Reverse Engineering III: PE Format

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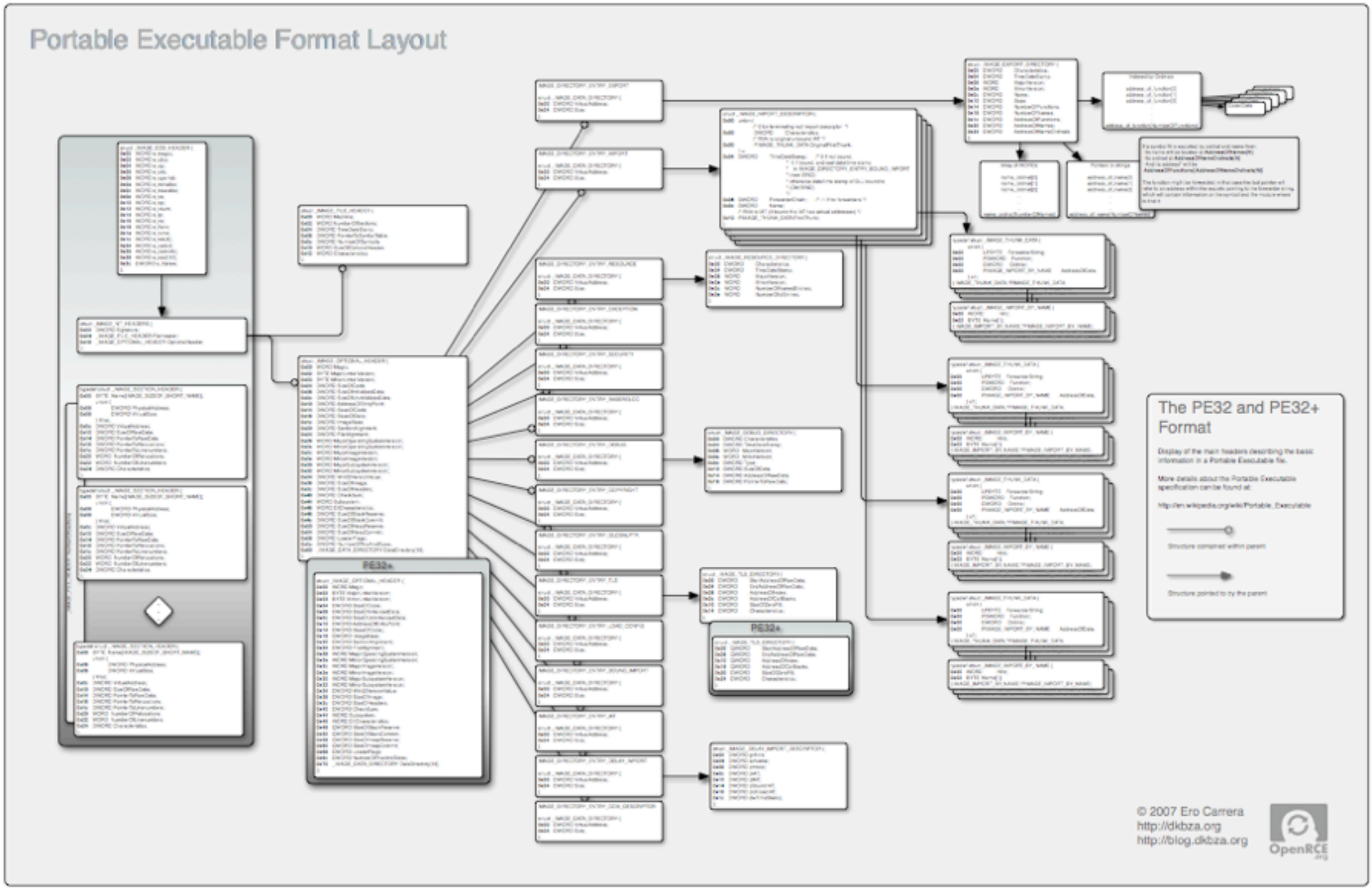
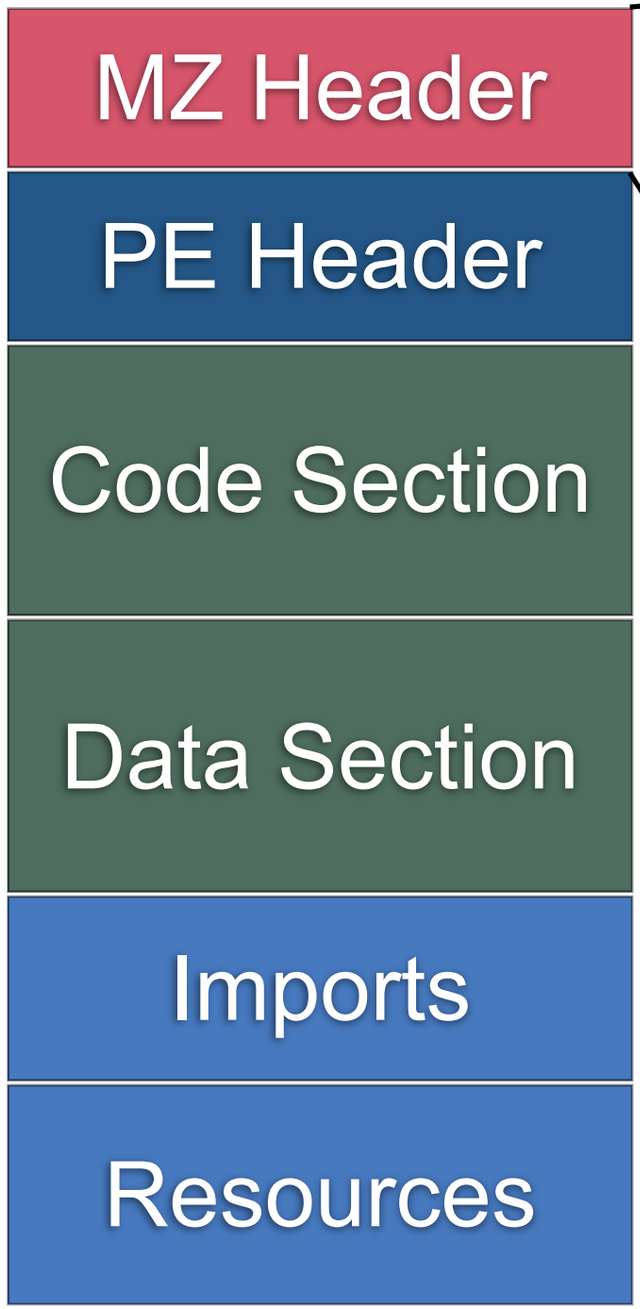
Introduction to PE

