

UEFI and The Task of the Translator

Using cross-architecture UEFI quines as a framework
for UEFI exploit development

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DISCLAIMER:

The views expressed in this presentation are my own and do not reflect the opinions of my past, present or future employers

Viewer Discretion is advised.

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Security Consultant at Leviathan Security Group

Reverse engineer + artist + hacker

I <3 UEFI, hardware hacking, binary exploitation, skateboarding,
learning languages, creating art, writing programs in assembly languages, etc.

greetz 2 the following for their assistance/support w this talk:

0day (@0day_simpson), James Chambers (@jamchamb_),

Erik Cabetas, netspooky (@netspooky), dnz (@dnoiz1), zeta

Xeno Kovah (@xenokovah)

Ben Mason (@suidroot),

Richard Johnson (@richinseattle),

The team at Leviathan

OffensiveCon



This talk is dedicated to Sophia d'Antoine



Format of this talk

Format of this Talk

This is a talk about translation

Part 1: UEFI Quines (self-replicating UEFI apps) in three architectures

x86-64, arm64, EBC

Part 2: The evolution of an SMM exploit

From simple Chipsec PoC to standalone malicious driver

Housekeeping

Notes on terminology [This is a talk about translation after all]

“EBC isn’t an “architecture,” it’s a platform agnostic intermediary language that leverages natural-indexing to automatically adjust its instruction width to either 32-bit or 64-bit dependent on the architecture of the host machine. It uses a VM! That sounds like ring -1 to me!”

I know. But referring to it as an architecture at this point in the talk is sufficient for our understanding of EBC in relation to the narrative. And it’s more succinct. We’ll get to EBC and the spec. Hang tight.

Wait... is the architecture arm64? Or aarch64? Or is it AArch64? Aarch64? ARM64? Arm64? Which is it?
Team Edward or Team Jacob??

arm64 is the term I will use in this presentation to refer to the assembly language of the Armv8 64-bit architecture, known as ARM64/AArch64

Team
arm64



What is “The Task of the Translator”

An essay by Walter Benjamin

- Walter Benjamin was a philosopher, cultural critic, essayist
- Other famous works by Benjamin:
“The Work of Art in the Age of Mechanical Reproduction”
The Arcades Project
- His essay “The Task of the Translator” was a seminal work in translation theory
- For this presentation, I’ll be referring to Steven Rendall’s English translation of Benjamin’s essay:
https://german.yale.edu/sites/default/files/benjamin_translators_task.pdf



Walter Benjamin (1892–1940) ~1930 © Charlotte Joel

What is “The Task of the Translator” in UEFI?

A framing device for understanding how to write cross-architecture exploits

Combine the work of four separate projects using the framework of Walter Benjamin’s
“Task of the Translator”

1. UEFI Exploit Research and
Development at Leviathan →
SMM exploits



2. BGGP4 and UEFI binary golfing →
UEFI quines

3. OST2 ARM Assembly class →
UEFI exploit dev on arm64

4. VX-Underground Black Mass article →
EBC

How do we apply “The Task of the Translator” to UEFI?

Apply “the Task of the Translator” to two tasks:

1. Translating my winning BGGP4 UEFI quine from x86-64 asm to two other architectures: arm64 and EBC
2. Developing one exploit for an SMM callout vulnerability, then creating new generations of that exploit, altering the technique used, the language the exploit is written, the architecture it targets, etc.

One goal of optimization is to eliminate redundancy. Are we creating redundancy?

No, this isn’t redundant work.

I’m not creating *copies* of the original UEFI app (the UEFI app already creates copies of itself)

“Translation is a mode. In order to grasp it as such, we have to go back to the original.”

Walter Benjamin, “The Task of the Translator,” translated by Steven Rendall, page 152.

How do we apply “The Task of the Translator” to UEFI?

Notable examples to set the precedent

Developing a “next generation” for a piece of art:

- cr4sh - SmmBackdoorNg (Smm Backdoor Next Generation):
<https://github.com/Cr4sh/SmmBackdoorNg>
- See cr4sh’s earlier project SmmBackdoor:
<https://github.com/Cr4sh/SmmBackdoor>
- Star Trek [with the notable exception of Leonard Nimoy, Leonard Nimoy is eternal]

What is “The Task of the Translator” in UEFI?

