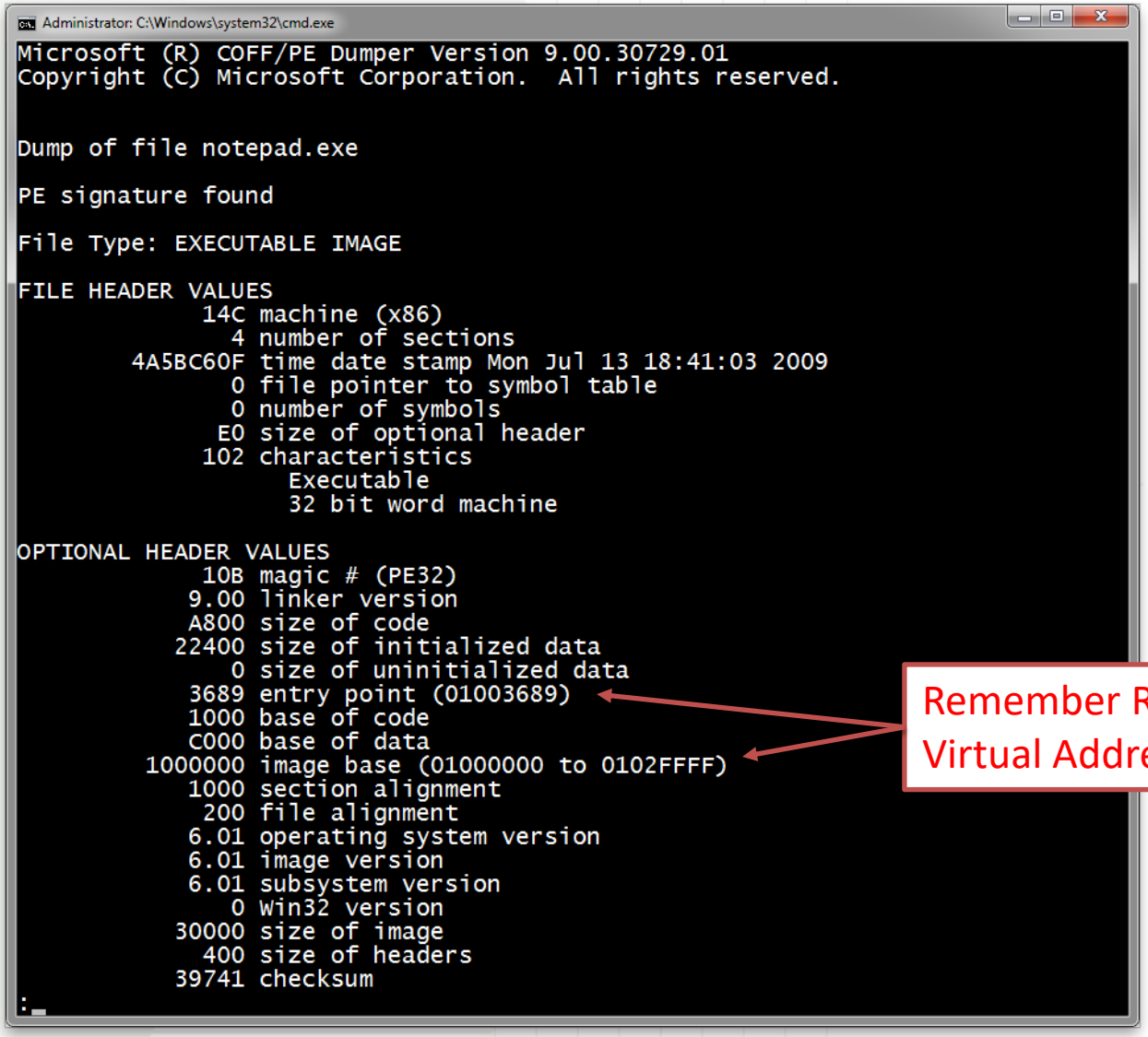
24	4	PointerToRelocations	The file pointer to the beginning of relocation entries for the section. This is set to zero for executable images or if there are no relocations.
28	4	PointerToLineNumbers	The file pointer to the beginning of line-number entries for the section. This is set to zero if there are no COFF line numbers. This value should be zero for an image because COFF debugging information is deprecated.
32	2	NumberOfRelocations	The number of relocation entries for the section. This is set to zero for executable images.
34	2	NumberOfLinenumbers	The number of line-number entries for the section. This value should be zero for an image because COFF debugging information is deprecated.
36	4	Characteristics	The flags that describe the characteristics of the section. For more information, see section 4.1, “Section Flags.”

IMPORTANT PE SECTIONS

- .bss section
  - Uninitialized data
- .data section
  - Initialized data
- .edata section
  - Export table for file
- .idata section
  - Import table for file
- .text section
  - Executable code
- Others
- Names are by convention—they can vary!

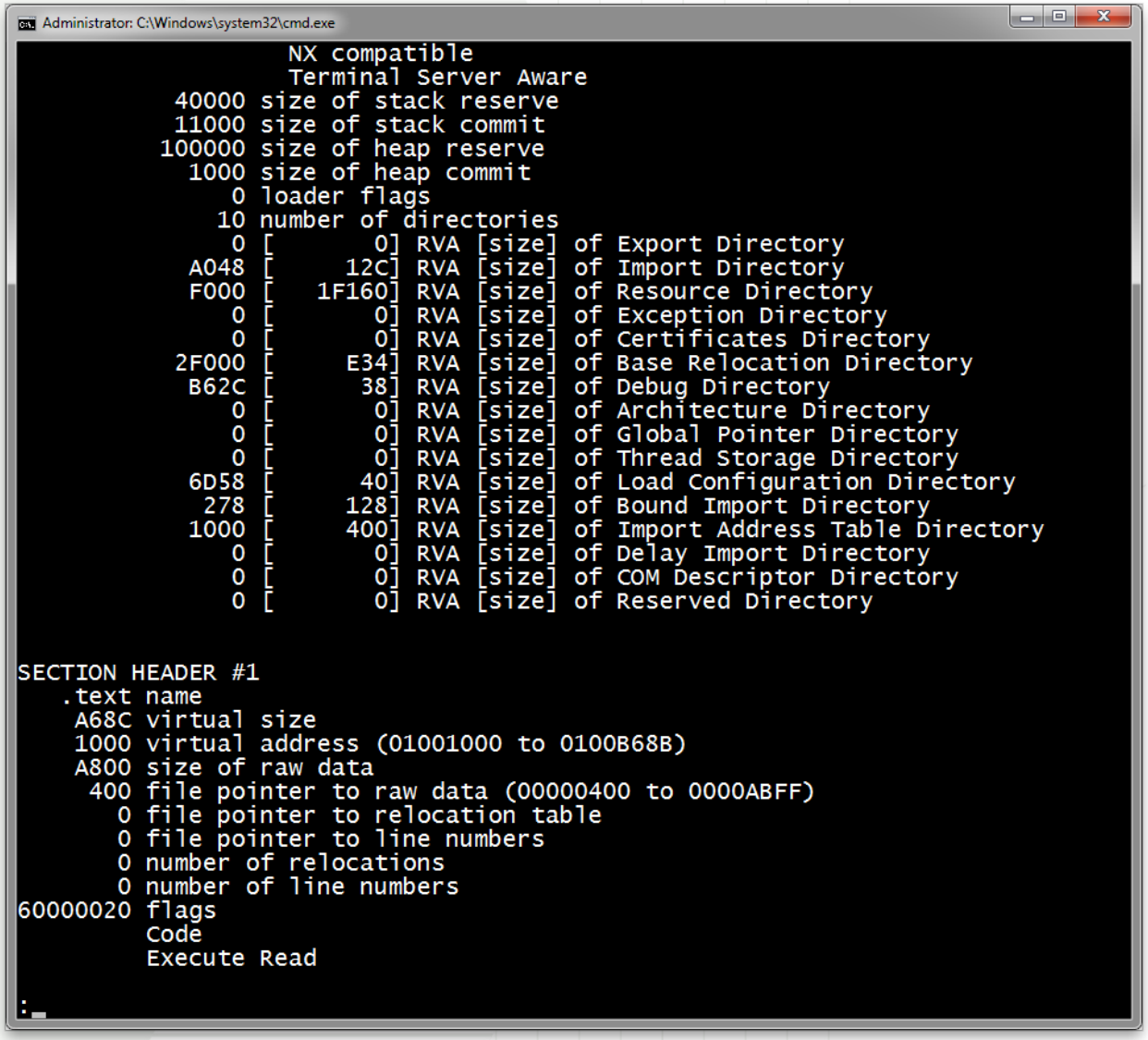
- Many tools exist for static analysis of PE file sections!
  - dumpbin
  - PEView
  - PE Explorer

