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CONSTANT INSECURITY: THINGS YOU DIDN'T KNOW ABOUT (PECOFF) PORTABLE EXECUTABLE FILE FORMAT

Constant Insecurity

- Maturing Code
  - PE has been on Windows for 18 Years now
  - Optional features
  - Backward compatibility
  - Deprecated functionality
  - Allowed values
  - Point release and bug fixes
- Multiple Specifications
- Negative Testing
- SDLC

Software Documentation

- Always behind
- Incorrectly translated
- Inaccurate by design
  - Developers are asked how should spec function?
  - They may not remember how it functions
- Spirit of the release 1 year later? 5 years later?
- Zero bugs = Perfectly documented
  - Who bug fixes documentation?
  - Who proof reads documentation for technical errors?

Agenda

- **Introduction**
  - Introduction to PECOFF file format
- **Introduction to simple PECOFF malformations**
  - PECOFF specification and its flexibility
- **Introduction to complex PECOFF malformations**
  - Programming with PECOFF features
  - Designing code to detect and stop malformations

PECOFF

- Portable executable and common object file format -

- **What is PECOFF?**
  - Microsoft migrated to the PE format with the introduction of the Windows NT 3.1 in 1993
  - The Portable Executable (PE) format is a file format for executables, object code and DLLs, used in 32-bit and 64-bit versions of Windows operating systems
  - The PE format is a data structure that encapsulates the information necessary for the Windows OS loader to manage the wrapped executable code
- **Where can you find it?**
  - Microsoft Windows / Windows CE / Xbox
  - Extensible Firmware Interface (EFI)
  - ReactOS
  - WINE

What is a malformation?

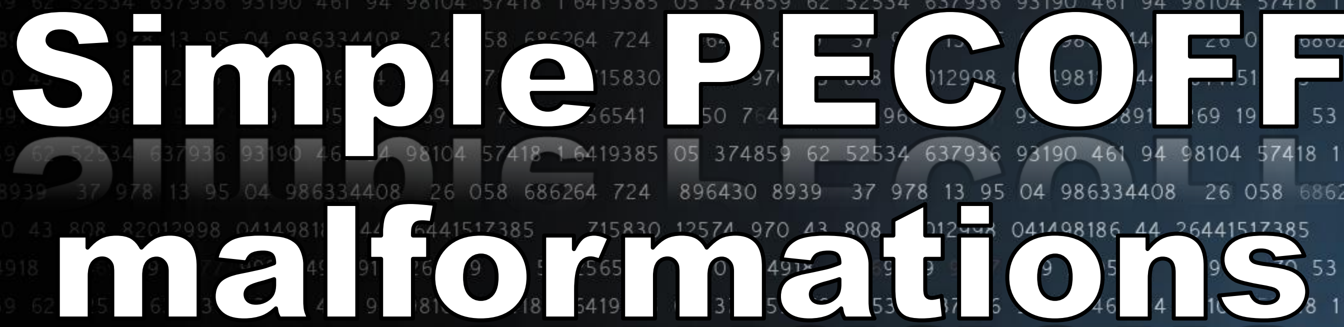
- **Malformations**
  - Malformations are simple or complex modifications
  - File format data and/or layout are modified
  - Unusual form is not inside the boundaries permitted by the file format documentation but is still considered valid from the standpoint of tools that parse them.
  - Malformation purpose is either breaking or omitting tools from parsing the malformed format correctly.
- **Simple malformations**
  - Require single field or data table modifications
- **Complex malformations**
  - Require multiple fields or data tables modifications

What does it affect?

- **Security consequences**
  - Malformations can have serious consequences
    - Breaking unpacking systems
    - Remote code execution
    - Denial of service
    - Sandbox escape
  - PE file format validation is hard!
    - Due to its complexity many things can work in multiple ways achieving the same result
    - Backward compatibility is very important and even though operating system loader evolves it still has to support obsolete compilers and files that are most definitely not compliant with the PECOFF docs

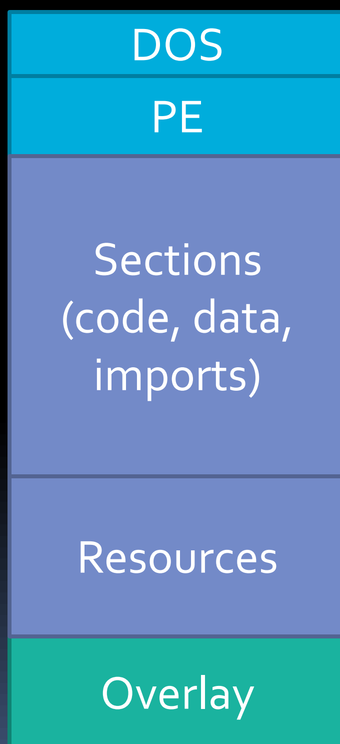
- **Previous published work on the PE subject**
  - PE Specification vs PE Loader - Alexander Liskin [SAS 2010]
  - PE Format as Source of Vulnerability - Ivan Teblin [SAS 2010]
  - Doin' The Eagle Rock - Peter Ferrie, Virus Bulletin, March 2010
  - Fun With Thread Local Storage (part 3) - Peter Ferrie, July 2008
  - Fun With Thread Local Storage (part 2) - Peter Ferrie, June 2008
  - Fun With Thread Local Storage (part 1) - Peter Ferrie, June 2008

Simple PECOFF malformations



General PE format layout

PE file format layout



Traditional layout

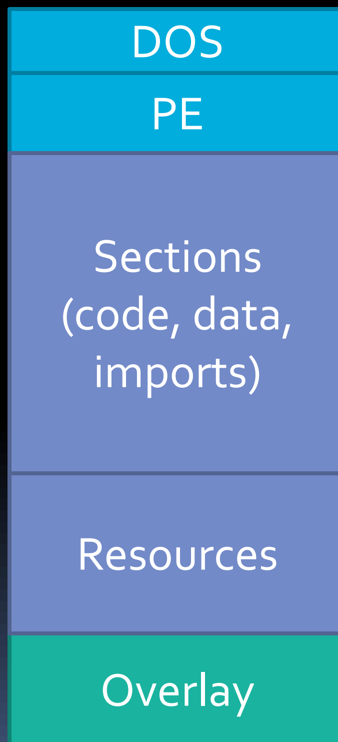
- Top level description
  - DOS header
    - "MZ" & e_lfanew
  - PECOFF header
    - COFF file header
    - Optional header
  - Sections
    - Code, data, imports, exports, resources…
  - Overlay
    - Appended file data

DOS header

- e_lfanew
  - Points to PE header
  - Is a 32 bit value
  - Must be 4 byte aligned