Research questions

- What are the essential techniques for UEFI reverse engineering and exploit development?
- How does one UEFI exploit differ when it is translated across multiple different architectures?
- What can architecture-specific requirements for an exploit teach us about how to approach finding vulnerabilities and writing new gnarly exploits?
- How many different ways can we write an exploit for an SMM callout vulnerability?
- What *is* the task of the translator?

A brief introduction to UEFI

Introduction to UEFI

In the beginning there was legacy BIOS

And now we have UEFI and everything is fine! And there are no more vulnerabilities and Secure Boot wasn't just a marketing strategy for a feature that was never intended as a security feature of UEFI in the first place!

```
F000:FFF0  jmp  far ptr bootblock_start
.....
F000:FFAA bootblock_start:
F000:FFAA  jmp  exec_jmp_table
.....
F000:A040 exec_jmp_table:           ;
F000:A040  jmp  _CPU_early_init
F000:A043 ; -----
F000:A043
F000:A043 _j2:                   ;
F000:A043  jmp  _goto_j3
```

Source: “BIOS Disassembly Ninjutsu Uncovered: Listing 5.27 AMI BIOS Boot Block Jump Table,” 1st edition, Darmawan Salihun (pinczakko), page 60, <https://github.com/pinczakko/BIOS-Disassembly-Ninjutsu-Uncovered>

Introduction to UEFI

In the beginning there was legacy BIOS

And now we have UEFI and everything is fine! And there are no more vulnerabilities and Secure Boot wasn't just a marketing strategy for a feature that was never intended as a security feature of UEFI in the first place!

Oh... wait, never mind.