DUMPBIN NOTEPAD.EXE

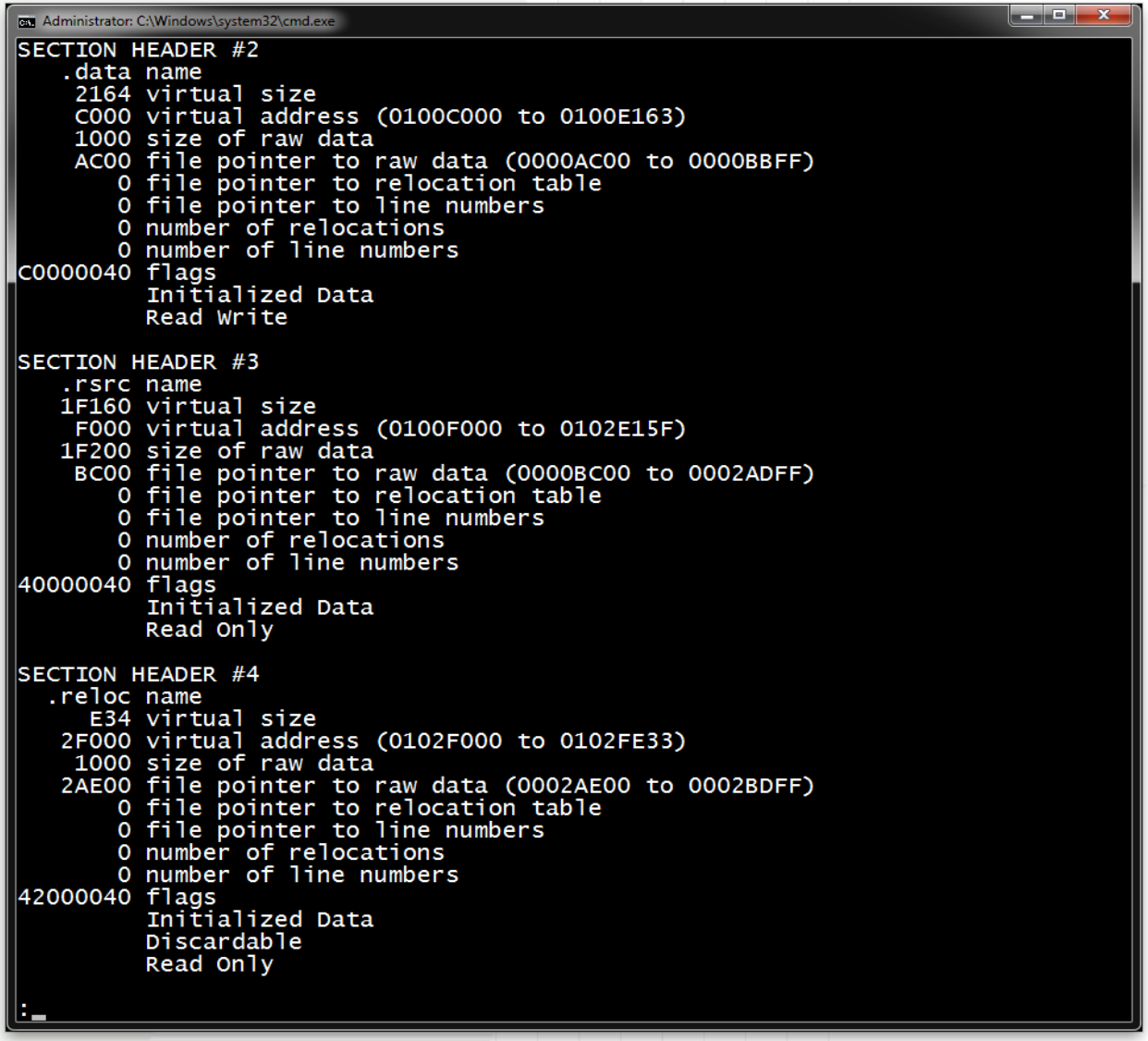


Remember Relative Virtual Addresses (RVAs)!

DUMPBIN NOTEPAD.EXE (2)



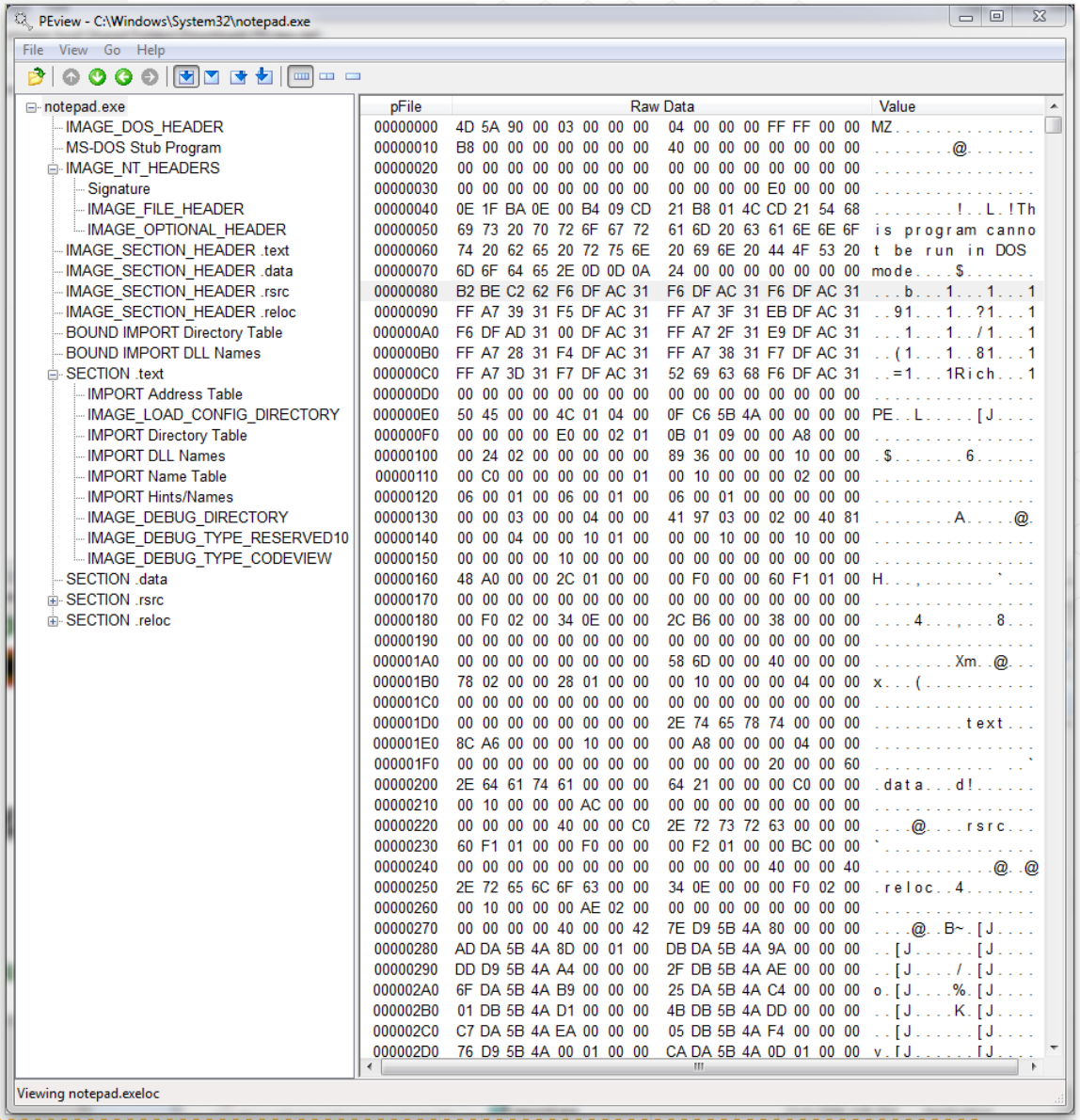
DUMPBIN NOTEPAD.EXE (3)



DUMPBIN NOTEPAD.EXE IMPORTS

```
C:\WINDOWS\system32\cmd.exe
C:\WINDOWS\system32>dumpbin notepad.exe /imports
Microsoft (R) COFF/PE Dumper Version 9.00.30729.01
Copyright (C) Microsoft Corporation.  All rights reserved.


Dump of file notepad.exe

File Type: EXECUTABLE IMAGE

  Section contains the following imports:

    comdlg32.dll
              10012C4 Import Address Table
              1007990 Import Name Table
            FFFFFFFF time date stamp
            FFFFFFFF Index of first forwarder reference

      763D4906       F PageSetupDlgW
      763C85CE       6 FindTextW
      763D9D84      12 PrintDlgExW
      763CC3E1       3 ChooseFontW
      763B2306       8 GetFileTitleW
      763C7B9D       A GetOpenFileNameW
      763C8602      15 ReplaceTextW
      763C0036       4 CommDlgExtendedError
      763C7C2B       C GetSaveFileNameW

    SHELL32.dll
              1001174 Import Address Table
              1007840 Import Name Table
            FFFFFFFF time date stamp
            FFFFFFFF Index of first forwarder reference

      7CA77C18      1F DragFinish
      7CA118CE      23 DragQueryFileW
      7CA2B1A9      1E DragAcceptFiles
      7CA62E6F     103 ShellAboutW

    WINSPOOL.DRV
              10012B4 Import Address Table
              1007980 Import Name Table
            FFFFFFFF time date stamp
            FFFFFFFF Index of first forwarder reference

      7300643C      78 GetPrinterDriverW
      73004D40      1B ClosePrinter
      73005091      7E OpenPrinterW

    COMCTL32.dll
              1001020 Import Address Table
              10076EC Import Name Table
            FFFFFFFF time date stamp
            FFFFFFFF Index of first forwarder reference

      773DD270       8 CreateStatusWindowW

    msvcrt.dll
              10012EC Import Address Table
              10079B8 Import Name Table
            FFFFFFFF time date stamp
            FFFFFFFF Index of first forwarder reference

      4DC22DAE      4E _XcptFilter
      4DC29E9A      F6 _exit
      4DC29ECE      C5 _c_exit
      4DC3AECF     317 time
      4DC3AB69     2D4 localtime
      4DC29EB6       C8 _cexit
      4DC0D036     2C6 iswctype
      4DC25C94       ED _except_handler3
      4DC0CE77     274 _wtol
      4DC3802F     32F wcsncmp
```

PEVIEW NOTEPAD.EXE



STRINGS, EVEN

- Can sometimes gain some clues by running strings command against executable
- strings malware.exe -> print all ASCII strings
- strings -el malware.exe -> print all Unicode strings

- Will not always be helpful
  - Packed/encrypted malware has no readable strings

- But memory forensics and reverse engineering started this way…

- Occasionally still useful

Real World Malware Investigation: W32.Gruel.a Email Worm

```
$ strings Email-Worm.Win32.Gruel.a
…
kIlLeRgUaTe 1.03, I mAke ThIs vIrUs BeCaUsE I
dOn'T hAvE NoThInG tO dO!!
We have created an error report thet you cand
send to us. we will treat this report as
confidential and anounymous.
Please tell microsoft about this problem.
Windows X found serious error.
…
```

Real World Malware Investigation: W32.Gruel.a Email Worm

```
$ strings -e l Email-Worm.Win32.Gruel.a
```

…

```
Norton Security Response: has detected a new
virus in the Internet. For this reason we
made this tool attachement, to protect your
computer from this serious virus. Due to the
number of submissions received from
customers, Symantec Security Response has
upgraded this threat to a Category 5 (Maximum
)
```

…

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BUT THESE WONT HELP YOU WITH PACKED BINARIES… ☹

SO LETS TALK ABOUT PACKERS

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- State-of-the-art malware doesn't present an easy target for reverse engineering attempts
- The stuff you've learned so far is essential for understanding what's going on once you can get a reasonable disassembly
- Modern malware doesn't want you to **even access** the disassembly
- Furthermore, modern malware doesn't want you to be able to closely analyze its runtime behavior either
- So packers evolved to add layers upon layers of misery to reverse engineering!