- PE stands for Portable Executable
- Microsoft introduced PE in Windows NT 3.1
- It originates from Unix COFF
- Features dynamic linking, symbol exporting/importing
- Can contain Intel, Alpha, MIPS and even .NET MSIL binary code
- 64-bit version is called PE32+

Complete Structure of PE



File Headers: MZ header




```
struct _IMAGE_DOS_HEADER {
0x00   WORD e_magic;
0x02   WORD e_cblp;
0x04   WORD e_cp;
0x06   WORD e_crlc;
0x08   WORD e_cparhdr;
0x0a   WORD e_minalloc;
0x0c   WORD e_maxalloc;
0x0e   WORD e_ss;
0x10   WORD e_sp;
0x12   WORD e_csum;
0x14   WORD e_ip;
0x16   WORD e_cs;
0x18   WORD e_lfarlc;
0x1a   WORD e_ovno;
0x1c   WORD e_res[4];
0x24   WORD e_oemid;
0x26   WORD e_oeminfo;
0x28   WORD e_res2[10];
0x3c   DWORD e_lfanew;
};
```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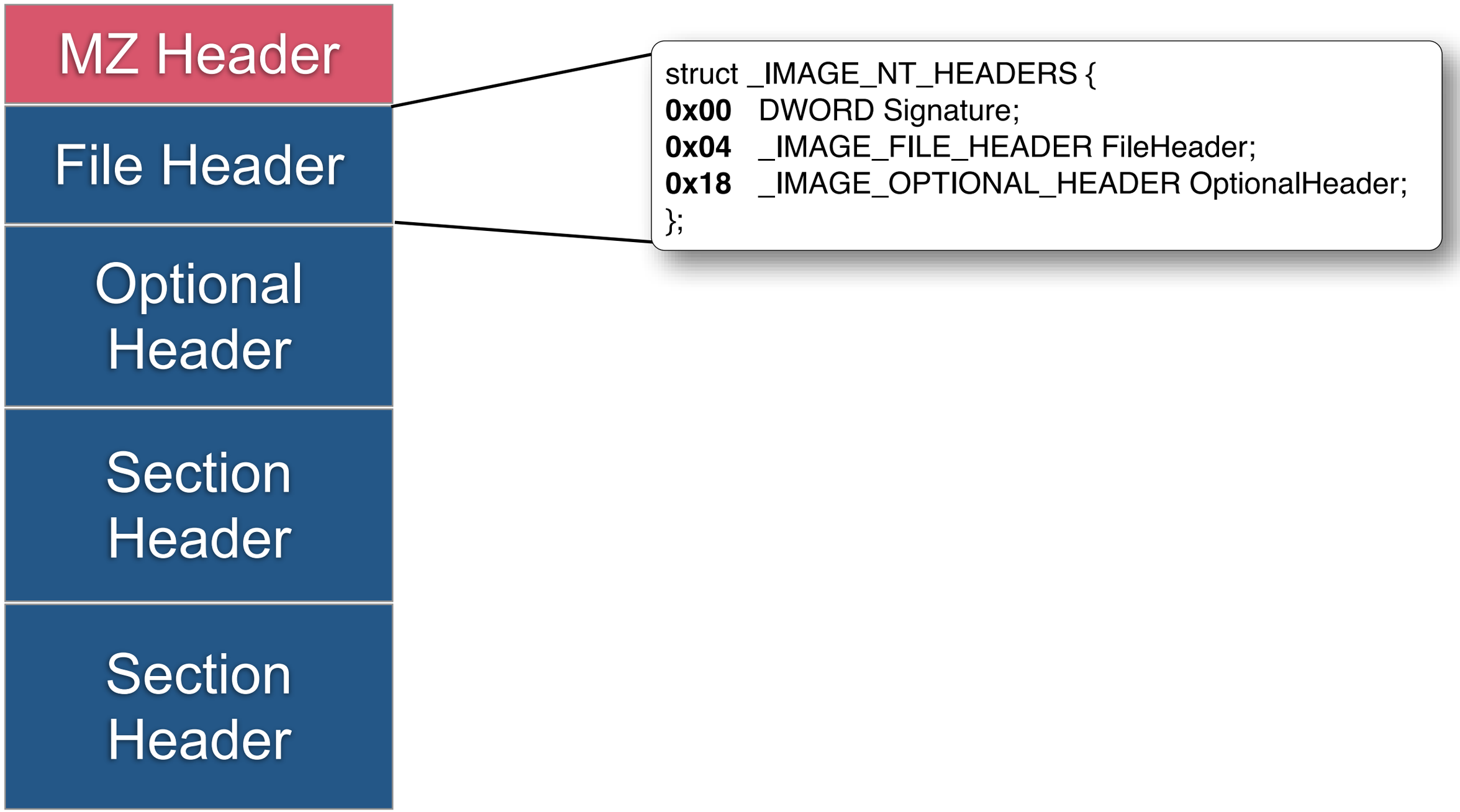
File Headers: PE Header