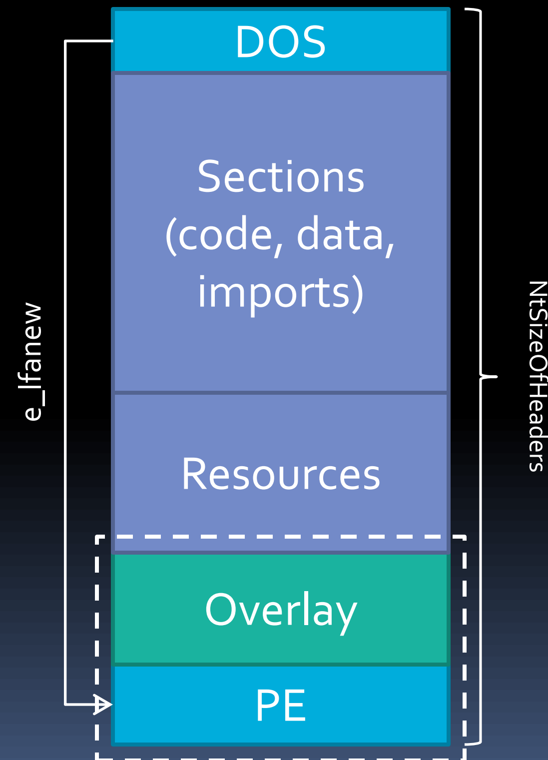
PE header|e_lfanew

PE file format layout



Traditional layout

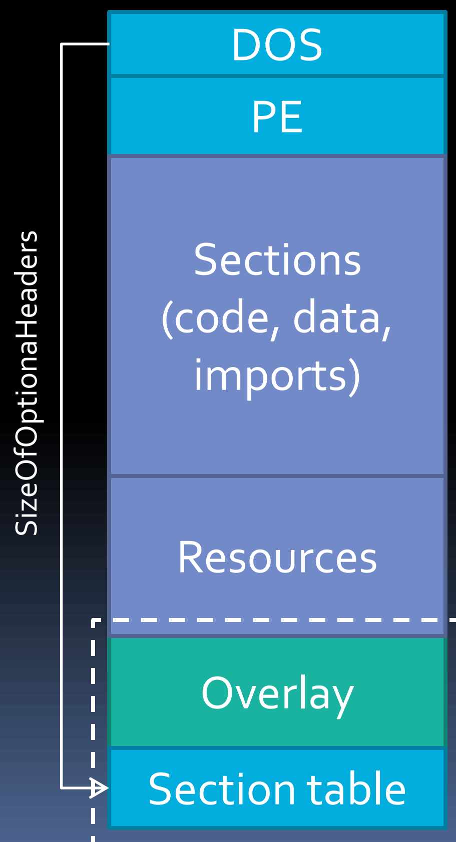
PE file malformation



PE header|SizeOfOptionalHeaders

demo

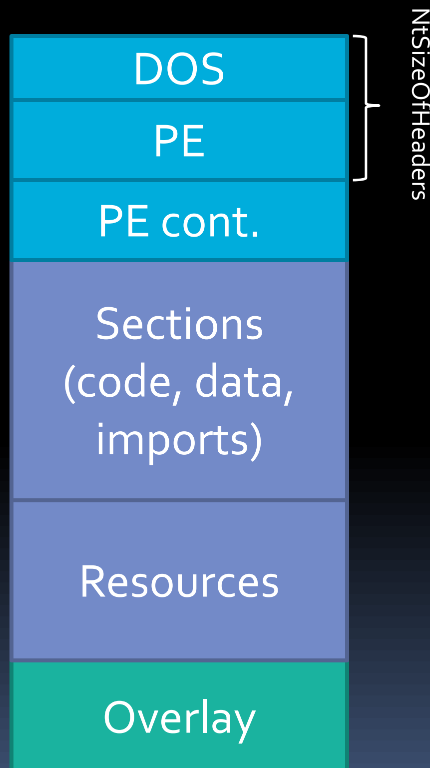
PE file format layout



- SizeOfOptionalHeaders
  - The size of the optional header, which is required for executable files but not for object files.
- Issues with SizeOfOptionalHeaders
  - Since the field that allows us to move the section table is a 16 bit field the maximum distance that we can move the table is just 0xFFFF. This doesn't limit the maximum size of the file as the section table doesn't need to be moved to the overlay for this to work, just the region of physical space which isn't mapped in memory.

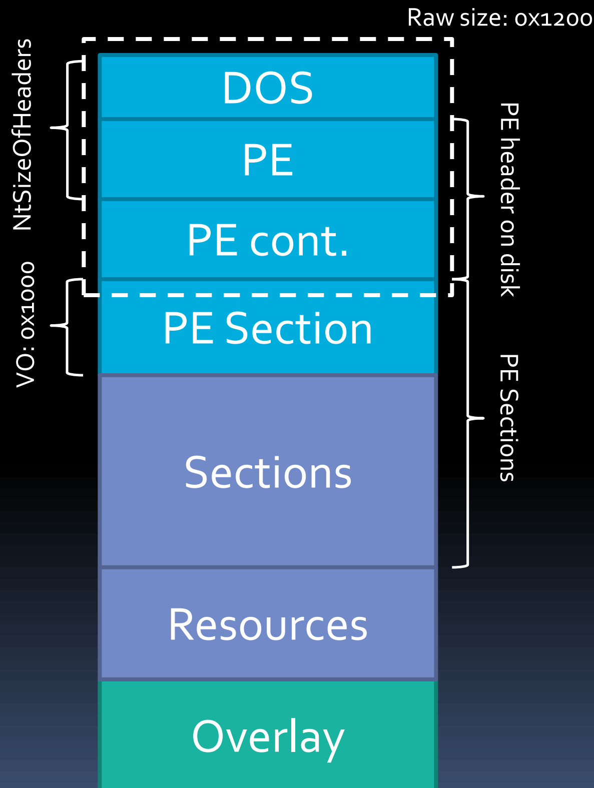
PE header|NtSizeOfHeaders

PE file format layout



- NtSizeOfHeaders
  - Is meant to determine the PE header physical boundaries
  - It also implicitly determines the virtual start of the first section
- Issues with NtSizeOfHeaders
  - It isn't rounded up to FileAlignment
  - Only the part of the PE header up until and including FileAlignment field needs to be inside the specified range
  - Regardless of the specified header size the rest of the header is processed from disk
    - But not all of it!

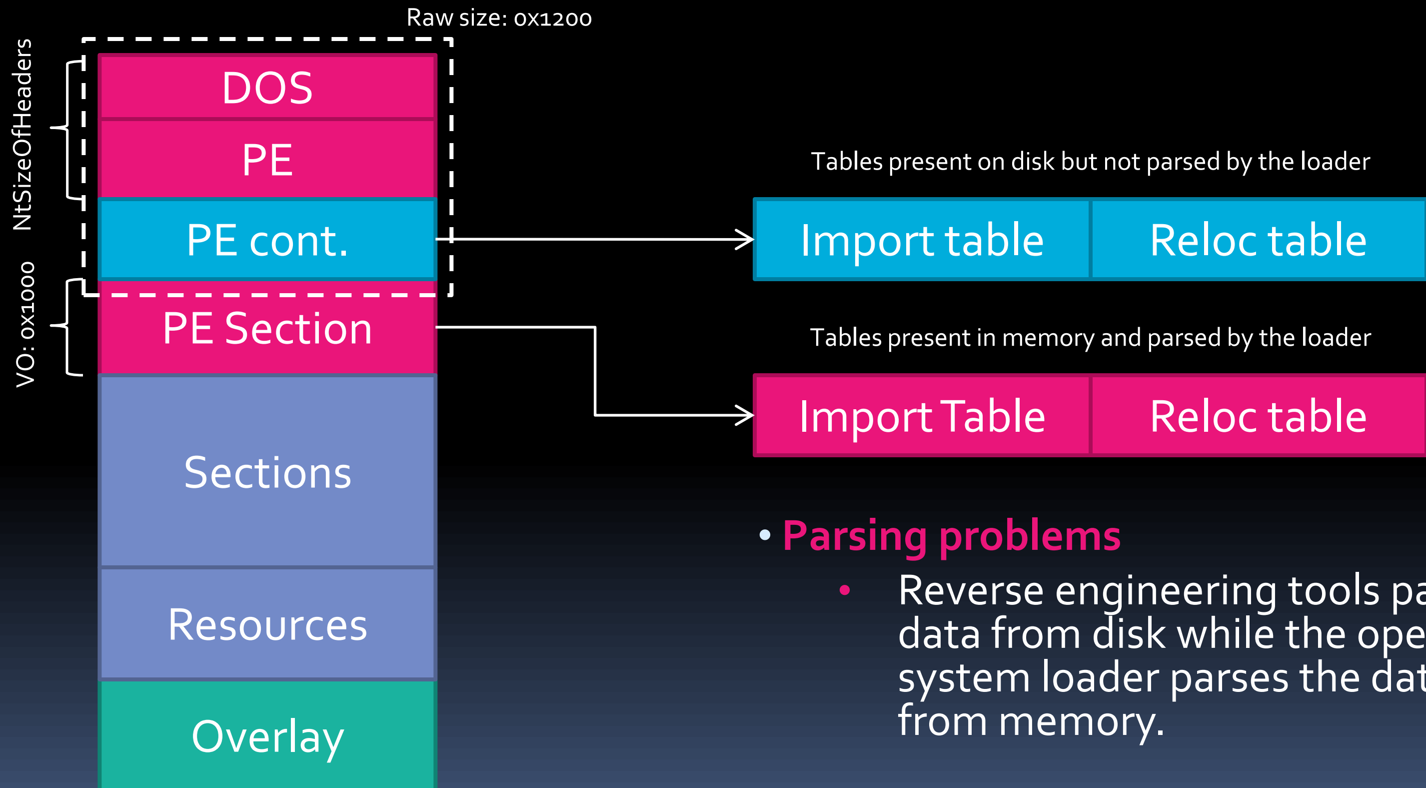
PE header|NtSizeOfHeaders



- Dual PE header malformation case
  - **e_lfanew** : 0xF80
  - **NtSizeOfHeaders** : 0x1000
    - Effectively truncating part of the PE header containing data tables
  - **FirstSectionRO**: 0x1200
  - **FirstSectionVO**: 0x1000
    - At the start of the section we store the continuation of the PE header containing data tables (e.g. imports are different and parsed from memory and not from disk by the loader)