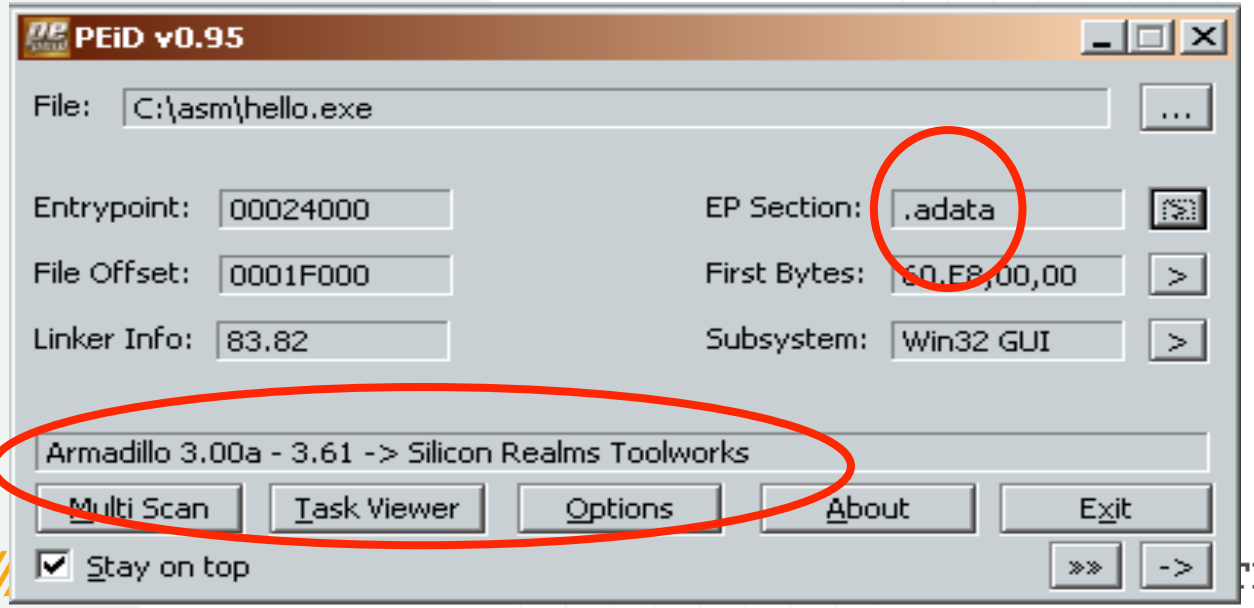
PACKERS: BASICS

- Packers add obfuscation/encryption to parts of the virus body to thwart static analysis
- Packing will hide one binary inside a benign outer “host” binary
  - Often the hidden binary is encrypted in the file
  - Decrypted only at execution time (possibly 1 small chunk at a time)
- General structure:
  - Compress/encrypt a target EXE file's code
  - Generate new EXE with encrypted code as a payload
  - New EXE has modified entry point, which points to an unpacking module
  - Unpacking module responsible for decryption
  - Unpacking module will likely contain anti-debugging tricks
  - Unpacker’s goal is to jump to entry point of original code
- Packers actually have both commercial and “malicious” uses
- Packed doesn’t necessarily imply malware, but very common in modern malware

STATIC ANALYSIS QUESTION #1: IS IT PACKED?

- Is it packed? If so, important to determine what sort of packer was used
- Is it something hand-rolled? Something known?

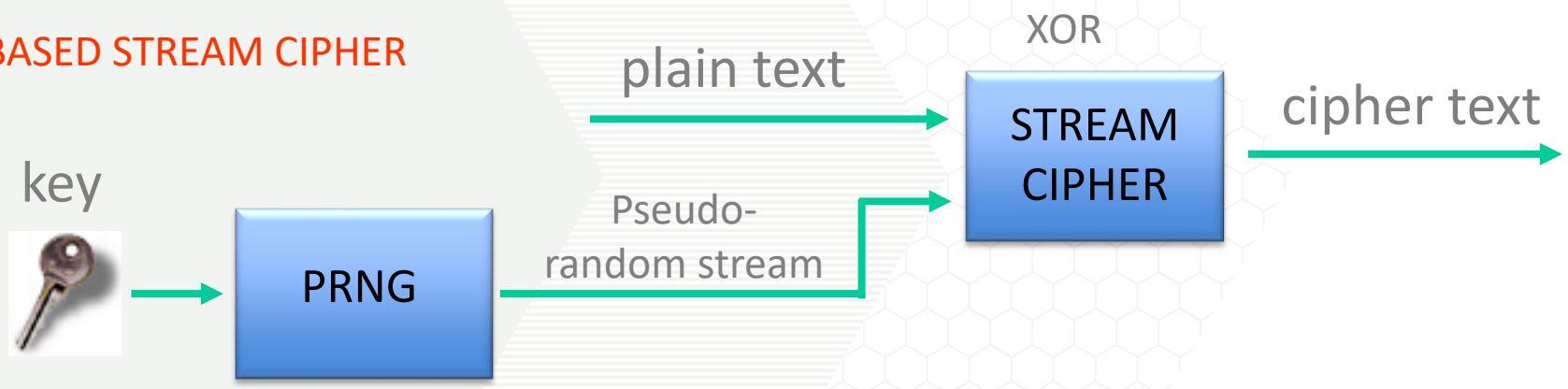
- Known packers have signatures too!
  - Many tools have been designed to detect packing
  - PEiD is still a fan favorite! https://www.aldeid.com/wiki/PEiD
  - Detects ~600 different packers



WORST CASE: ENTIRELY HAND-MADE PACKER

- PEID or similar may not help — could be an entirely new/home made packer
- If it's hand-rolled, commonly XOR-based stream cipher over part of the virus body (and possibly the original EXE contents), with only the decryption code in the clear

XOR-BASED STREAM CIPHER



PRNG == Pseudo-Random Number Generator

- PRNG code will probably be small — the virus is trying to be stealthy
- Luckily! The key hopefully has to be stored somewhere in the PE file
- Unless…

REAL WORST CASE: KEYLESS HAND-MADE PACKER!

- It can always get worse…
- The key could be downloaded from the malware's command & control servers!

- Or, there could be no key at all! The decrypt and hash loop 

- Read More: "The Art of Unpacking." Mark Vincent Yason. Blackhat USA 2007.
  - PDF on Canvas
- Read Even More: "Binary-code obfuscations in prevalent packer tools." Roundy, Kevin A., and Barton P. Miller. *ACM Computing Surveys (CSUR)* 46.1 (2013)
- Read Even More: "SoK: Deep Packer Inspection: A Longitudinal Study of the Complexity of Run-Time Packers." IEEE Security and Privacy 2015.

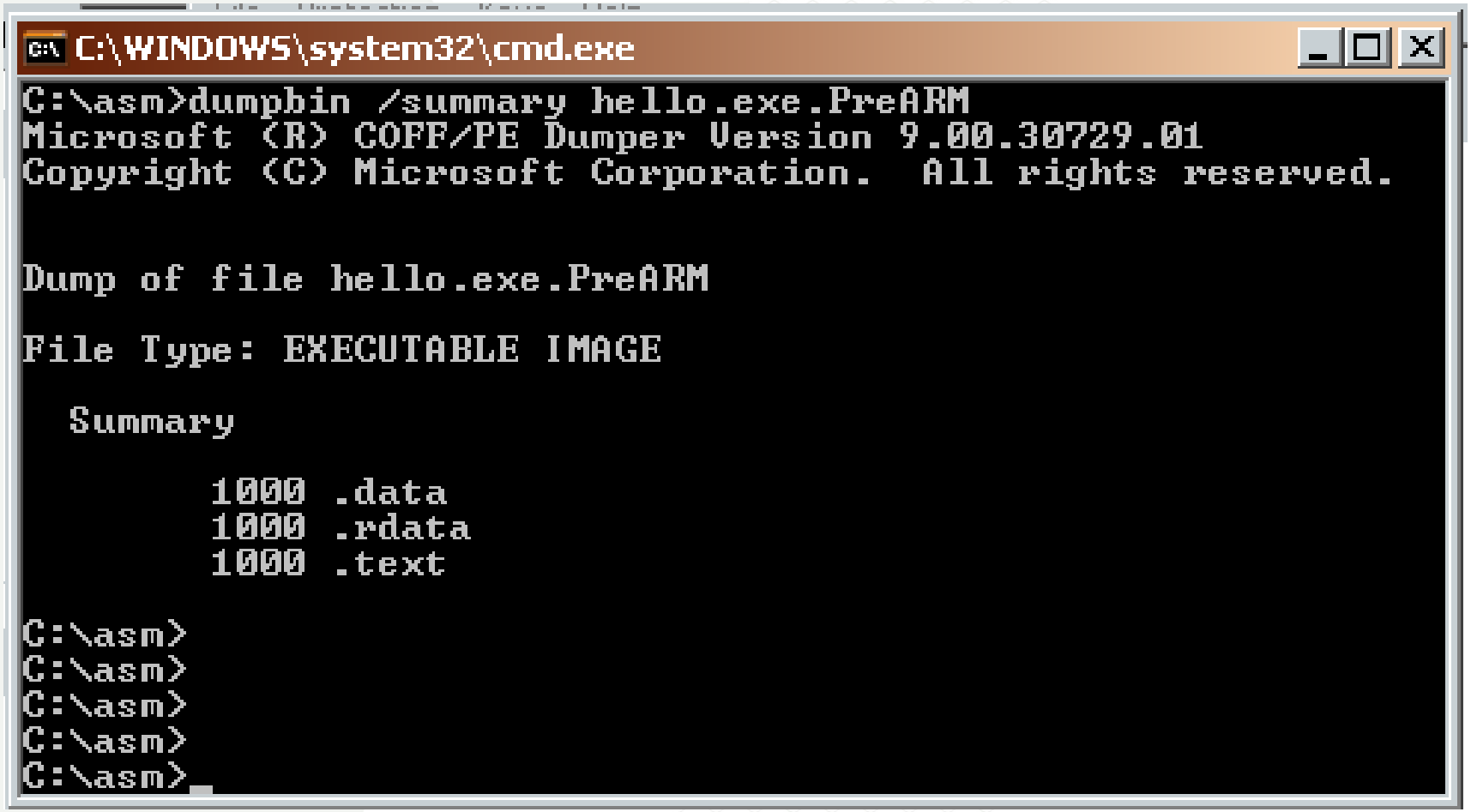
- If PEID (or the like) fail, resort to manual inspection ☹
- The following tests attempt to find a potential infection in general, not just packing