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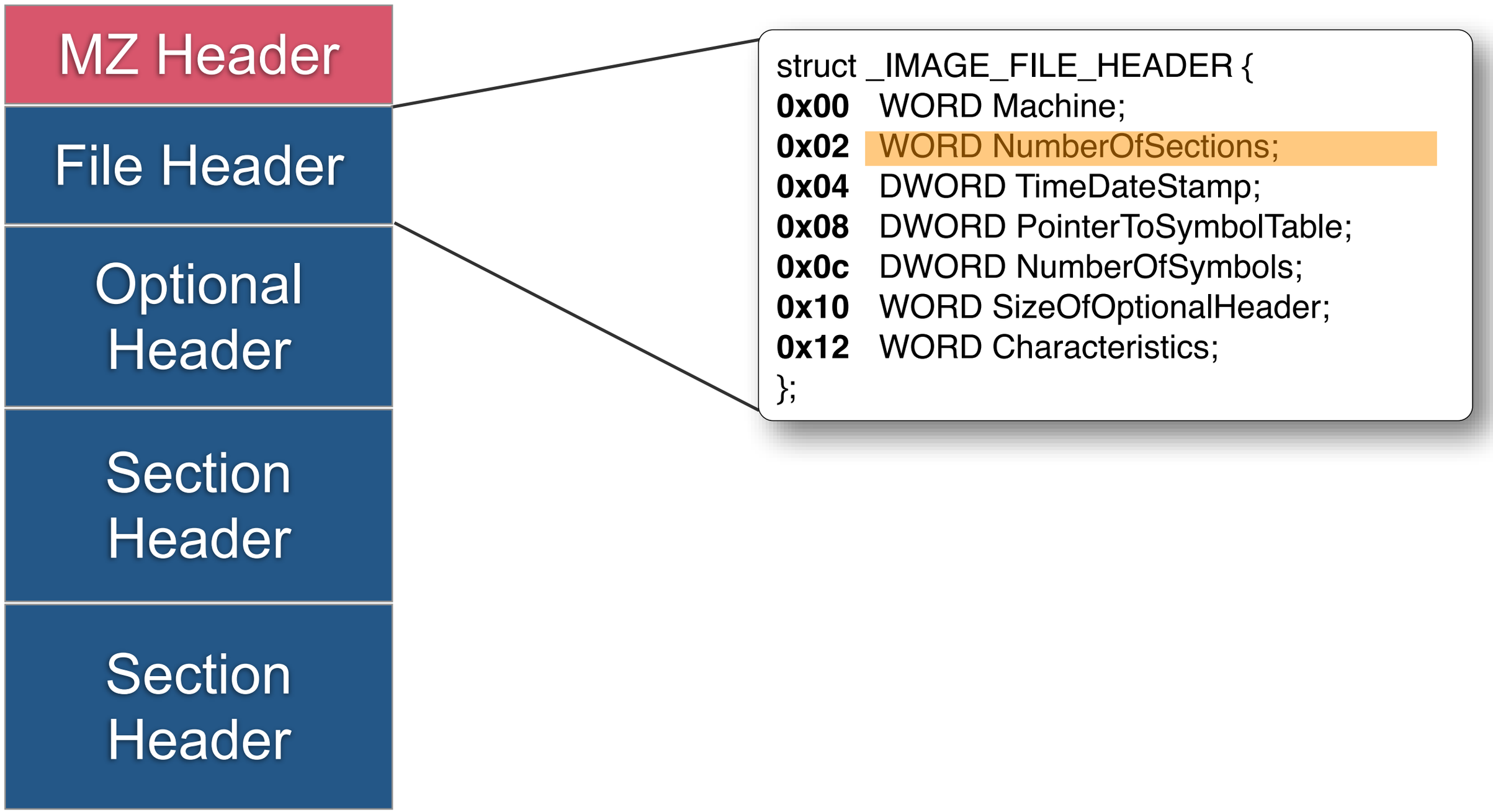
File Headers: File Header



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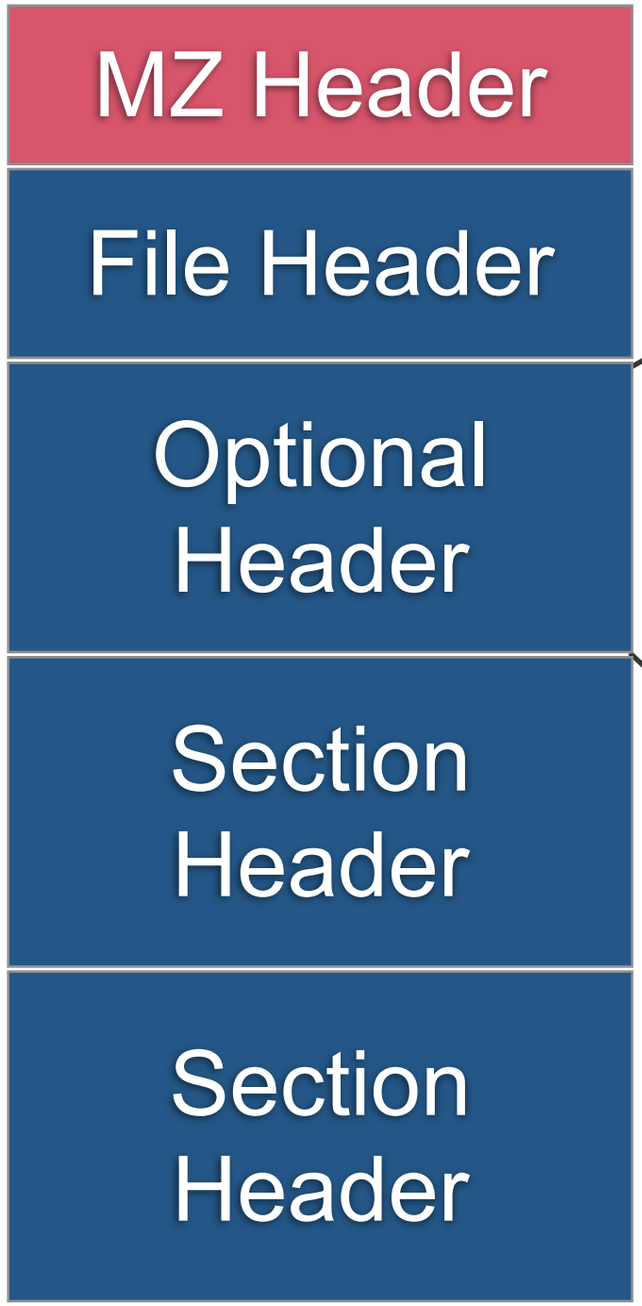
File Headers: Optional Header




```
struct _IMAGE_OPTIONAL_HEADER {
0x00   WORD Magic;
0x02   BYTE MajorLinkerVersion;
0x03   BYTE MinorLinkerVersion;
0x04   DWORD SizeOfCode;
0x08   DWORD SizeOfInitializedData;
0x0c   DWORD SizeOfUninitializedData;
0x10   DWORD AddressOfEntryPoint;
0x14   DWORD BaseOfCode;
0x18   DWORD BaseOfData;
0x1c   DWORD ImageBase;
0x20   DWORD SectionAlignment;
0x24   DWORD FileAlignment;
0x28   WORD MajorOperatingSystemVersion;
0x2a   WORD MinorOperatingSystemVersion;
0x2c   WORD MajorImageVersion;
0x2e   WORD MinorImageVersion;
0x30   WORD MajorSubsystemVersion;
0x32   WORD MinorSubsystemVersion;
0x34   DWORD Win32VersionValue;
0x38   DWORD SizeOfImage;
0x3c   DWORD SizeOfHeaders;
0x40   DWORD CheckSum;
0x44   WORD Subsystem;
0x46   WORD DllCharacteristics;
0x48   DWORD SizeOfStackReserve;
0x4c   DWORD SizeOfStackCommit;
0x50   DWORD SizeOfHeapReserve;
0x54   DWORD SizeOfHeapCommit;
0x58   DWORD LoaderFlags;
0x5c   DWORD NumberOfRvaAndSizes;
0x60   _IMAGE_DATA_DIRECTORY DataDirectory[16];
};
```