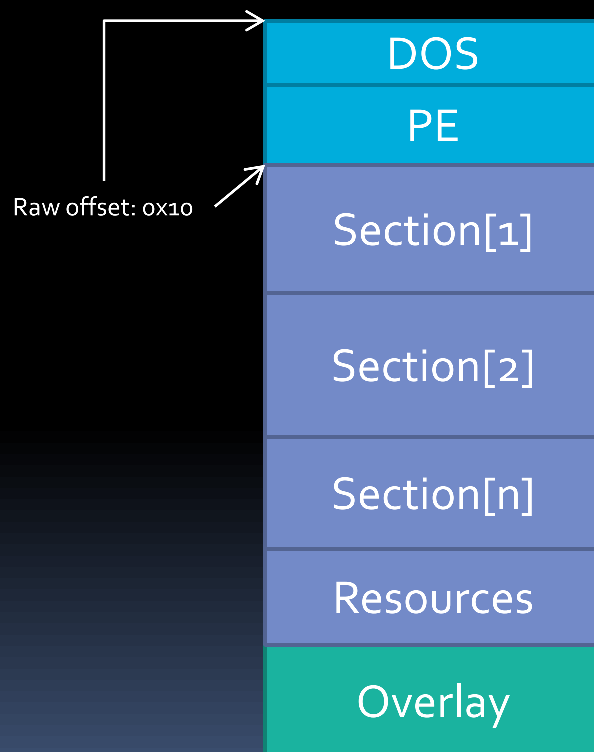
PE header|Dual data tables

demo



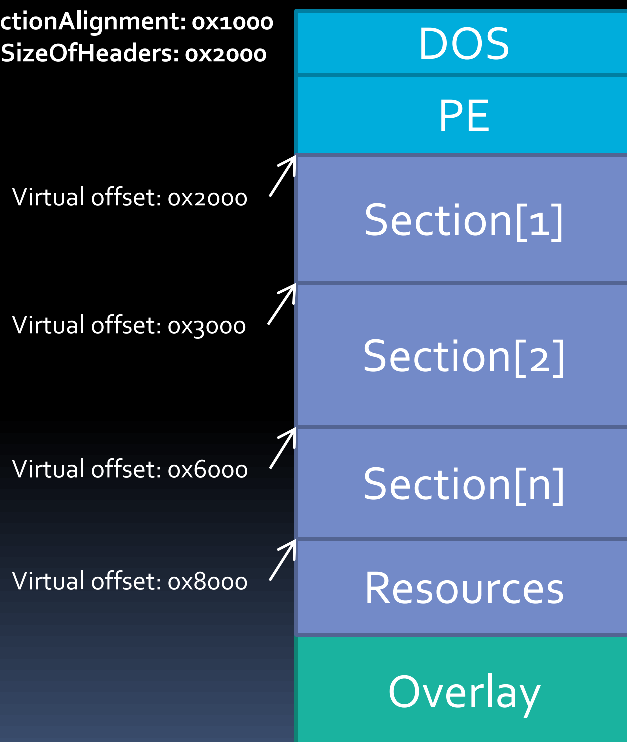
PE header|FileAlignment

PE file malformation



- **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.
- **FileAlignment issues**
  - Because of the conditions set by the PECOFF documentation whose excerpt is stated above we can safely assume that the value of FileAlignment can be hardcoded to 0x200.
  - Raw start of the sections is calculated by the formula (section_offset / 0x200) * 0x200

PE header|SectionAlignment



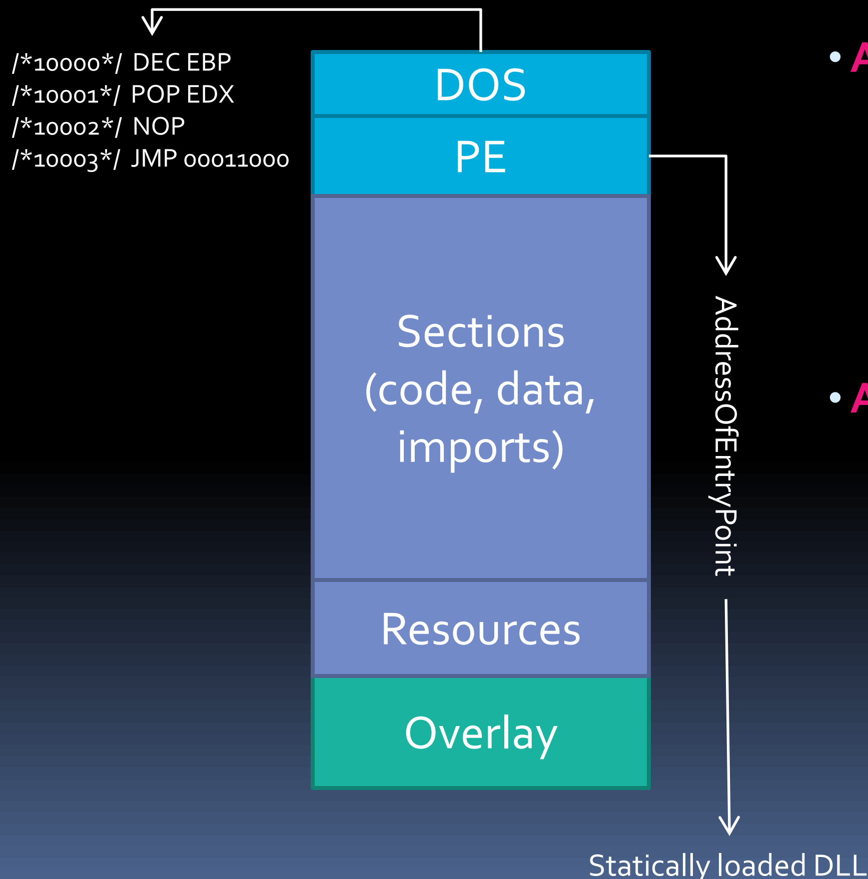
- **SectionAlignment**
  - SectionAlignment is the alignment (in bytes) of sections when they are loaded into memory. It must be greater than or equal to FileAlignment. The default is the page size for the architecture or a greater value which is the multiplier of the default page size.
- **SectionAlignment issues**
  - While every section must start as the multiplier of SectionAlignment the first section doesn't always start at the address which is equal to the value of SectionAlignment. Virtual start of the first section is calculated as the rounded up SizeOfHeaders value. That way header and all subsequent sections are committed to memory continuously with no gaps in between them.

PE header|Writable headers

demo

- **DOS/PE headers**
  - By default the PE header has read and execute attributes set. If DEP has been turned on the header has read only attributes.
- **SectionAlignment / FileAlignment issues**
  - If the values of FileAlignment and SectionAlignment have been set to the same value below 0x1000 the header will become writable. Typical value selected for this purpose is 0x200.