MANUAL INSPECTION OF SECTION NAMES

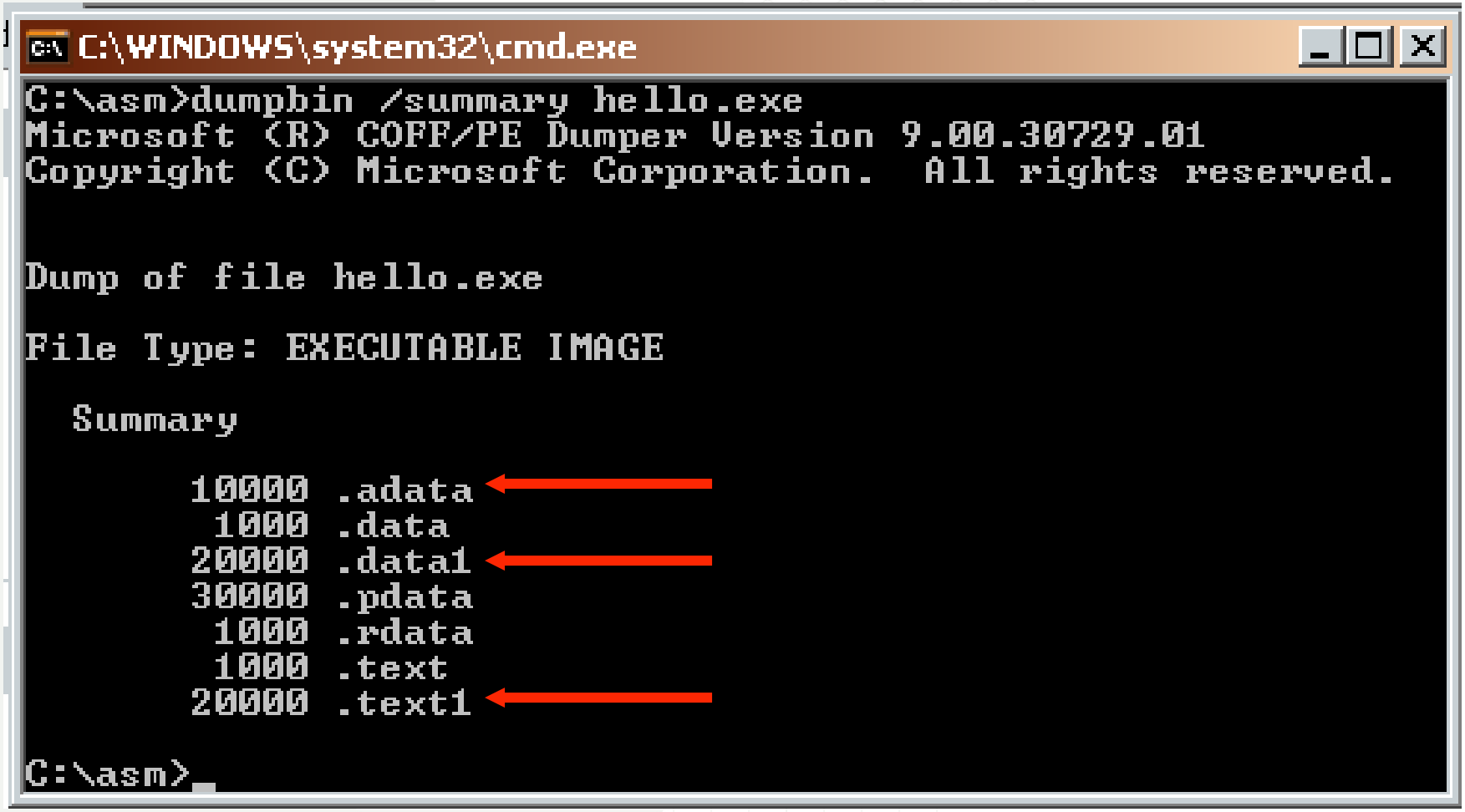
- Where are they hiding?

- Typical section names:
  - .code / .text [executable code]
  - .bss [uninitialized data]
  - .data [initialized data]
  - .reloc [relocation info]
  - .idata [imports]
  - .edata [exports]
  - .pdata [execution handling]
  - .tls
  - …
- There are others…have a close look at our old friend, the PE/COFF specification
- Do section names look unusual?
- If yes, suspicious

SECTION NAMES: NOT UNUSUAL

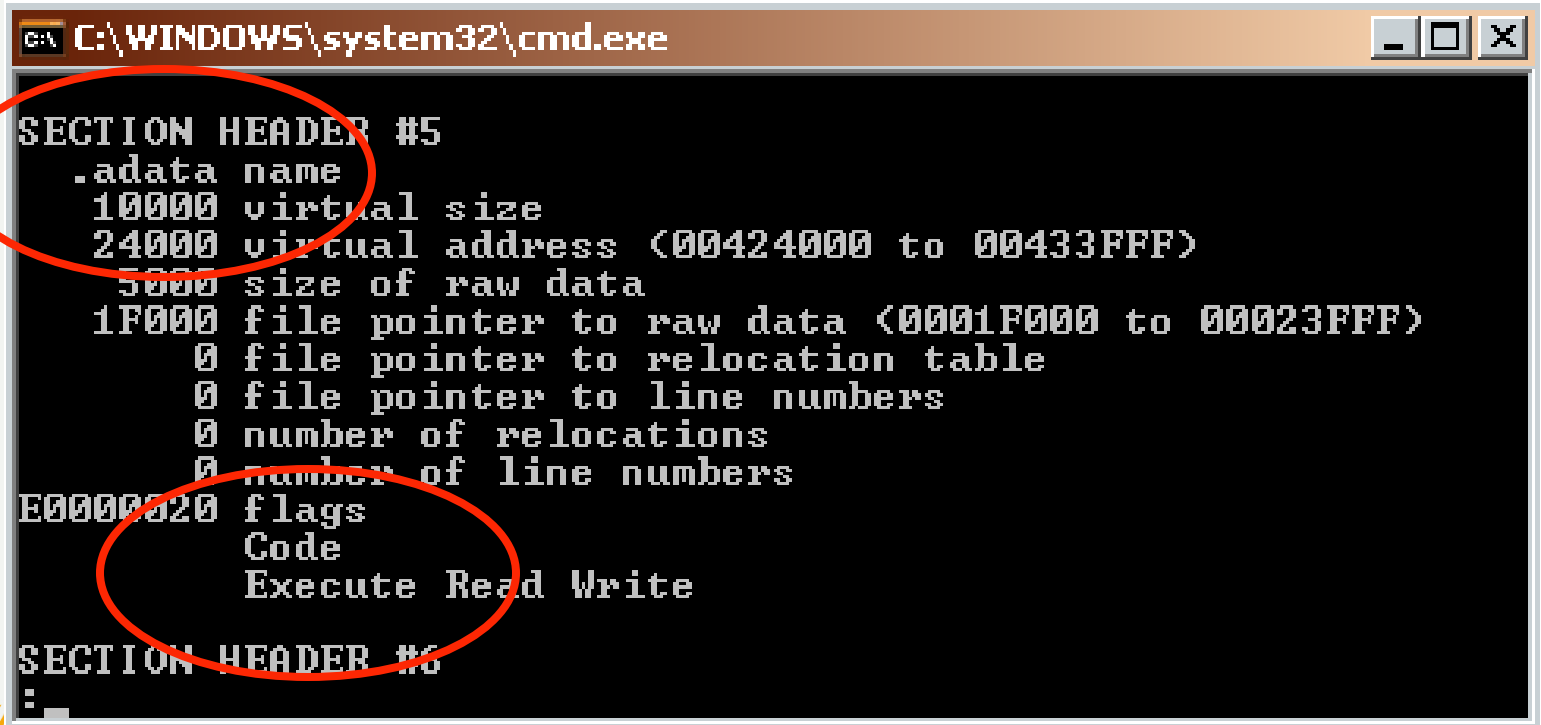


SECTION NAMES: YES UNUSUAL



INSPECTION OF SECTION PERMISSIONS

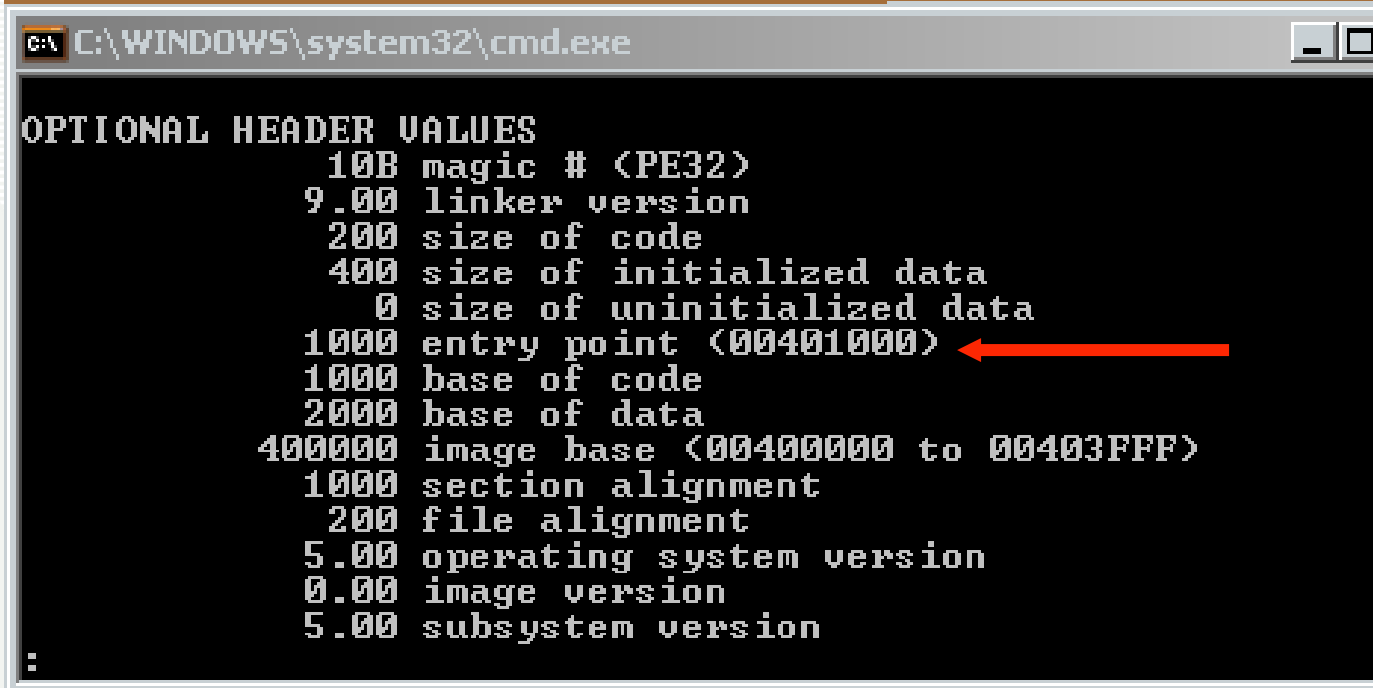
- Only .code / .text should be executable
- See other executable sections?