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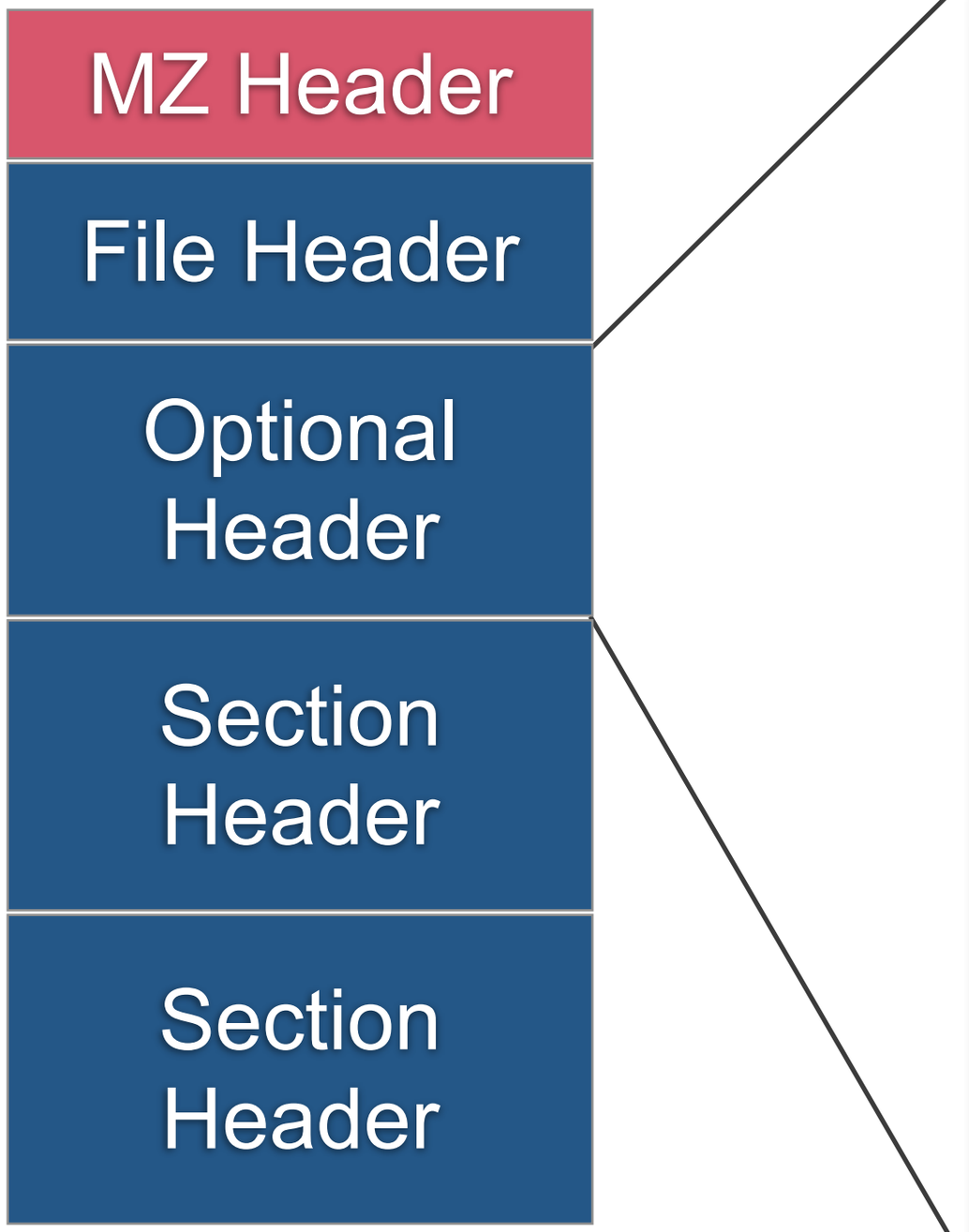
File Headers: Optional Header




```
struct _IMAGE_OPTIONAL_HEADER {
0x00  WORD Magic;
0x02  BYTE MajorLinkerVersion;
0x03  BYTE MinorLinkerVersion;
0x04  DWORD SizeOfCode;
0x08  DWORD SizeOfInitializedData;
0x0c  DWORD SizeOfUninitializedData;
0x10  DWORD AddressOfEntryPoint;
0x14  DWORD BaseOfCode;
0x18  DWORD BaseOfData;
0x1c  DWORD ImageBase;
0x20  DWORD SectionAlignment;
0x24  DWORD FileAlignment;
0x28  WORD MajorOperatingSystemVersion;
0x2a  WORD MinorOperatingSystemVersion;
0x2c  WORD MajorImageVersion;
0x2e  WORD MinorImageVersion;
0x30  WORD MajorSubsystemVersion;
0x32  WORD MinorSubsystemVersion;
0x34  DWORD Win32VersionValue;
0x38  DWORD SizeOfImage;
0x3c  DWORD SizeOfHeaders;
0x40  DWORD CheckSum;
0x44  WORD Subsystem;
```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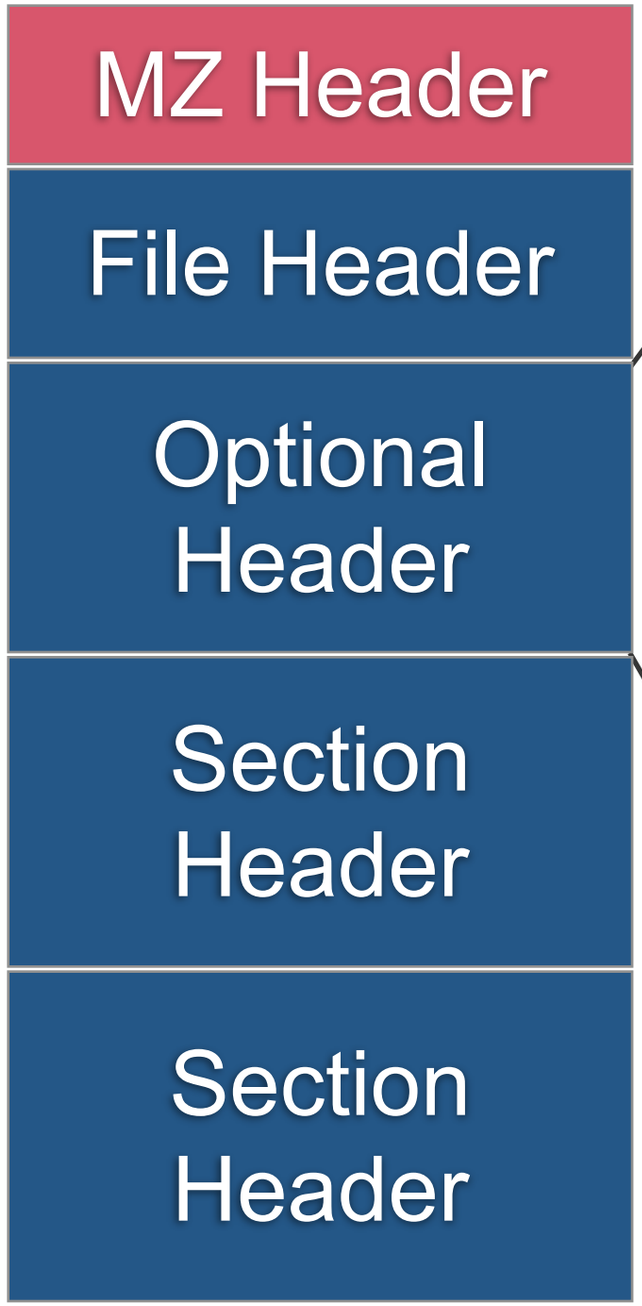