PE header|AddressOfEntryPoint

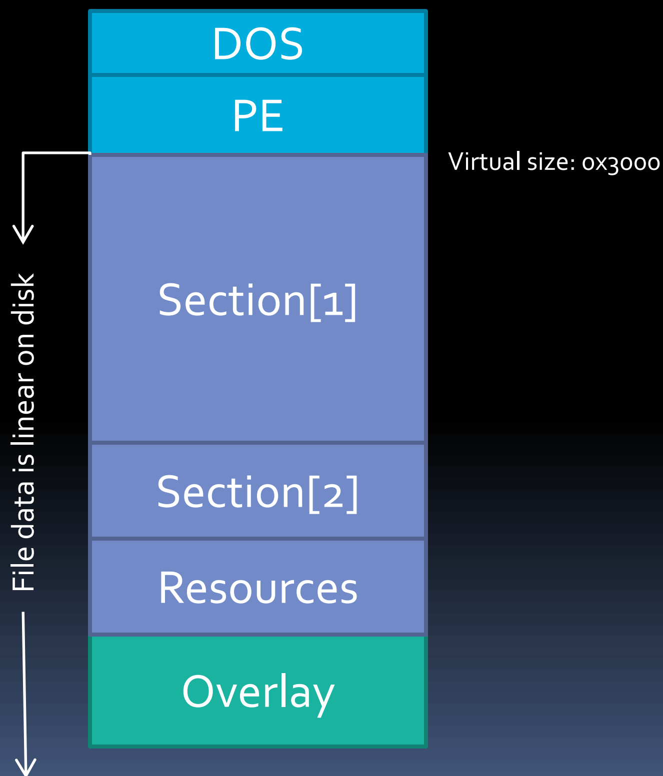


- **AddressOfEntryPoint**
  - The address of the entry point is relative to the image base when the executable file is loaded into memory. For program images, this is the starting address. For device drivers, this is the address of the initialization function. An entry point is optional for DLLs. When no entry point is present, this field must be zero.
- **AddressOfEntryPoint issues**
  - This excerpt from the PECOFF documentation implies that the entry point is only zero for DLLs with no entry point and that the entry point must reside inside the image. Neither of these two statements is true.

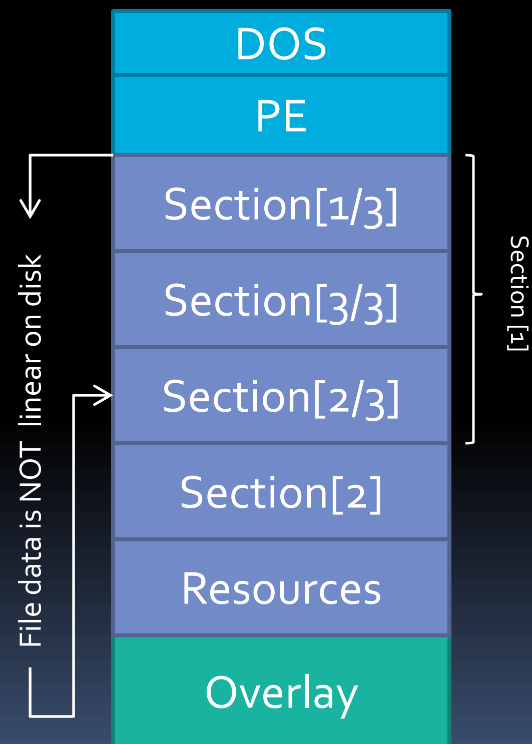
PE header|Section data

demo

- **Layout problem with writing static unpackers**
  - PE file disk layout

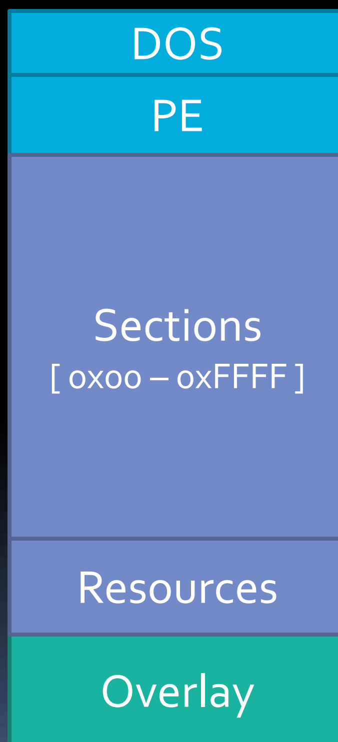


Section data shuffling



PE header|SectionNumber

PE file layout

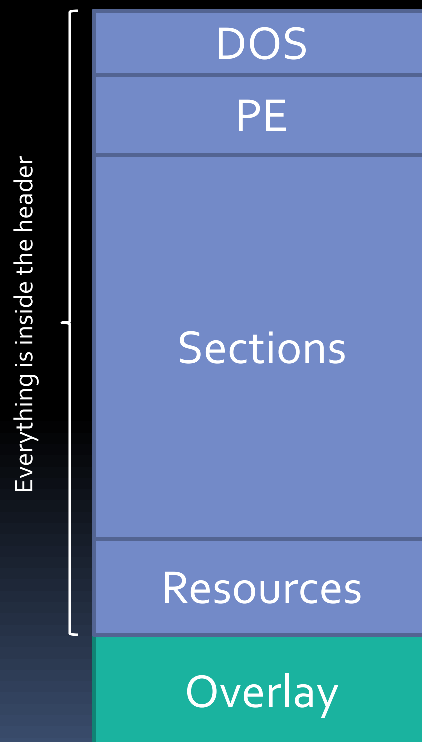


- **SectionNumber**
  - PE files have arbitrary section numbers; however it is assumed that the number of possible sections that a file can consist of is within a range from one to 96 as stated by the PECOFF documentation.
- **SectionNumber issues**
  - The latest implementations allow for this limit to be expanded to the range from zero sections to the maximum value allowed by the 16 bit field SectionNumber which is 0xFFFF.
  - Huge number of sections is problematic for many reverse engineering and security tools
  - No sections is even more problematic!

PE header|Zero section file

demo

Zero section PE file layout

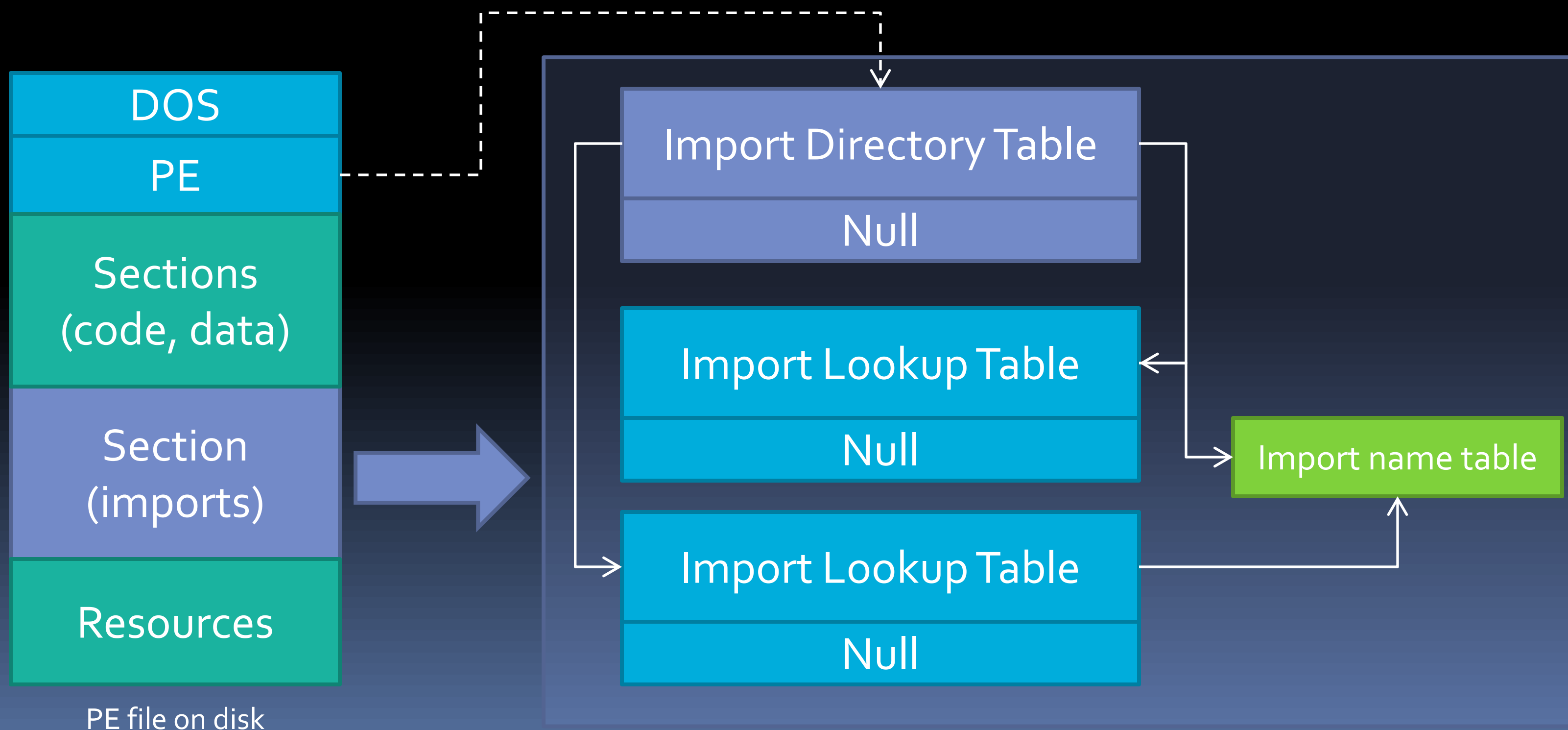


- **Making a zero section file**
  - File must be converted to flat memory model in which all relative virtual addresses are equivalent to their physical counterparts
  - Section table is removed and the number of section is set to zero
  - NtSizeOfHeaders is set to the physical size of the mapped memory
  - NtSizeOfImage is set to equal or grater value than NtSizeOfHeaders
  - FileAlignment and SectionAlignment are set to same value 0x200 to make the header writable