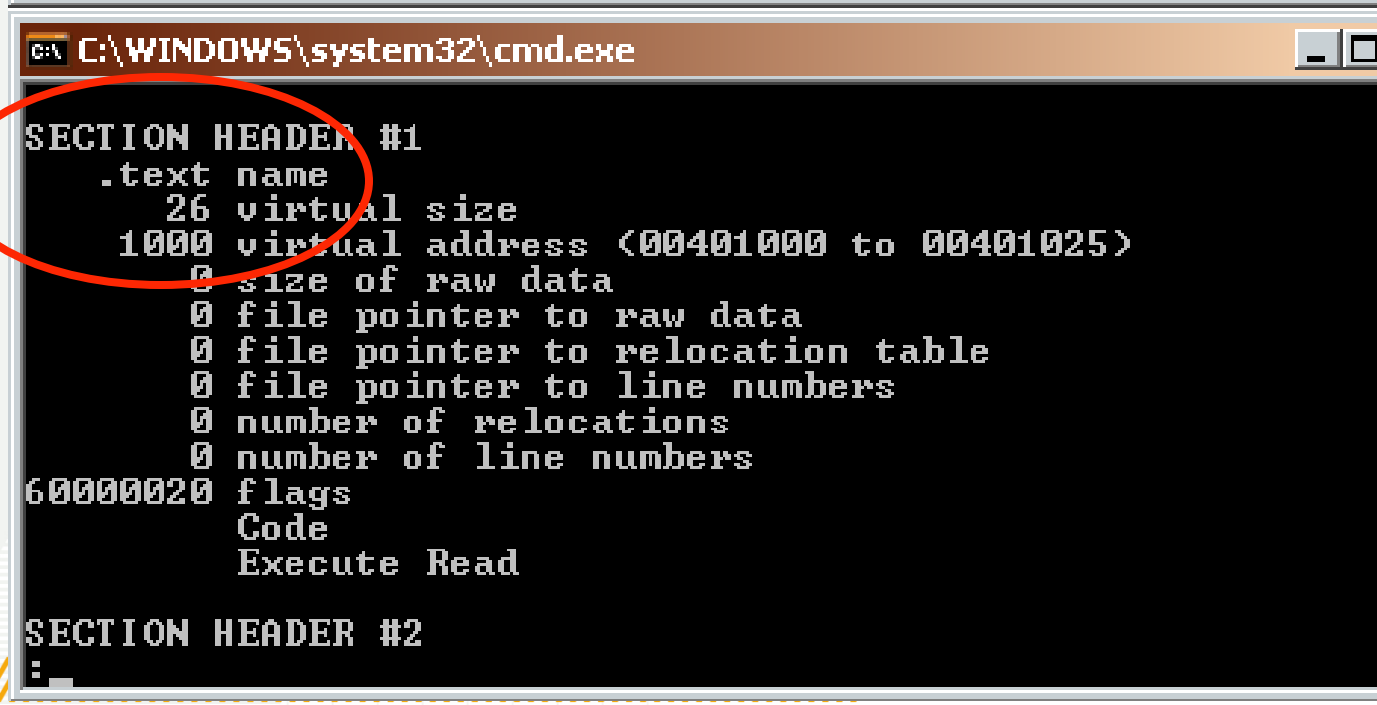


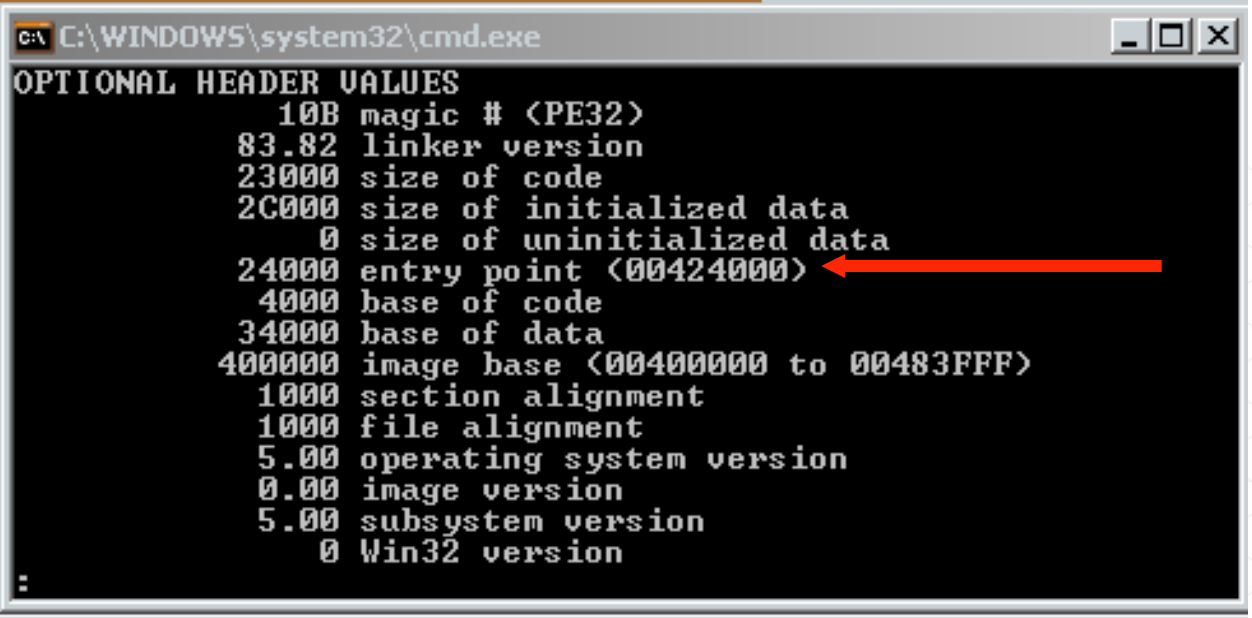
MANUAL INSPECTION OF ENTRY POINT

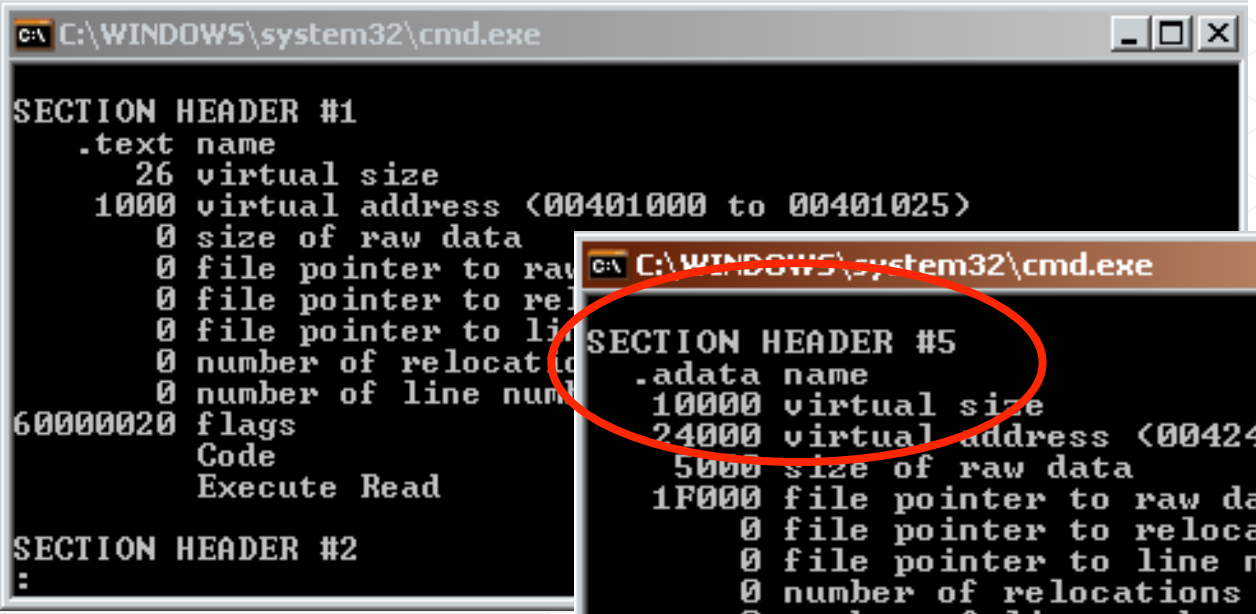
- Is the entry point in the .text or .code section?
- If not, suspicious

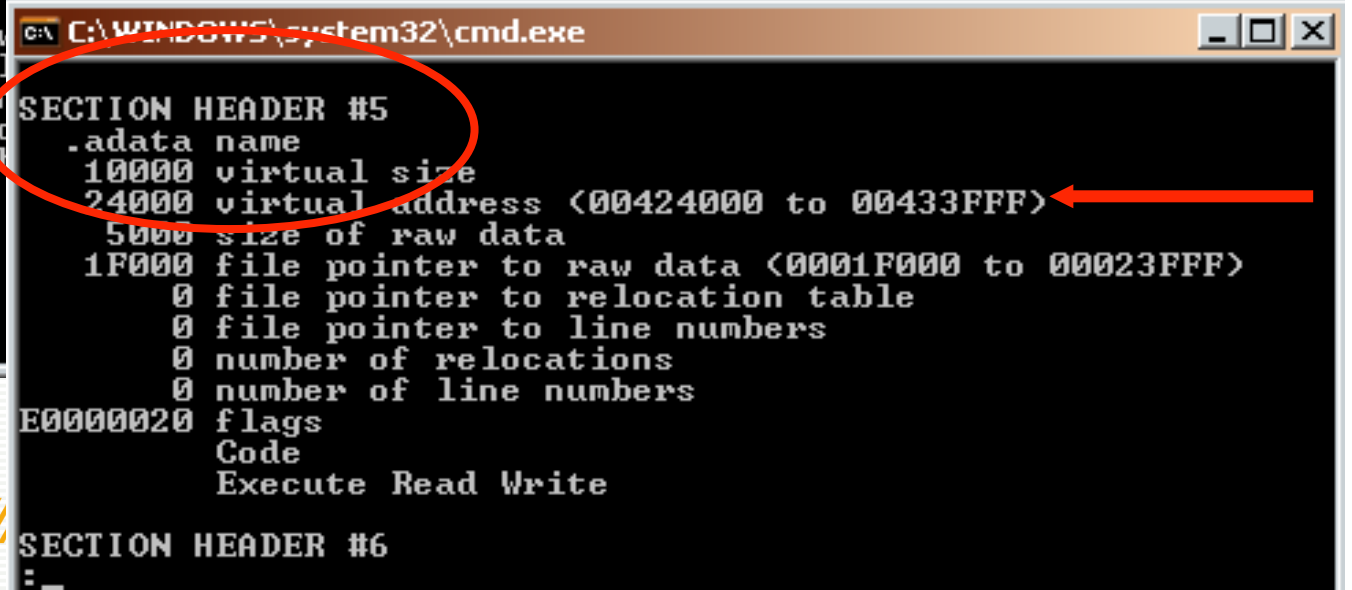
- Entry point should typically be in first code section
- Code should only be in .text / .code











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VERY UNUSUAL ENTRY POINT, WOULDN'T YOU SAY?

MANUAL INSPECTION TO REVEAL PRINTABLE STRINGS

- Strings again? Really??
- Yes.

- Unusual for executables not to have human-readable strings

- Some packed executables do have printable strings, particularly commercial wrappers that need to provide some help for users

- Run strings against .EXE file
- What do you see?