File Headers: Optional Header




```
0x1c  DWORD ImageBase;
0x20  DWORD SectionAlignment;
0x24  DWORD FileAlignment;
0x28  WORD MajorOperatingSystemVersion;
0x2a  WORD MinorOperatingSystemVersion;
0x2c  WORD MajorImageVersion;
0x2e  WORD MinorImageVersion;
0x30  WORD MajorSubsystemVersion;
0x32  WORD MinorSubsystemVersion;
0x34  DWORD Win32VersionValue;
0x38  DWORD SizeOfImage;
0x3c  DWORD SizeOfHeaders;
0x40  DWORD CheckSum;
0x44  WORD Subsystem;
0x46  WORD DllCharacteristics;
0x48  DWORD SizeOfStackReserve;
0x4c  DWORD SizeOfStackCommit;
0x50  DWORD SizeOfHeapReserve;
0x54  DWORD SizeOfHeapCommit;
0x58  DWORD LoaderFlags;
0x5c  DWORD NumberOfRvaAndSizes;
0x60  _IMAGE_DATA_DIRECTORY DataDirectory[16];
};
```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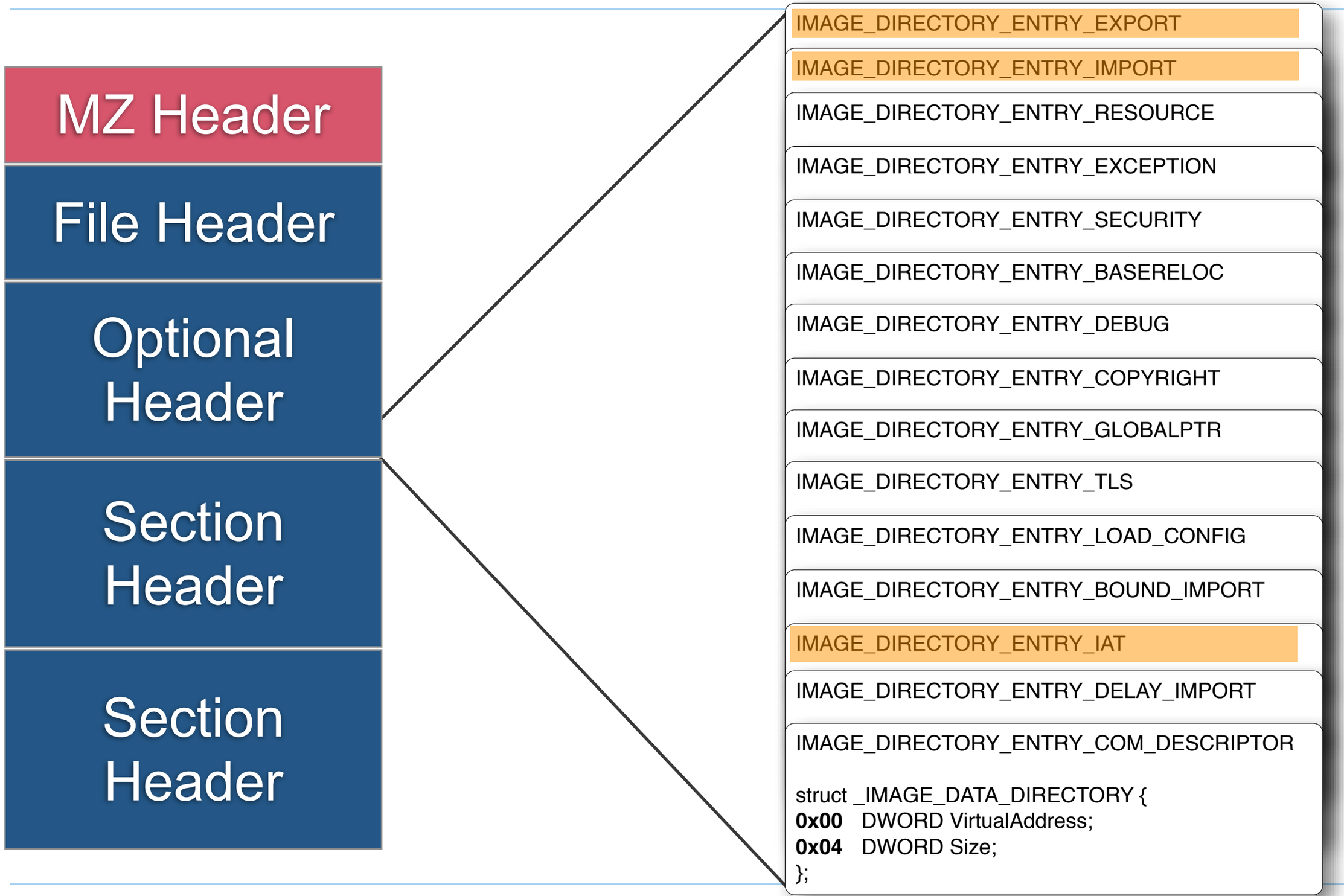
File Headers: Image Directory