Complex PECOFF
malformations

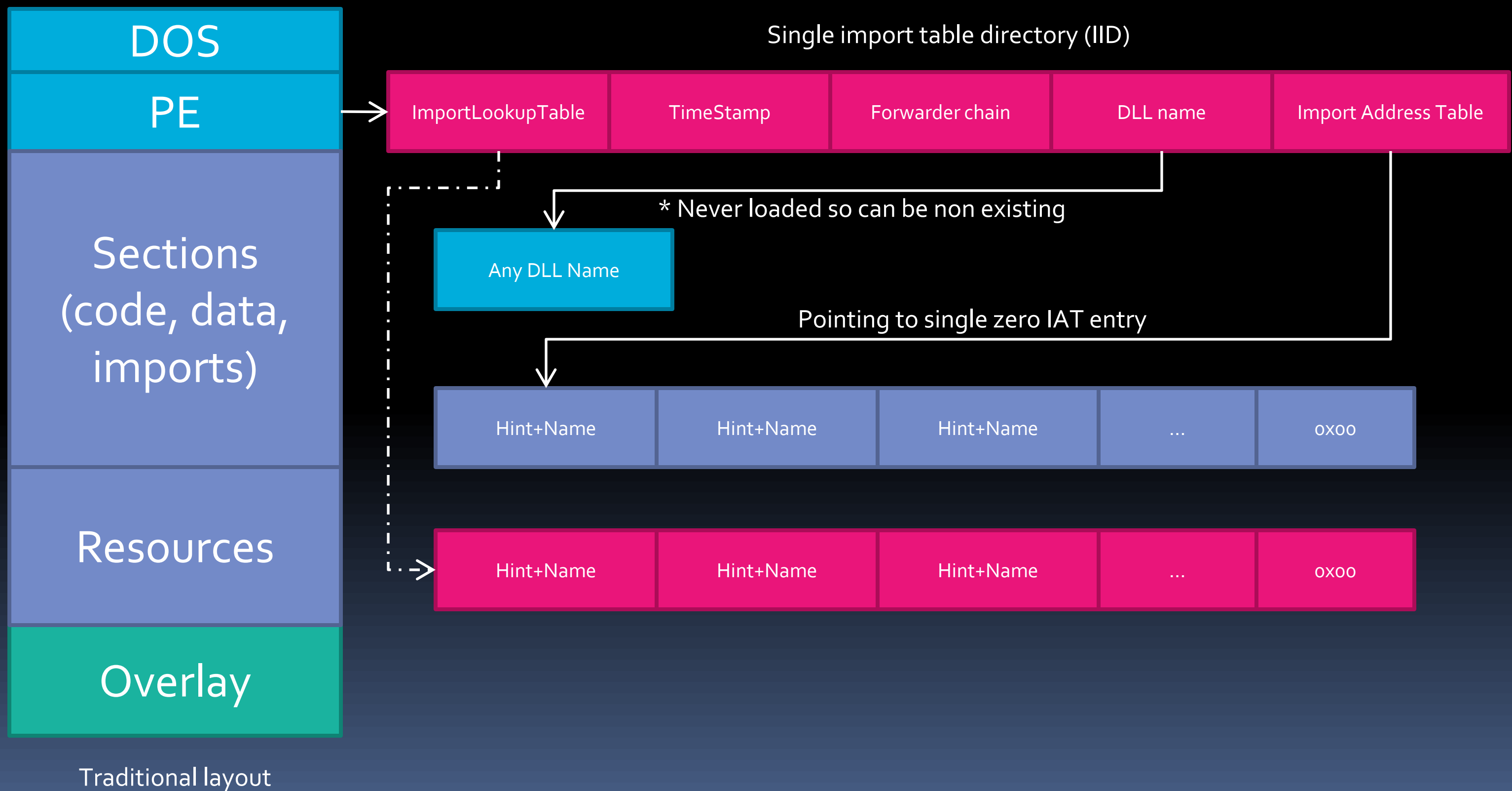
PE|Import table

- **Import table overview**
  - PE files that import symbols statically have an import table
  - Import table consists of names of dynamic link libraries and function names and/or function ordinal numbers