MANUAL INSPECTION OF IMPORT TABLE

- Does the IAT seem suspiciously empty?
- Most Windows programs have a lot of imports

```
C:\WINDOWS\system32\cmd.exe

C:\malware\UPX>dumpbin /imports strings.preupx.exe
Microsoft (R) COFF/PE Dumper Version 9.00.30729.01
Copyright (C) Microsoft Corporation.  All rights reserved.


Dump of file strings.preupx.exe

File Type: EXECUTABLE IMAGE

  Section contains the following imports:

    KERNEL32.dll
                40C038 Import Address Table
                41008C Import Name Table
                     0 time date stamp
                     0 Index of first forwarder reference

                  11D FindFirstFileA
                  1A7 GetCurrentDirectoryA
                  1DC GetFullPathNameA
                  12E FindNextFileA
                  2A6 HeapSize
                  3FC SetStdHandle
                  48C WriteConsoleW
                  199 GetConsoleOutputCP
                  482 WriteConsoleA
                  119 FindClose
                   78 CreateFileA
                  1E6 GetLastError
                  368 ReadFile
                  3DF SetFilePointer
                  220 GetProcAddress
                   43 CloseHandle
                  147 FormatMessageA
                  1A9 GetCurrentProcess
                  2F9 LocalAlloc
                  2F1 LoadLibraryA
                  2FD LocalFree
                  1F6 GetModuleHandleA
                  29D HeapAlloc
                  2A1 HeapFree
                   D9 EnterCriticalSection
                  2EF LeaveCriticalSection
                  16F GetCommandLineA
```

No packing

MANUAL INSPECTION OF IMPORT TABLE

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- Packers typically don't need many imports
  - LoadLibrary()
  - GetProcAddress()
  - etc.

- Complete import table for packed code will be reassembled before it is executed
- But won't be found by static analysis

Packing

```
C:\WINDOWS\system32\cmd.exe
C:\malware\UPX>dumpbin /imports strings.exe
Microsoft (R) COFF/PE Dumper Version 9.00.30729.01
Copyright (C) Microsoft Corporation.  All rights reserved.


Dump of file strings.exe

File Type: EXECUTABLE IMAGE

  Section contains the following imports:

    KERNEL32.DLL
                417454 Import Address Table
                     0 Import Name Table
                     0 time date stamp
                     0 Index of first forwarder reference

                    0 LoadLibraryA
                    0 GetProcAddress
                    0 VirtualProtect
                    0 VirtualAlloc
                    0 VirtualFree
                    0 ExitProcess

    ADVAPI32.dll
                417470 Import Address Table
                     0 Import Name Table
                     0 time date stamp
                     0 Index of first forwarder reference

                    0 RegCloseKey

    COMDLG32.dll
                417478 Import Address Table
                     0 Import Name Table
                     0 time date stamp
                     0 Index of first forwarder reference

                    0 PrintDlgA

    GDI32.dll
                417480 Import Address Table
                     0 Import Name Table
                     0 time date stamp
                     0 Index of first forwarder reference
```

FINALLY, MANUAL INSPECTION OF CODE

- Attempt disassembly, e.g. in IDA Pro
- Do large parts of the executable, particularly the targets of JMP/CALLs appear to be obfuscated?
- Suspect packing/encryption

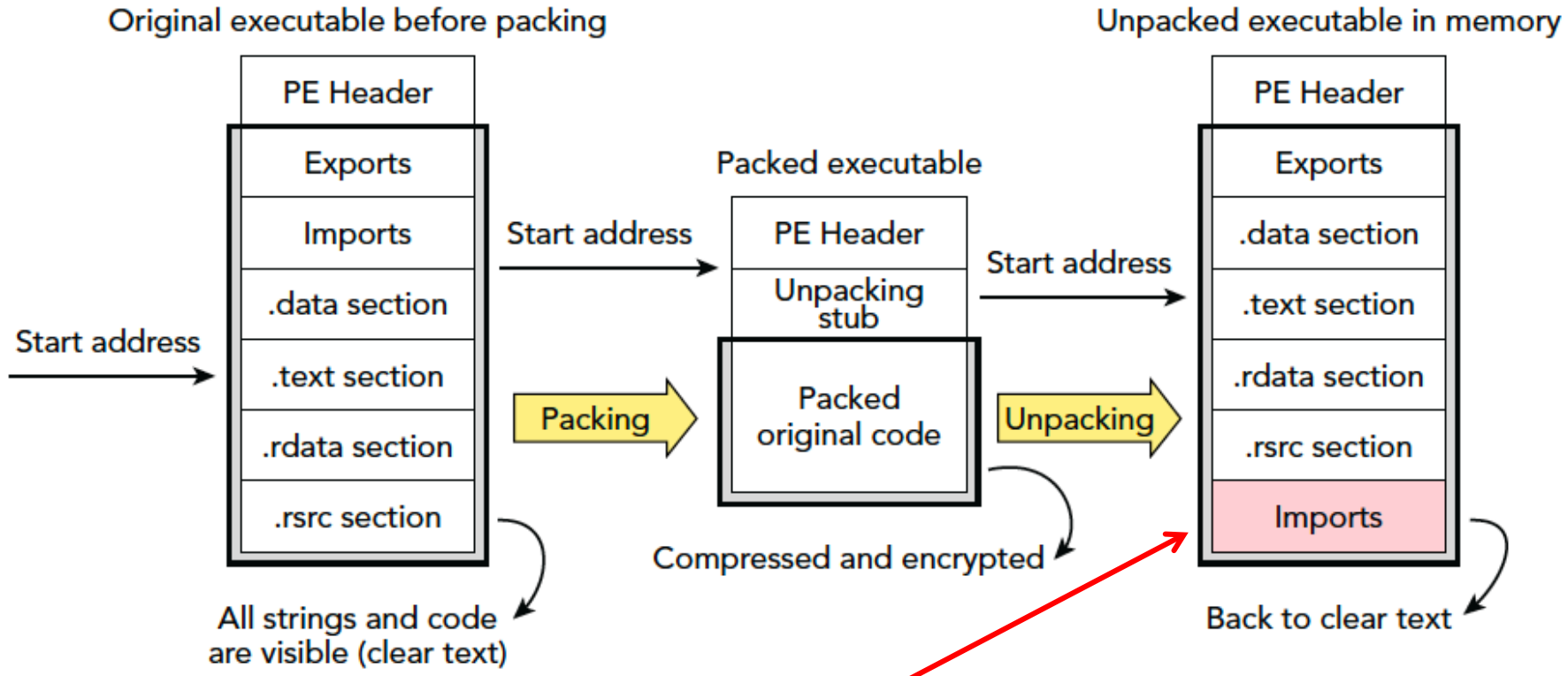
- Ultimate goal is to get unpacked & de-obfuscated executable for analysis
- Need to isolate packer code/encrypted payload and then find original entry point of the payload
- Essentially, locating the point at which decryption is complete
- But How??

- Real Malware: Lucius (later) -> Hand-rolled encryption of virus body
- You will unpack and reverse engineer Lucius! ☺

FINDING ENTRY POINT OF PAYLOAD

- Static analysis — just look for it … I'm exhausted already!
- Single step in a debugger or emulator
  - e.g., in ollydbg (details coming soon!)
  - Advantage: Allows you to gain deeper understanding of the effects of the unpacking process (or ignore/modify them)
  - Disadvantages:
  - Slow
  - VERY DANGEROUS --- Where does unpacking end and "kill everyone" payload begin??
- Scan function call graph in IDA Pro
  - Advantage: May save large amounts of time
  - Disadvantages:
  - Tightly rolled packers won't show you much
  - But for tightly rolled packers, it may be easier to discover where they terminate

Figure 8-5 in The Art of Memory Forensics: Detecting Malware and Threats in Windows, Linux, and Mac Memory



- Grab memory image at every JMP?
- In many cases, unpacking will be complete (but not always)
- Then proceed with static analysis.

BRIEF PACKER CASE STUDY: THEMIDA

- Commercial from Oreans Technologies
- Typically used to protect commercial software
- Encryption
- Anti-debugger tricks
- Anti-acquisition tricks to prevent process memory dumping
- Garbage instruction insertion
- FPU bugs to injure debuggers
- Kernel mode (Ring 0) components
- VM-based emulation of x86 code
- See http://www.oreans.com/themida_features.php
- Definitely used to protect some malware
- See: http://www.wilderssecurity.com/showthread.php?t=184840
- Defeats anti-virus
- Result: Themida-protected executables may simply be disallowed in secure environments!

BRIEF PACKER CASE STUDY: THEMIDA

- And has a nice UI!

BRIEF PACKER CASE STUDY: UPX

- Very commonly used open source packer
- http://upx.sourceforge.net

- Goal is to decrease executable size and load time
- Not to defeat debuggers, etc.

- Good as basic practice for unpacking
- Of course, **upx –d** will unpack for you ☺

- Go try it for yourself!

BACK TO STATIC ANALYSIS TOOLS AND TECHNIQUES

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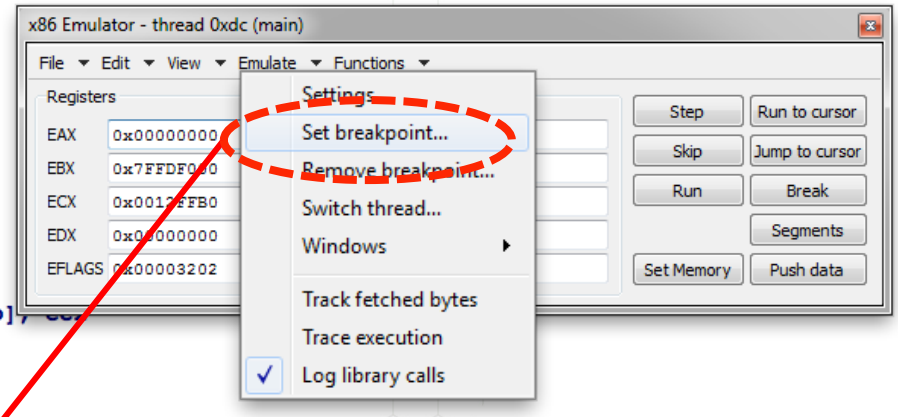
THE SWISS ARMY KNIFE: DISASSEMBLERS

- Goal: Automate process of generating ASM source from executable
- Difficulties:
  - High Level Language (HLL) -> binary is a VERY lossy process
  - Code/data mixture
    - What's code? What's data?
    - Different approaches to tackling this problem
  - Branch targets computed at runtime
  - Dynamically loaded code (e.g., DLLs)
  - Branches that do not target the beginning of instructions
    - E.g., Jump inside multi-byte instructions or inside data areas
  - Self-modifying code
  - Deliberate obfuscation/packing/encryption (e.g., Armadillo from before)