File Headers: Section Header

MZ Header

File Header

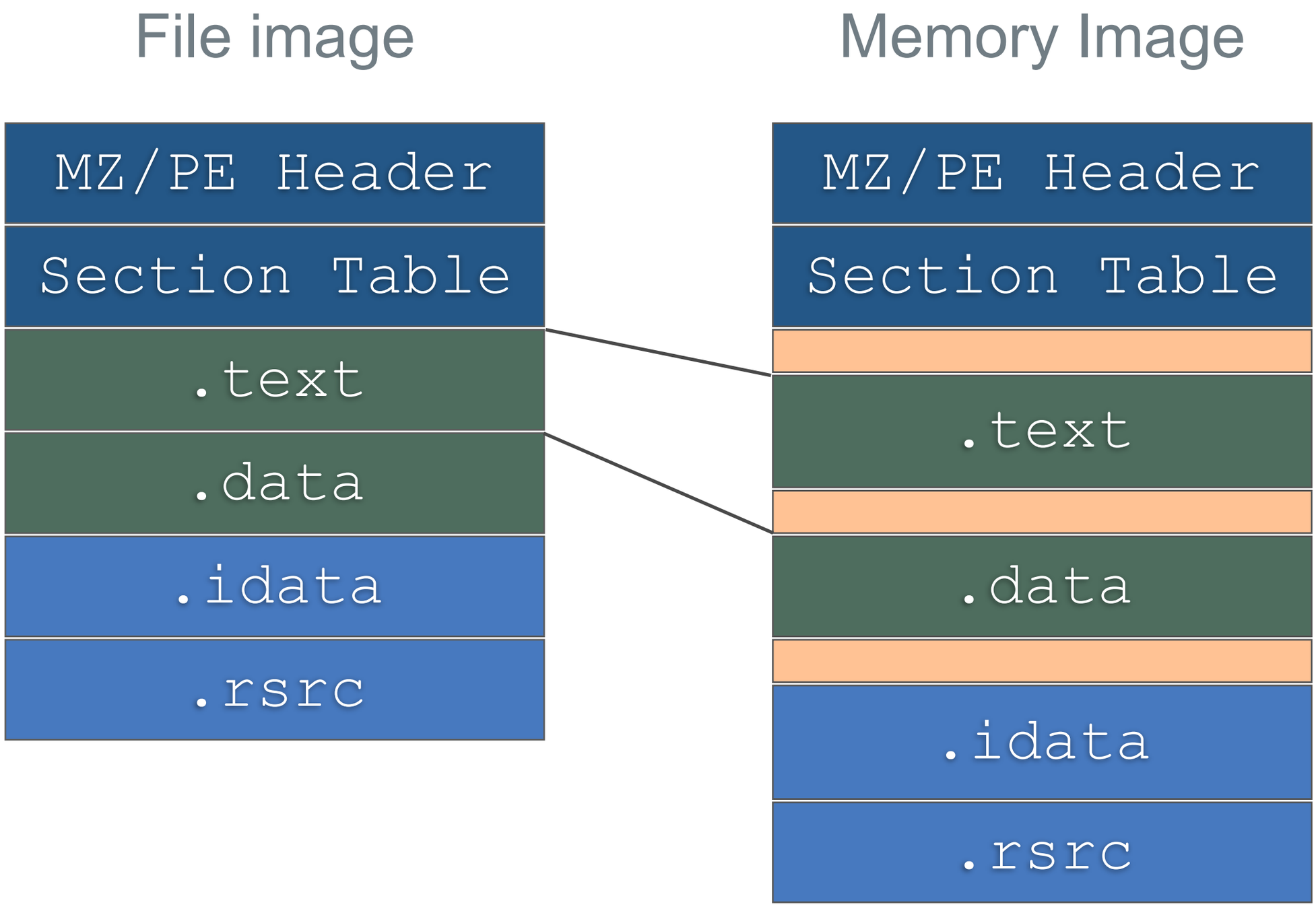
Optional Header

Section Header

Section Header

```
typedef struct _IMAGE_SECTION_HEADER {
0x00    BYTE  Name[IMAGE_SIZEOF_SHORT_NAME];
        union {
0x08            DWORD PhysicalAddress;
0x08            DWORD VirtualSize;
        } Misc;
0x0c    DWORD VirtualAddress;
0x10    DWORD SizeOfRawData;
0x14    DWORD PointerToRawData;
0x18    DWORD PointerToRelocations;
0x1c    DWORD PointerToLinenumbers;
0x20    WORD  NumberOfRelocations;
0x22    WORD  NumberOfLinenumbers;
0x24    DWORD Characteristics;
};
```

PE Image Loading



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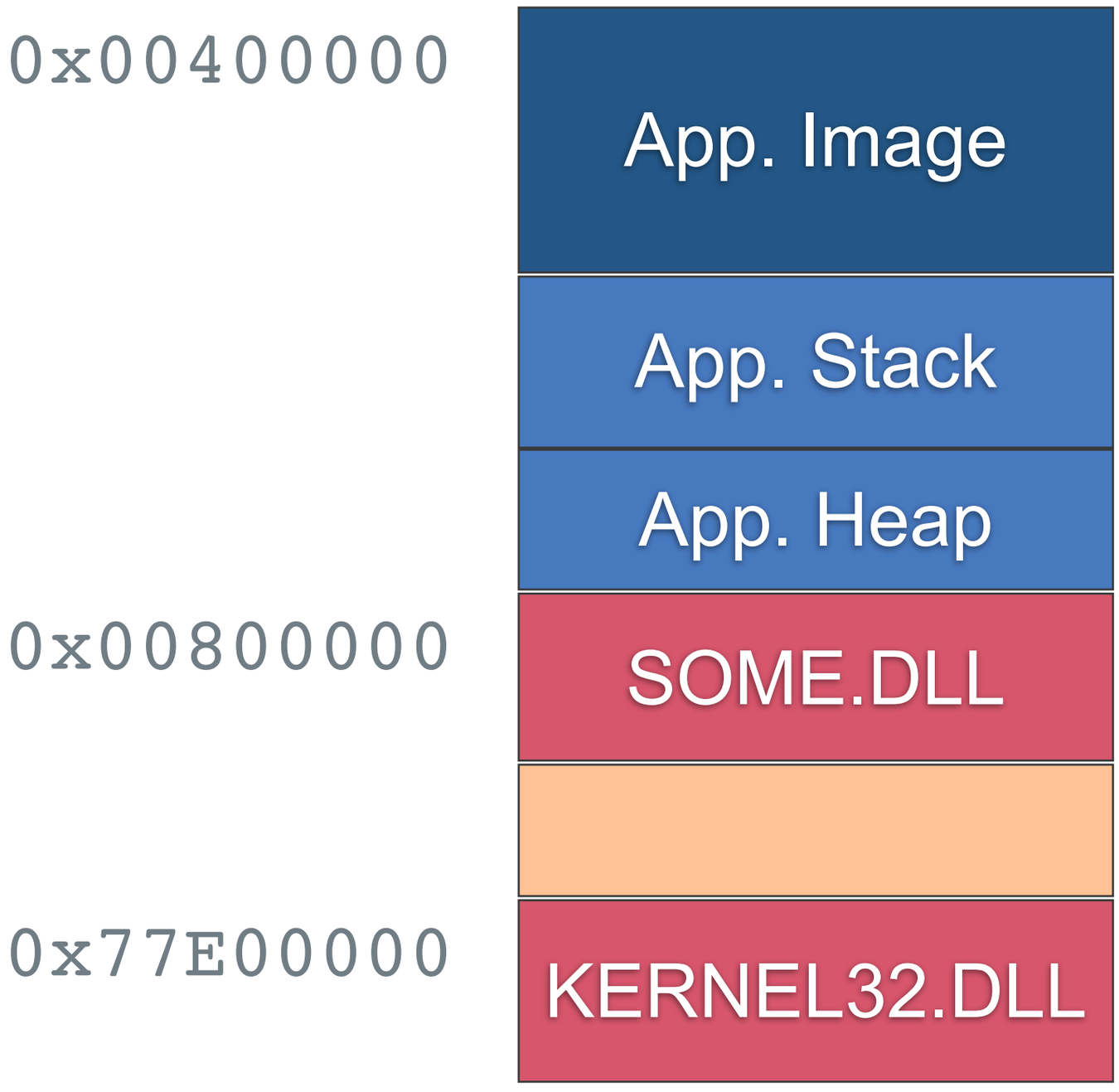
Memory Layout