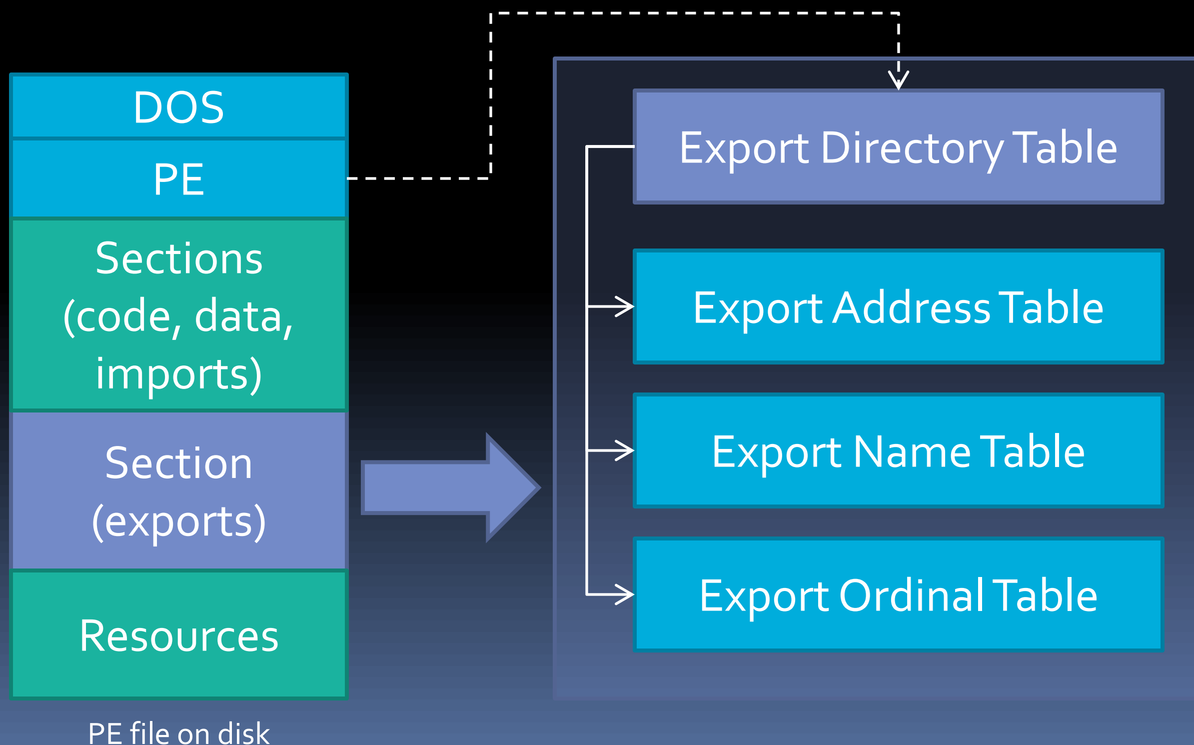
PE header|Import table

Dummy import table entries



PE|Export table

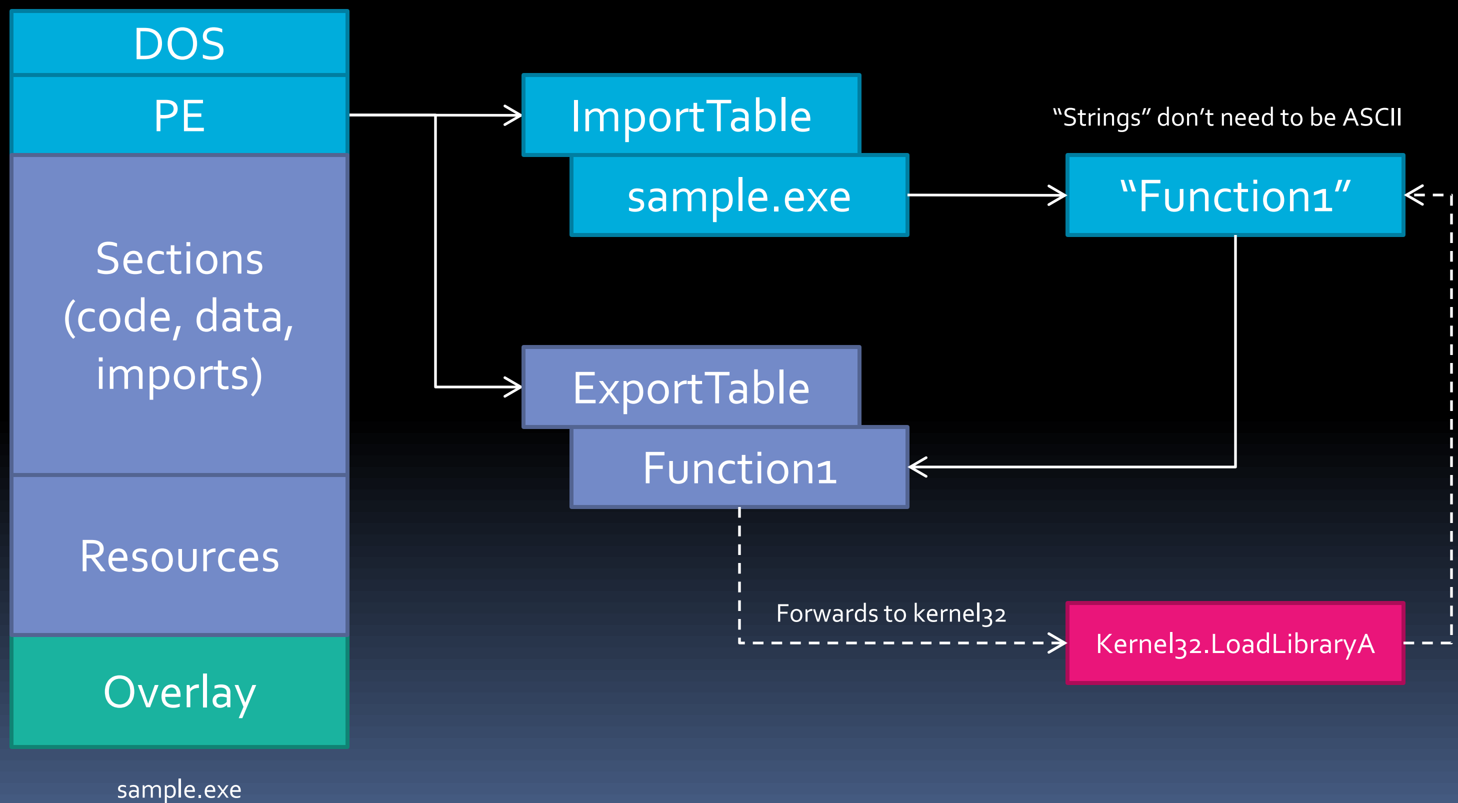
- **Export table overview**
  - PE files can also export symbols that other PE files import
  - PE files can export functions and variables