IDA PRO TO THE RESCUE!

```
.data:00403027                  jnz     short loc_40302B
.data:00403029                  jmp     short loc_403079
.data:0040302B ; ---------------------------------------------------------------
.data:0040302B
.data:0040302B loc_40302B:                              ; CODE XREF: .data:00403027↑j
.data:0040302B                  mov     ecx, 0C31h
.data:00403030                  lea     esi, byte_401065[ebp]
.data:00403036                  mov     edi, esi
.data:00403038
.data:00403038 loc_403038:                              ; CODE XREF: .data:00403071↓j
.data:00403038                  lodsb
.data:00403039                  push    eax
.data:0040303A                  push    ecx
.data:0040303B                  mov     eax, ss:dword_401061[ebp]
.data:00403041                  xor     edx, edx
.data:00403043                  mov     ecx, 1F31Dh
.data:00403048                  div     ecx
.data:0040304A                  mov     ecx, eax
.data:0040304C                  mov     eax, 41A7h
.data:00403051                  mul     edx
.data:00403053                  mov     edx, ecx
.data:00403055                  mov     ecx, eax
.data:00403057                  mov     eax, 0B14h
.data:0040305C                  mul     edx
.data:0040305E                  sub     ecx, eax
.data:00403060                  xor     edx, edx
.data:00403062                  mov     eax, ecx
.data:00403064                  mov     ss:dword_401061[ebp], eax
.data:0040306A                  mov     edx, eax
.data:0040306C                  pop     ecx
.data:0040306D                  pop     eax
.data:0040306E                  xor     al, dl
.data:00403070                  stosb
.data:00403071                  loop    loc_403038
.data:00403073                  jmp     short loc_403079
.data:00403073 ; ---------------------------------------------------------------
.data:00403075                  db  3Bh ; ;
.data:00403076                  db  27h ; '
.data:00403077                  db  9Ah ;
.data:00403078                  db    0
.data:00403079 ; ---------------------------------------------------------------
.data:00403079
.data:00403079 loc_403079:                              ; CODE XREF: .data:00403029↑j
.data:00403079                                          ; .data:00403073↑j
.data:00403079                  call    far ptr 60AEh:261A6341h
.data:00403080                  db      3Eh
.data:00403080                  insb
.data:00403080 ; ---------------------------------------------------------------
.data:00403082                  db 0C7h ;
.data:00403083                  db  4Fh ; O
```

Decryption loop



IDA ALSO ANALYZES THE FILE FORMAT

- For example, IDA will show the section each offset falls within:

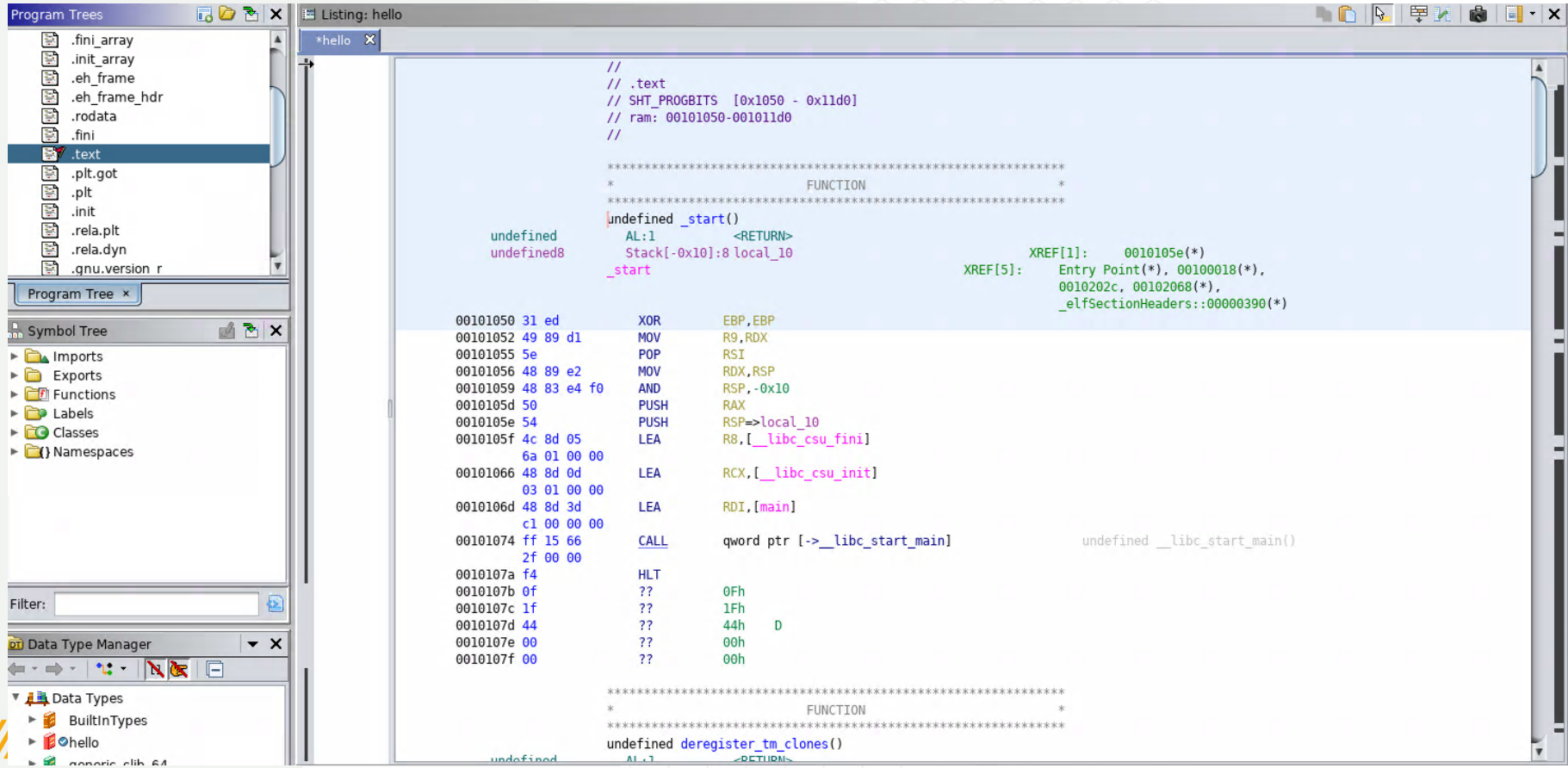
```
.text:00000000004015DA                mov     rax, [rbp+640h+arg_8]
.text:00000000004015E1                mov     rax, [rax]
.text:00000000004015E4                mov     rdx, rax
.text:00000000004015E7                lea     rcx, aYouCanChangeTh ; "[*] You can change this
.text:00000000004015EE                call    printf
```

```
.idata:0000000000409544 ; SOCKET __stdcall socket(int af, int type, int protocol)
.idata:0000000000409544                 extrn __imp_socket:qword ; DATA XREF: main+105↓r
.idata:0000000000409544                                          ; socket↓r
```

```
__cstring:0000000100000F46 ; ===========================================
__cstring:0000000100000F46
__cstring:0000000100000F46 ; Segment type: Pure data
__cstring:0000000100000F46 __cstring       segment byte public
__cstring:0000000100000F46                 assume cs:__cstring
__cstring:0000000100000F46                 ;org 100000F46h
__cstring:0000000100000F46 ; char aD[]
__cstring:0000000100000F46 aD              db '%d',0
__cstring:0000000100000F49 ; char aZero[]
__cstring:0000000100000F49 aZero           db 'Zero',0
__cstring:0000000100000F4E ; char aOne[]
__cstring:0000000100000F4E aOne            db 'One',0
__cstring:0000000100000F52 ; char aTwo[]
__cstring:0000000100000F52 aTwo            db 'Two',0
__cstring:0000000100000F56 ; char aThree[]
__cstring:0000000100000F56 aThree          db 'Three',0
__cstring:0000000100000F5C ; char aNoIdea_[]
__cstring:0000000100000F5C aNoIdea_        db 'No idea.',0
__cstring:0000000100000F5C __cstring       ends
__cstring:0000000100000F5C
```

FILE FORMAT IN GHIDRA ALSO

- Ghidra analyzes the file format as well
- It stores section header names in the Program Trees window
- Double clicking takes you to the relevant section in code.



HLL -> BINARY IS VERY LOSSY

- One to many
  - Compilation process is not unique
  - HLL code may result in many different binaries
    - Depending on compilation environment/optimization/target architecture
- Data types are lost
- Names and useful symbols are lost
- Debugging information is probably stripped
- Intention of programmer is even further obfuscated

DISASSEMBLY: FLAVOR 1 OF 2

- Recursive-descent disassembly:
  - Attempt to reconstruct and follow the program control flow
  - Disassemble sequences of bytes only if they can be reached from another valid instruction
- Bad: Can't easily handle:
  - Indirect jumps/dynamically computed branches
  - Self-modifying code
- Good: Better at handling interleaved code/data
- IDA Pro, GHIDRA, OllyDbg (debugger—covered later)

DISASSEMBLY: FLAVOR 2 OF 2

- Linear-sweep disassembly:
  - From first instruction, disassemble entire stream of bytes
  - Next instruction is assumed to follow previous valid instruction
- Bad:
  - For dense instruction sets (e.g., Intel) not easy to tell if you're off track
  - Easily tripped up by interleaved code and data
- Good:
  - Coverage: If data and code aren't interleaved, not confused by indirect/indexed jumps
- WinDbg, SoftICE (discontinued), gdb, objdump

DISASSEMBLY: SPECULATIVE OR HYBRID

- Can also use hybrid approaches
- Example: Do both recursive descent and linear sweep and note similarities/differences

- Speculative: Mark portions of binary that have been disassembled and speculatively disassemble others
  - "See what happens"
  - Speculative portions are marked for possible human intervention

- One description of hybrid disassembly:
  - B. Schwarz, S. Debray, G. Andrews, "Disassembly of Executable Code Revisited." IEEE Working Conference on Reverse Engineering (WCRE 2002).
  - "Superset Disassembly: Statically Rewriting x86 Binaries Without Heuristics." Erick Bauman, Zhiqiang Lin, Kevin Hamlen. NDSS 2018.