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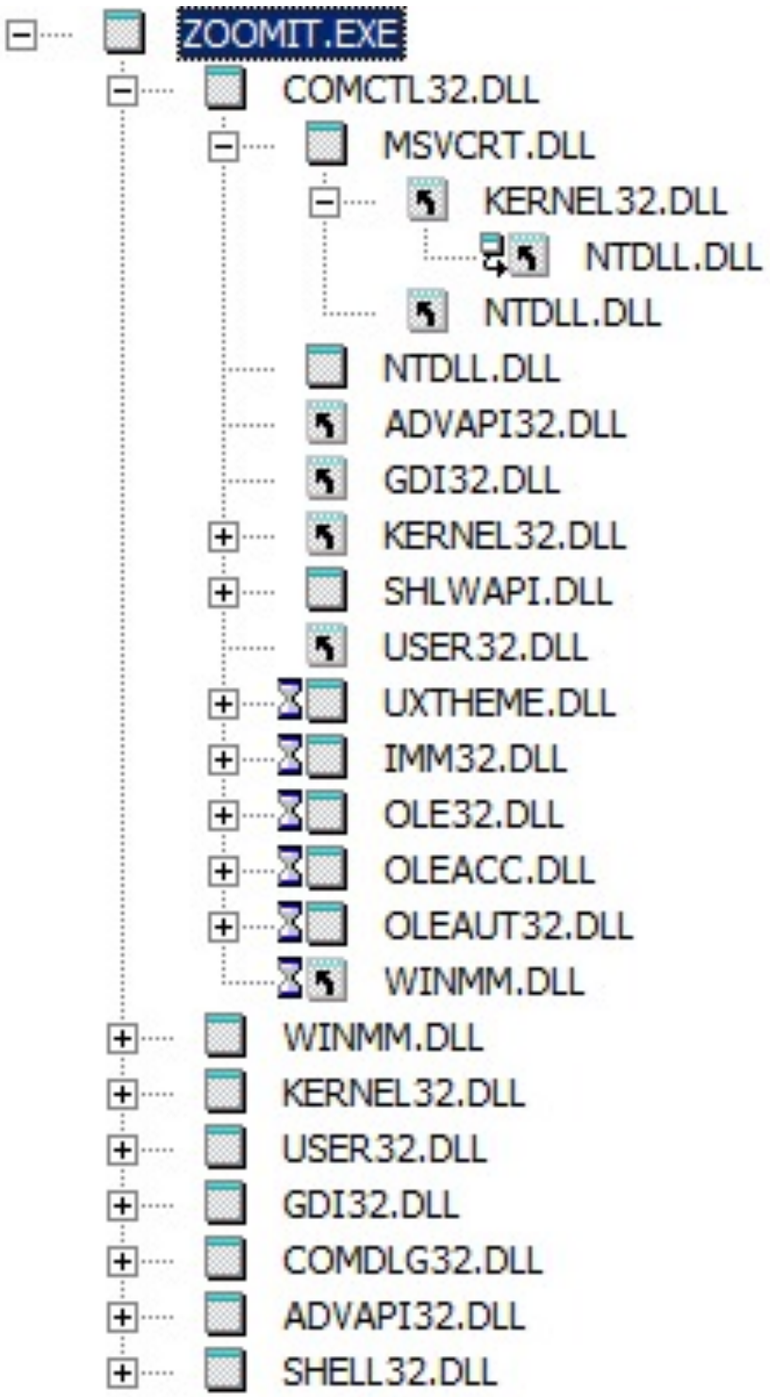
Importing Symbols

- Symbols (functions/data) can be imported from external DLLs
- The loader will load external DLLs automatically
- All the dependencies are loaded as well
- DLLs will be loaded only once
- External addresses are written to the Import Address Table (IAT)
- IAT is most often located in the .idata section

DLL Dependency Tree



Depends tool shows all dependencies

http://www.dependencywalker.com/

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Importing Symbols

- Each DLL has one IMAGE_IMPORT_DESCRIPTOR
- The descriptor points to two parallel lists of symbols to import
  - Import Address Table (IAT)
  - Import Name Table (INT)
- The primary list is overwritten by the loader, the second one is not
- Executables can be pre-bound to DLLs to speed up loading
- Symbols can be imported by ASCII name or ordinal

Imports

.idata section

```
IMPORT_DESCRIPTORS:
   USER32.DLL
   ADVAPI32.DLL

Import Name Table(INT):
   'IMPORT1'
   'IMPORT2'

Import Adddress Table (IAT):
   DWORD IMPORT1
   DWORD IMPORT2
```

```
Calling:

CALL [IMPORT1]

...

CALL [IMPORT2]
```