PE header|Import & Export table

demo

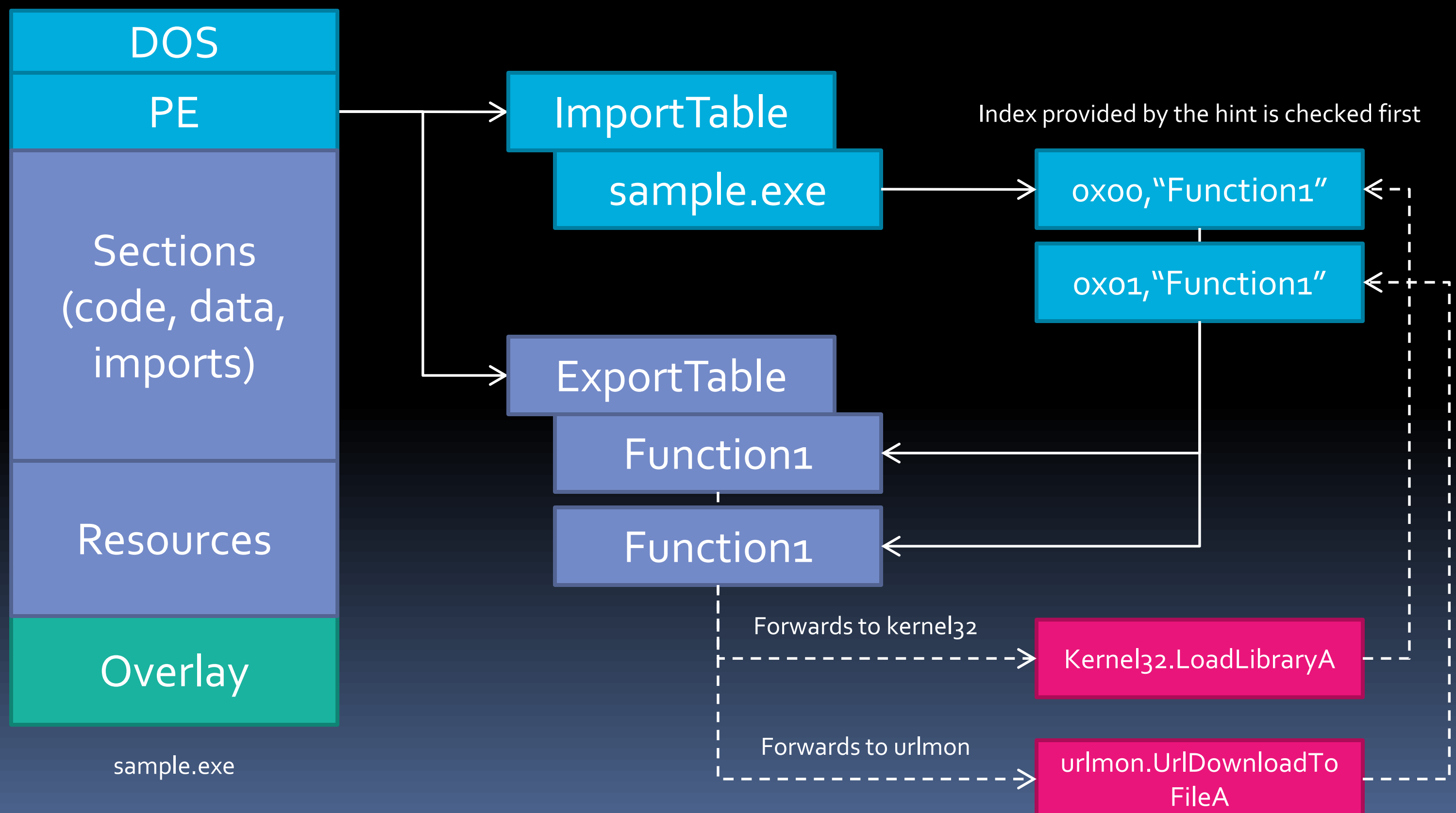
Import obfuscation



PE header|Import & Export table

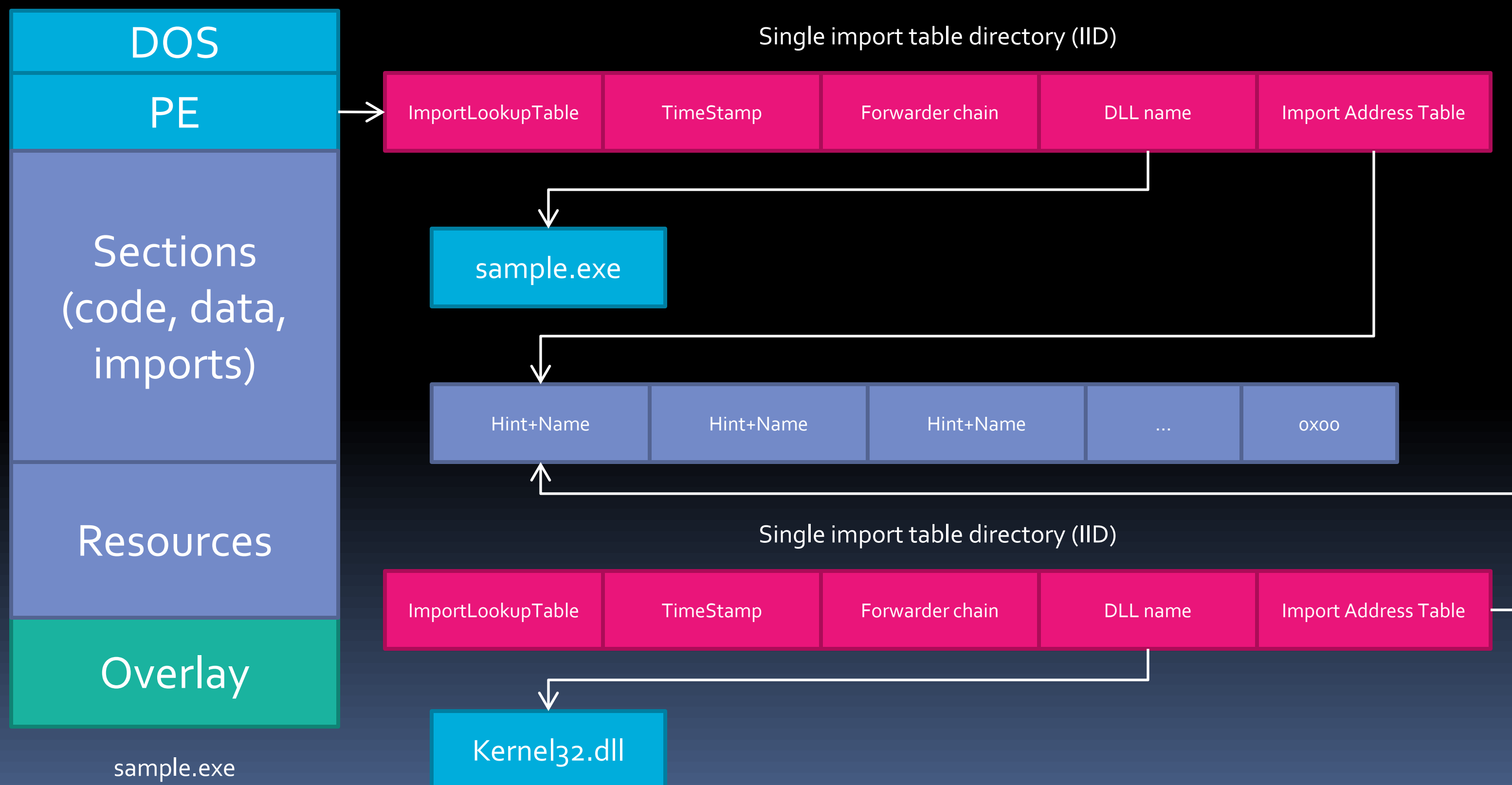
demo

Import obfuscation with hint



PE header|Import & Export table

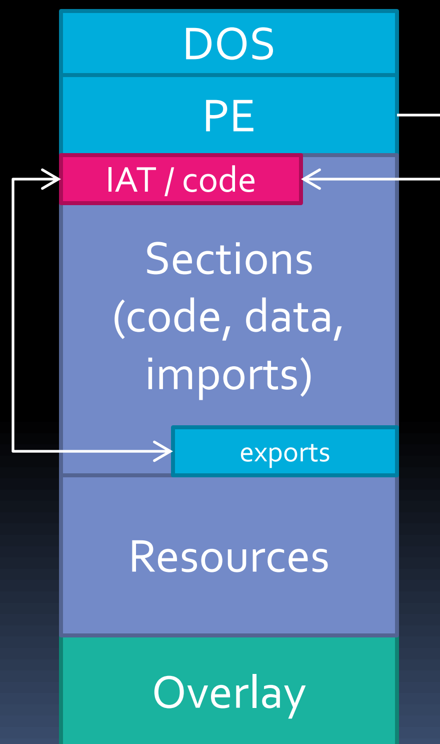
Rebuilding data with exports



PE header|Export table

demo

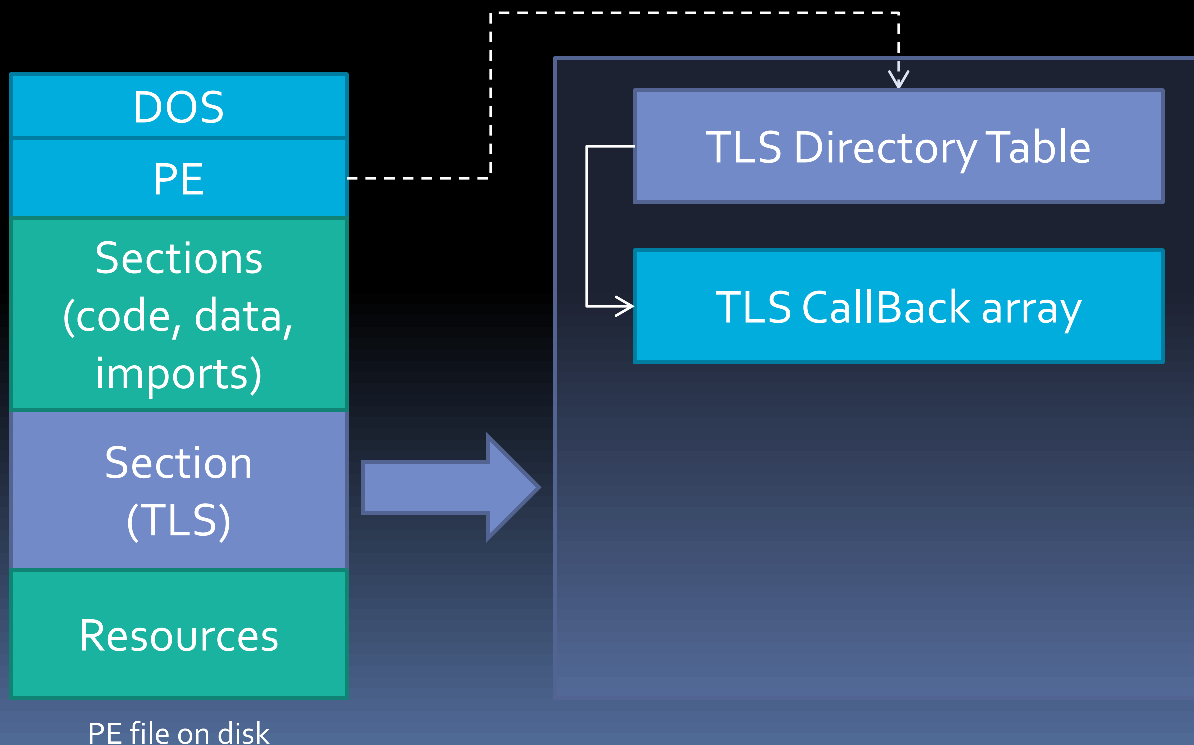
Rebuilding code with exports



- **Rebuilding code from exports**
  - File imports functions from its own export table.
  - Export table doesn't hold the valid pointers, it holds data that will be written to the import table.
  - Import table pointers are stored at the original code location (e.g. entry point)
  - Once file is loaded its import table is filled with the original code which in turn executes after that normally.