KING OF STATIC ANALYSIS TOOLS: DECOMPILERS

- Goal: Reverse compilation process
  - Binary -> HLL
- **Very** difficult to do
- Producing original source is impossible, since compilation is lossy

- Some limited open source solutions
  - e.g., http://boomerang.sourceforge.net/, https://github.com/avast-tl/retdec

- Commercial systems are expensive
  - Hex-Rays Decompiler (plug in for IDA Pro) is probably the most famous
- Does a fair job in many cases…
- Very very expensive!!! Only researchers at Georgia Tech have access

DECOMP EXAMPLE: ORIGINAL SOURCE

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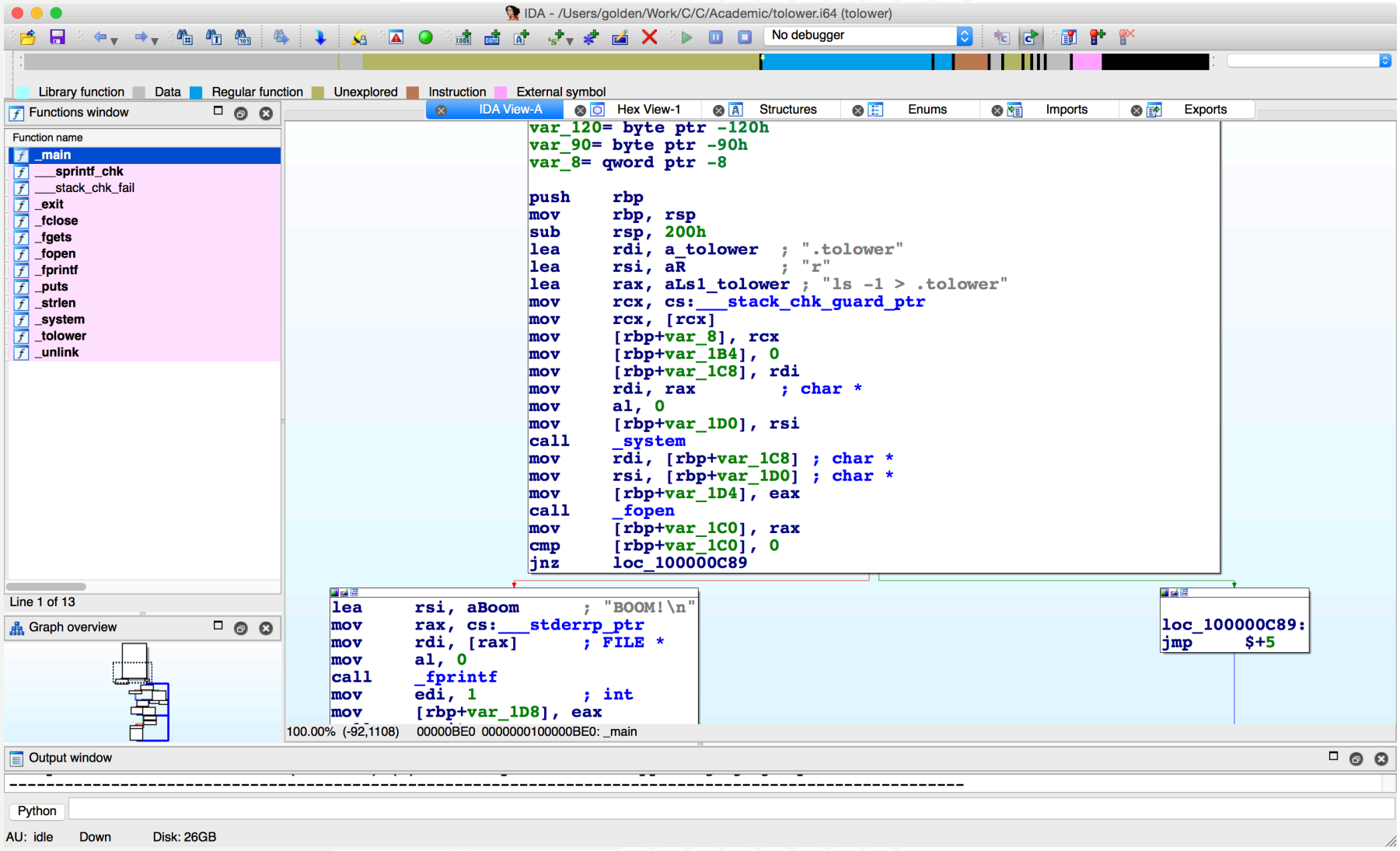
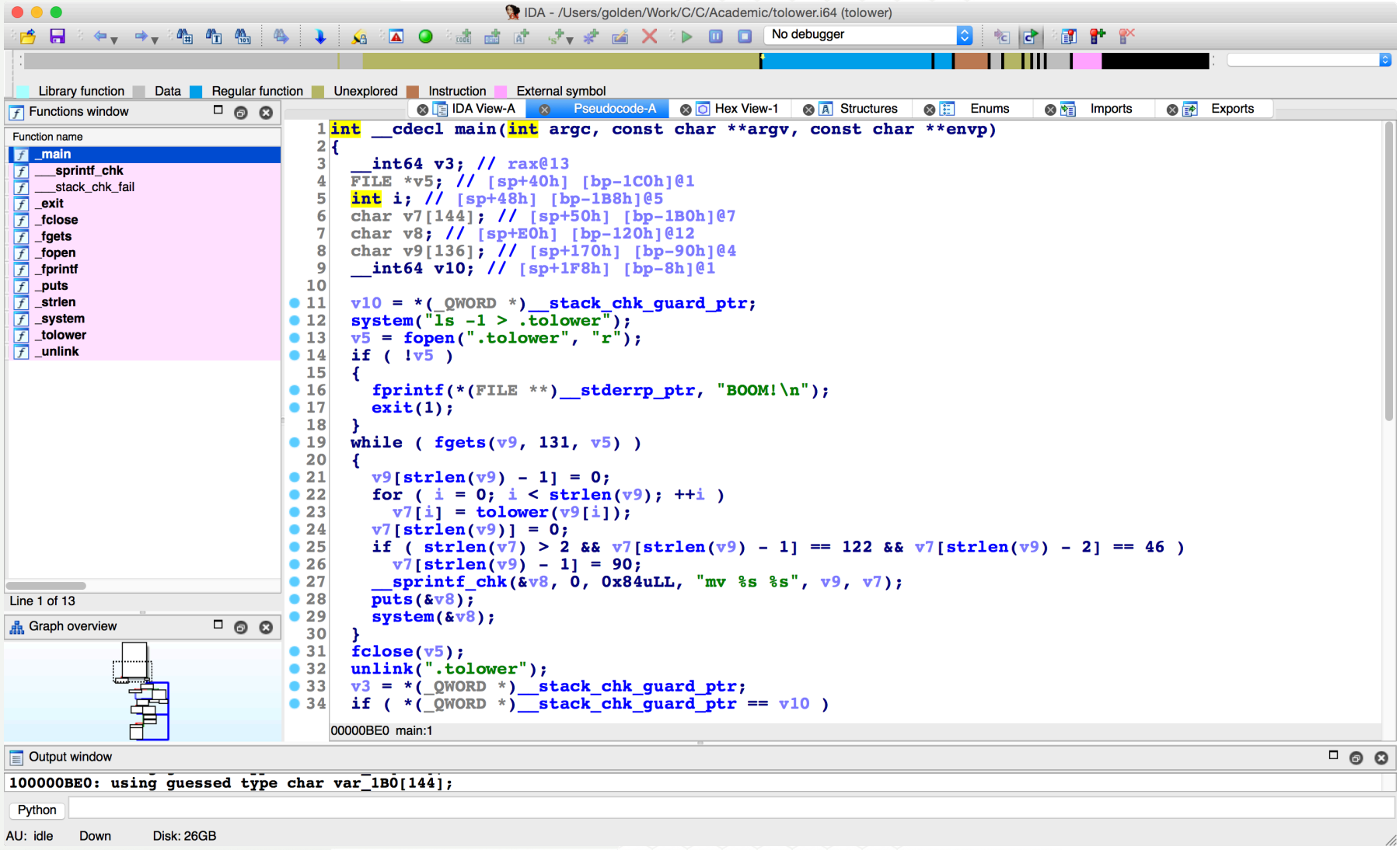
1. less

```
{
  char buf[132], buf2[132], lowbuf[132];
  int i;
  FILE *fp;

  system("ls -1 > .tolower");

  fp = fopen(".tolower","r");
  if (fp == NULL) {
    fprintf(stderr,"BOOM!\n");
    exit(1);
  }
  else {
    while (fgets(buf,131,fp) != NULL) {
      buf[strlen(buf) - 1] = NULL;
      for (i=0; i < strlen(buf); i++) {
        lowbuf[i]= tolower(buf[i]);
      }
      lowbuf[strlen(buf)] = NULL;

      /* don't mess up filenames of compressed files */

      if (strlen(lowbuf) > 2 && lowbuf[strlen(buf)-1] == 'z' &&
                                lowbuf[strlen(buf)-2] == '.') {
          lowbuf[strlen(buf)-1] = 'Z';
      }
      sprintf(buf2,"mv %s %s",buf,lowbuf);
      puts(buf2);
      system(buf2);
    }
    fclose(fp);
    unlink(".tolower");
  }
}
:
```

DECOMP EXAMPLE: DISASSEMBLY



DECOMP EXAMPLE: DECOMPILATION



GHIDRA: BUILT IN DECOMPILER

- Ghidra comes with a decompiler out of the box!
  - One of the primary reasons for Ghidra's widespread adoption
- Synchronizes well with code viewer – highlights, renames, comments in one window show up in the other ☺
- Can be configured to show more/less information if needed
  - e.g.: show unreachable code, hide variable casting, etc.
- ...Of course, since it's open source, there's already a port that put the code into IDA
- https://github.com/Cisco-Talos/GhIDA

Decompile: FUN_00407522 - (dd674592500b1f71d1255abd7e440d3de329695f559197b9048f1ae8da976a26)

```
1
2  void __cdecl FUN_00407522(LPCWSTR param_1)
3
4  {
5    uint nNumberOfBytesToWrite;
6    DWORD _Size;
7    BOOL BVar1;
8    DWORD local_14;
9    LPCVOID local_10;
10   HANDLE local_c;
11   uint local_8;
12
13   local_c = CreateFileW(param_1,0x40000000,0,(LPSECURITY_ATTRIBUTES)0x0,3,0,(HANDLE)0x0);
14   if (local_c != (HANDLE)0xffffffff) {
15     nNumberOfBytesToWrite = GetFileSize(local_c,(LPDWORD)0x0);
16     local_8 = nNumberOfBytesToWrite;
17     if (nNumberOfBytesToWrite != 0xffffffff) {
18       _Size = nNumberOfBytesToWrite;
19       if (0xffff < nNumberOfBytesToWrite) {
20         _Size = 0x10000;
21       }
22       local_8 = nNumberOfBytesToWrite;
23       local_10 = calloc(1,_Size);
24       if (local_10 != (void *)0x0) {
25         while (nNumberOfBytesToWrite != 0) {
26           if (0xffff < nNumberOfBytesToWrite) {
27             nNumberOfBytesToWrite = 0x10000;
28           }
29           BVar1 = WriteFile(local_c,local_10,nNumberOfBytesToWrite,&local_14,(LPOVERLAPPED)0x0)
30           if (BVar1 == 0) goto LAB_004075ab;
31           nNumberOfBytesToWrite = local_8 - nNumberOfBytesToWrite;
32           local_8 = nNumberOfBytesToWrite;
33         }
34         FlushFileBuffers(local_c);
35 LAB_004075ab:
36         free(local_10);
37       }
38     }
39     CloseHandle(local_c);
40   }
41   DeleteFileW(param_1);
42   return;
43 }
44
```

NEXT CLASS = IN CLASS LAB!!

- Next class will be an in class lab!
- We will be using PE file format analyzers to discover malware hiding inside of an infected PE file!
- We will then use a debugger to extract the malware!
- Before next class: Read “Peering Inside the PE”
  - Online at: https://msdn.microsoft.com/en-us/library/ms809762(d=printer).aspx
  - PDF also on Canvas!
  - You **MUST** read and understand this in order to do the lab!
- During next class: At least one team member MUST bring a laptop!

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QUESTIONS?

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