Import Descriptors

```
IMAGE_DIRECTORY_ENTRY_IMPORT

struct _IMAGE_DATA_DIRECTORY {
0x00   DWORD VirtualAddress;
0x04   DWORD Size;
};
```

```
struct _IMAGE_IMPORT_DESCRIPTOR {
0x00   union {
                /* 0 for terminating null import descriptor  */
0x00            DWORD        Characteristics;
                /* RVA to original unbound IAT */
0x00            PIMAGE_THUNK_DATA OriginalFirstThunk;
        } u;
0x04   DWORD        TimeDateStamp;      /* 0 if not bound,
        0x08   DWORD        ForwarderChain;      /* -1 if no forwarders */
0x0c   DWORD        Name;
        /* RVA to IAT (if bound this IAT has actual addresses) */
0x10   PIMAGE_THUNK_DATA FirstThunk;
};
```

```
typedef struct _IMAGE_THUNK_DATA {
        union {
0x00            LPBYTE    ForwarderString;
0x00            PDWORD    Function;
0x00            DWORD     Ordinal;
0x00            PIMAGE_IMPORT_BY_NAME       AddressOfData;
        } u1;
} IMAGE_THUNK_DATA,*PIMAGE_THUNK_DATA;
```

```
typedef struct _IMAGE_IMPORT_BY_NAME {
0x00   WORD          Hint;
0x02   BYTE  Name[1];
} IMAGE_IMPORT_BY_NAME,*PIMAGE_IMPORT_BY_NAME;
```

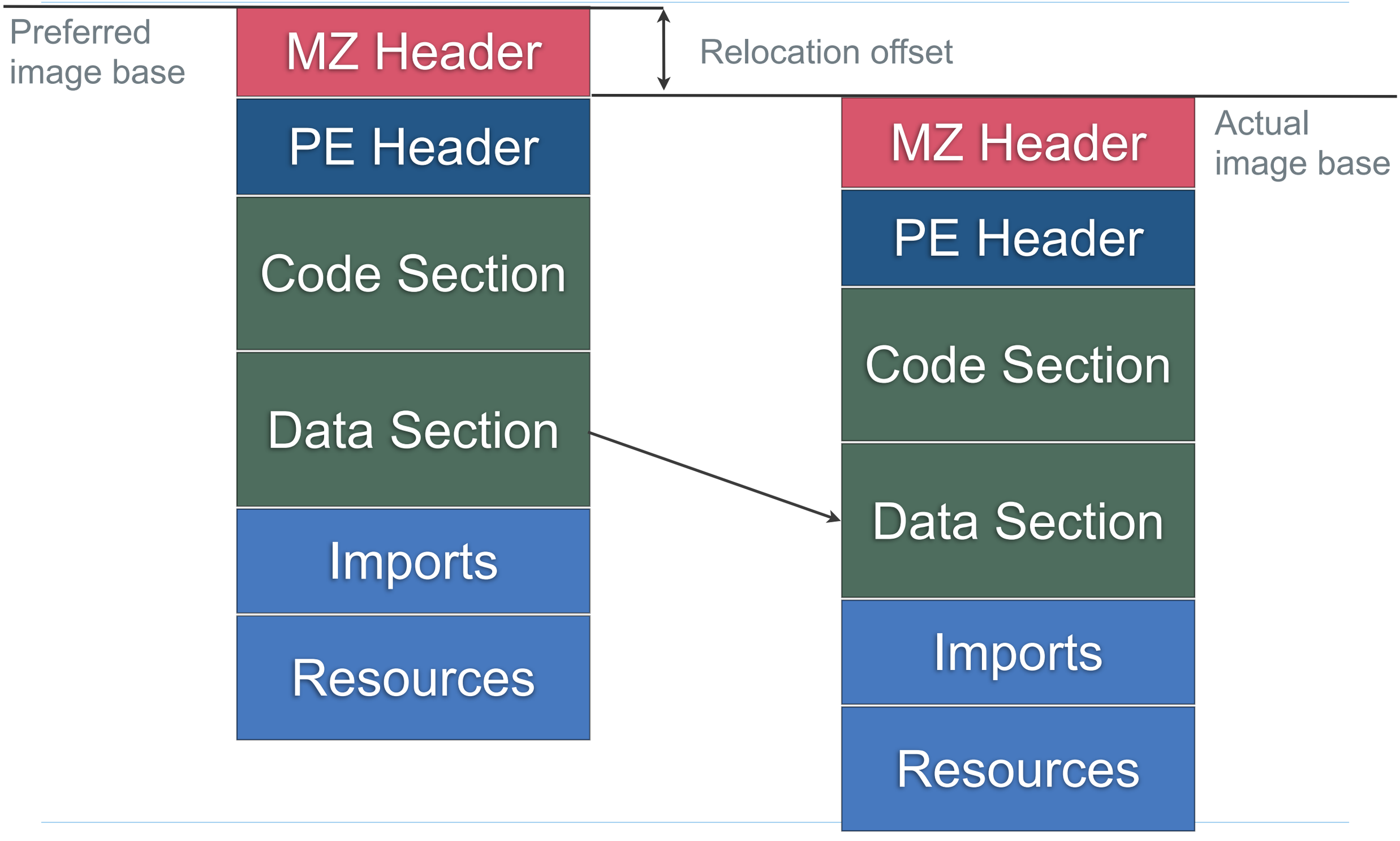
Exporting Symbols

- Symbols can be exported with ordinals, names or both
- Ordinals are simple index numbers of symbols
- Name is a full ASCII name of the exported symbol
- Exports are described by three simple lists
  - List of ordinals
  - List of symbol addresses
  - List of symbol names
- Exports can be forwarded to another DLL
  - Example: NTDLL.RtlAllocHeap
- Forwarded symbol’s address points to a name in the exports section

Resources

- Resources in PE are similar to an archive (think ZIP)
- Resource files can be organised into directory trees
- The data structure is quite complex but there are tools to handle it
- Most common resources:
  - Icons
  - Version information
  - GUI resources

Base Relocation



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Base Relocation

- Sometimes a DLL can not be loaded to its preferred address
- When rebasing, the loader has to adjust all hardcoded addresses
- Relocations are done in 4KiB blocks (page size on x86)
- Each relocation entry gives a type and points to a location
- The loader calculates the base address difference
- The offsets are adjusted according to the difference

Tools for PE Files

Hex Editors

- HT Editor at http://hte.sourceforge.net/
- BIEW at http://sourceforge.net/projects/beye/
- Hiew at http://www.hiew.ru/

Programmatic Access

- pefile – python module at http://code.google.com/p/pefile/

Reading

Matt Pietrek: An In-Depth Look into PE:

http://msdn.microsoft.com/msdnmag/issues/02/02/PE/default.aspx

http://msdn.microsoft.com/msdnmag/issues/02/03/PE2/default.aspx

Microsoft Portable Executable and Common Object File Format Specification

http://www.microsoft.com/whdc/system/platform/firmware/PECOFF.mspx

Closing

Special thanks to Ero Carrera for his beautiful PE diagrams and the permission to use them in this presentation!

https://www.openrce.org/reference_library/files/reference/PE%20Format.pdf

http://blog.dkbza.org/2007/03/tiny-and-crazy-pe.html