PE|TLS table

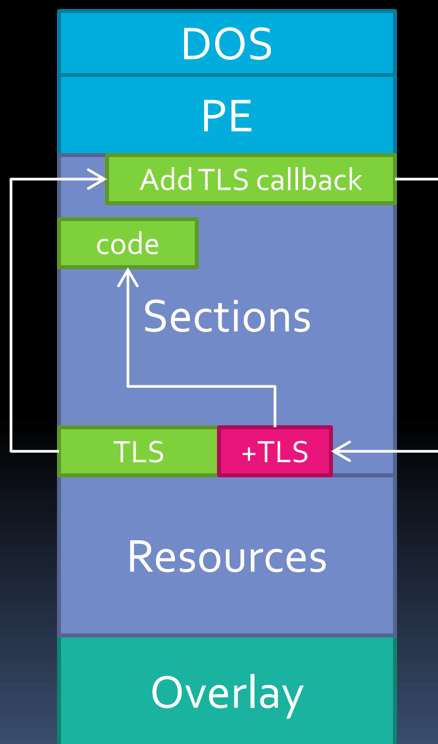
- **Thread local storage table overview**
  - TLS is a special storage class that Windows support in which a data object is not an automatic (stack) variable, yet is local to each individual thread that runs the code. Thus, each thread can maintain a different value for a variable declared by using TLS.



PE header|TLS table

demo

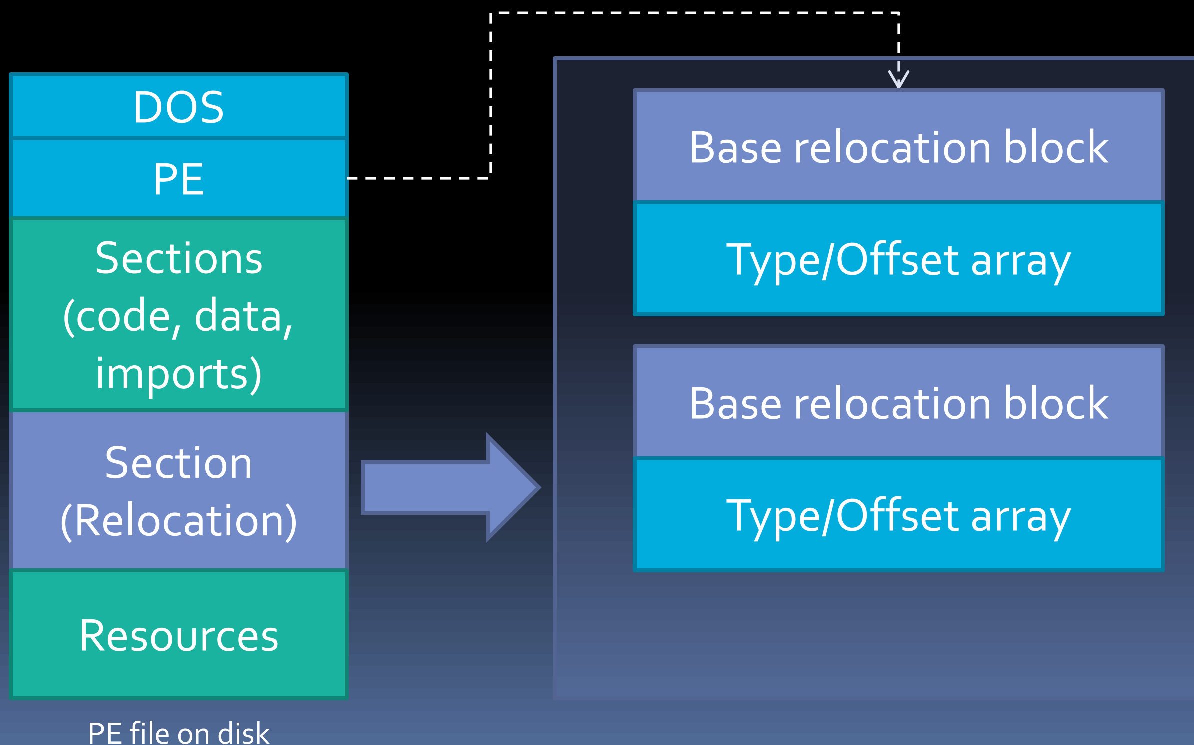
Dynamic callbacks



- **Dynamic callback table generation**
  - TLS callback array is processed from memory so it is possible that its content is modified from the first callback.
  - TLS callback array can be overlapped with import table so that code which gets executed is outside image.
  - TLS callback array can be overlapped with linked import & export table so that the executed code is still in the same image.

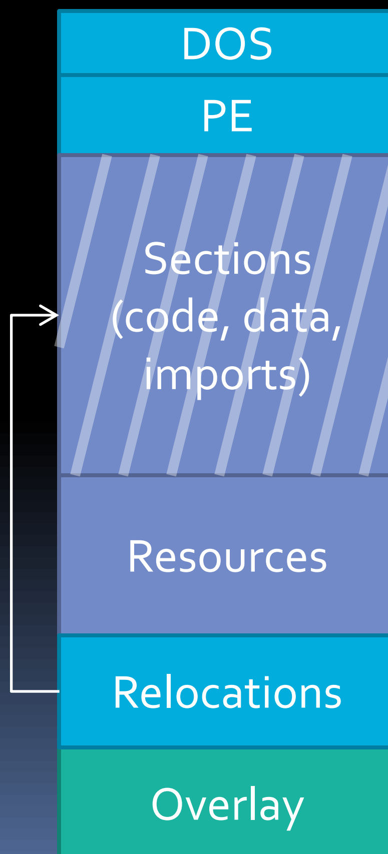
PE | Relocation table

- **Relocation table overview**
  - Base relocation table is used by the operating system loader to rebase the file in memory if the PE file needs to load on the base address which is different from its default one which is specified by the ImageBase PE header field.



PE header|Relocation table

Decryption via relocations

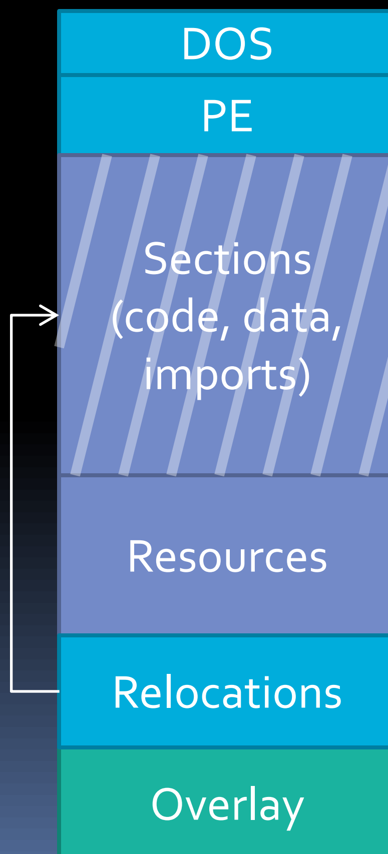


- **Decryption via relocations**
  - To be able to decrypt the content correctly the file always needs to be loaded through relocation process on the same base address. That way the decryption key wont change and the data will be decrypted correctly every time.
  - Pre Windows 7 SP1: If the file has an ImageBase 0x00 it will always be loaded on the base address 0x10000.
  - Post Windows 7 SP1: If the file has a base address inside kernel memory it will always be loaded on the base address 0x10000.

PE header|Relocation table

demo

Decryption via relocations



- **Decryption via relocations**
  - Every byte of selected section is encrypted with forward addition encryption. The value added is the value that the operating system loader will subtract when relocating the file.
  - New relocation table is created with four entries per page so that decryption is performed for every byte in reverse.
  - Every DWORD inside the selected section is processed four times.
  - Scary? First malware (LeRock) using it was detected last year. Its behavior was described by Peter Ferrie in VirusBulletin.

Detecting
malformations

- **PE file validations**
  - Headers
    - Disallow files which have headers outside the NtSizeOfHeaders
    - Disallow files which have too big NtSizeOfOptionalHeaders field value
    - Disallow files which have entry point outside the file
  - Sections
    - Disallow files with zero sections
  - Imports
    - String validation
    - Disallow table reuse and overlap
  - Exports
    - Disallow multiple entries with the same name
    - Disallow entries which have invalid function addresses
  - Relocations
    - Block files which utilize multiple relocations per address
  - TLS
    - Disallow files whose TLS callbacks are outside the image

- **on PE file format malformations**
  - PE is riddled with possibilities for malformation and we can’t always predict them all or design our tools to be aware of all of them
  - Malformations can lead to serious consequences such application crashes, buffer and integer overflows
  - Everyone implements their own PE parser which makes it impossible to say whether or not a product is affected by a malformation and if so by which ones
  - Unified document published by ReversingLabs is available at http://pecoff.reversinglabs.com and will help you test your product’s resilience to malformations (RL will maintain this document)

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Questions?

Q & A