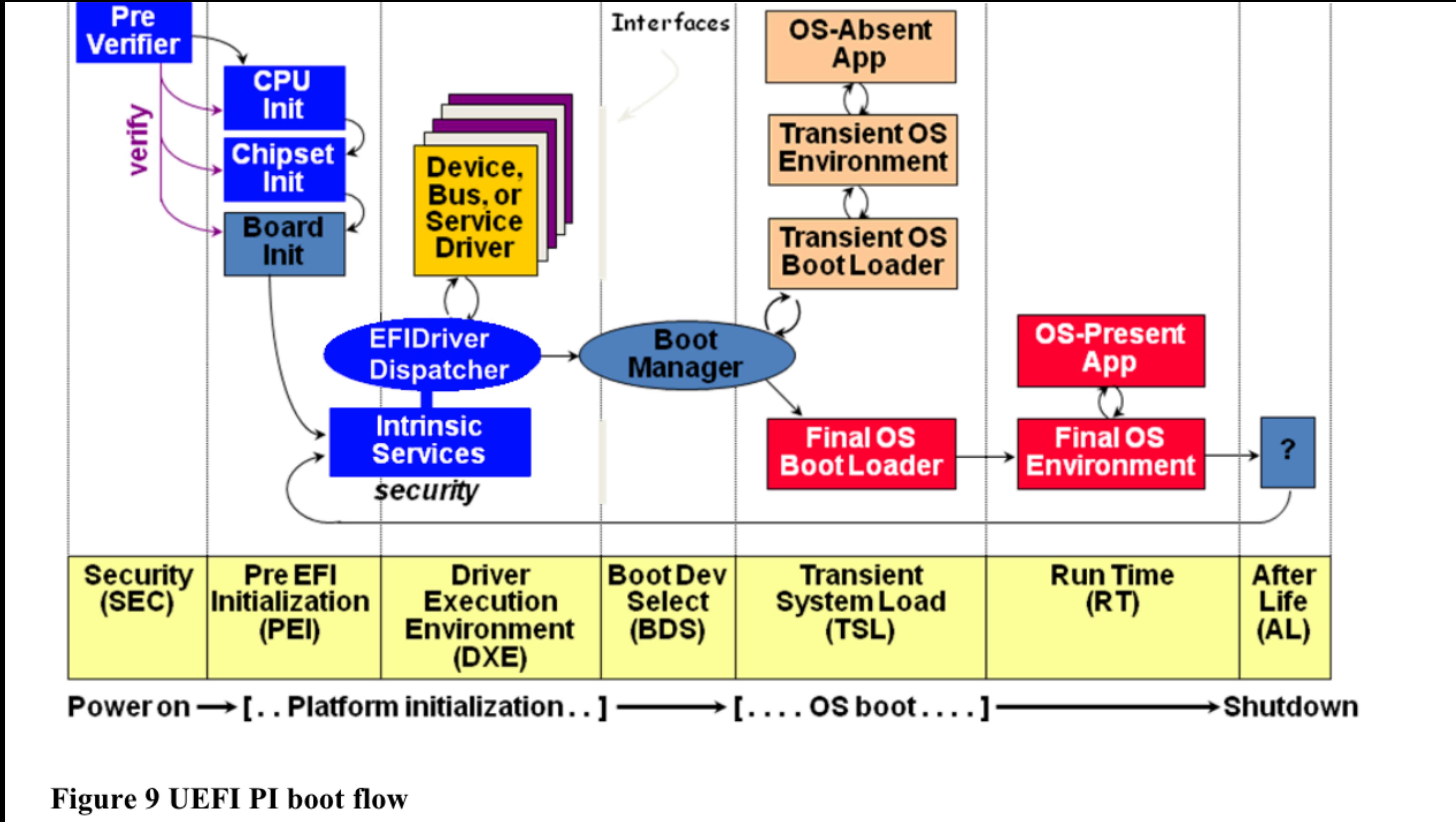


Figure 9 UEFI PI boot flow

Source:

"Trusted Platforms UEFI, PI and TCG-based firmware," Vincent J. Zimmer (Intel Corporation), Shiva R. Dasari Sean P. Brogan (IBM), White Paper by Intel Corporation and IBM Corporation, September 2009

<https://www.intel.com/content/dam/doc/white-paper/uefi-pi-tcg-firmware-white-paper.pdf>

Introduction to UEFI

Legacy BIOS Reverse Engineering

- BIOS code was written in 16-bit assembly and it ran in real mode
- Legacy BIOSes were non-standardized, IBM specific implementations
- Legacy BIOS was responsible for important functionality— initialization of platform hardware in preparation for loading an OS — but it was limited in scope and size
- Refer to “[BIOS Disassembly Ninjutsu Uncovered](#)” by Darmawan Salihun (pinczakko) for the holy scripture of Legacy BIOS RE + xdev

```
F000:A08E    call  near ptr copy_decomp_block
F000:A091    call  sub_F000_A440
.....
F000:A21B    copy_decomp_block proc far      ; _F0000:_j27
F000:A21B    mov   al, 0D5h ; '-'
from
F000:A21B          ; ROM to lower system memory and control
F000:A21B          ; is given to it. BIOS now executes out of
F000:A21B          ; RAM. Copies compressed boot block code
F000:A21B          ; to memory in right segments. Copies BIOS
F000:A21B          ; from ROM to RAM for faster access.
F000:A21B          ; Performs main BIOS checksum, and updates
F000:A21B          ; recovery status accordingly.
F000:A21D    out   80h, al      ; Send POST code D5h to diagnostic port.
F000:A21F    push  es
F000:A220    call  get_decomp_block_size    ; On return:
F000:A220          ; ecx = decomp_block_size
F000:A220          ; esi = decomp_block_phy_addr
F000:A220          ; At this point, ecx = 0x6000
F000:A220          ; and esi = 0xFFFFA000
F000:A223    mov   ebx, esi
F000:A226    push  ebx
F000:A228    shr   ecx, 2      ; decomp_block_size / 4
F000:A22C    push  8000h
```

Source: “BIOS Disassembly Ninjutsu Uncovered: 5.2.3.2. Decompression Block Relocation,” 1st edition, Darmawan Salihun (pinczakko), page 62, https://github.com/pinczakko/BIOS-Disassembly-Ninjutsu-Uncovered/blob/master/BIOS_Disassembly_Ninjutsu_Uncovered.pdf

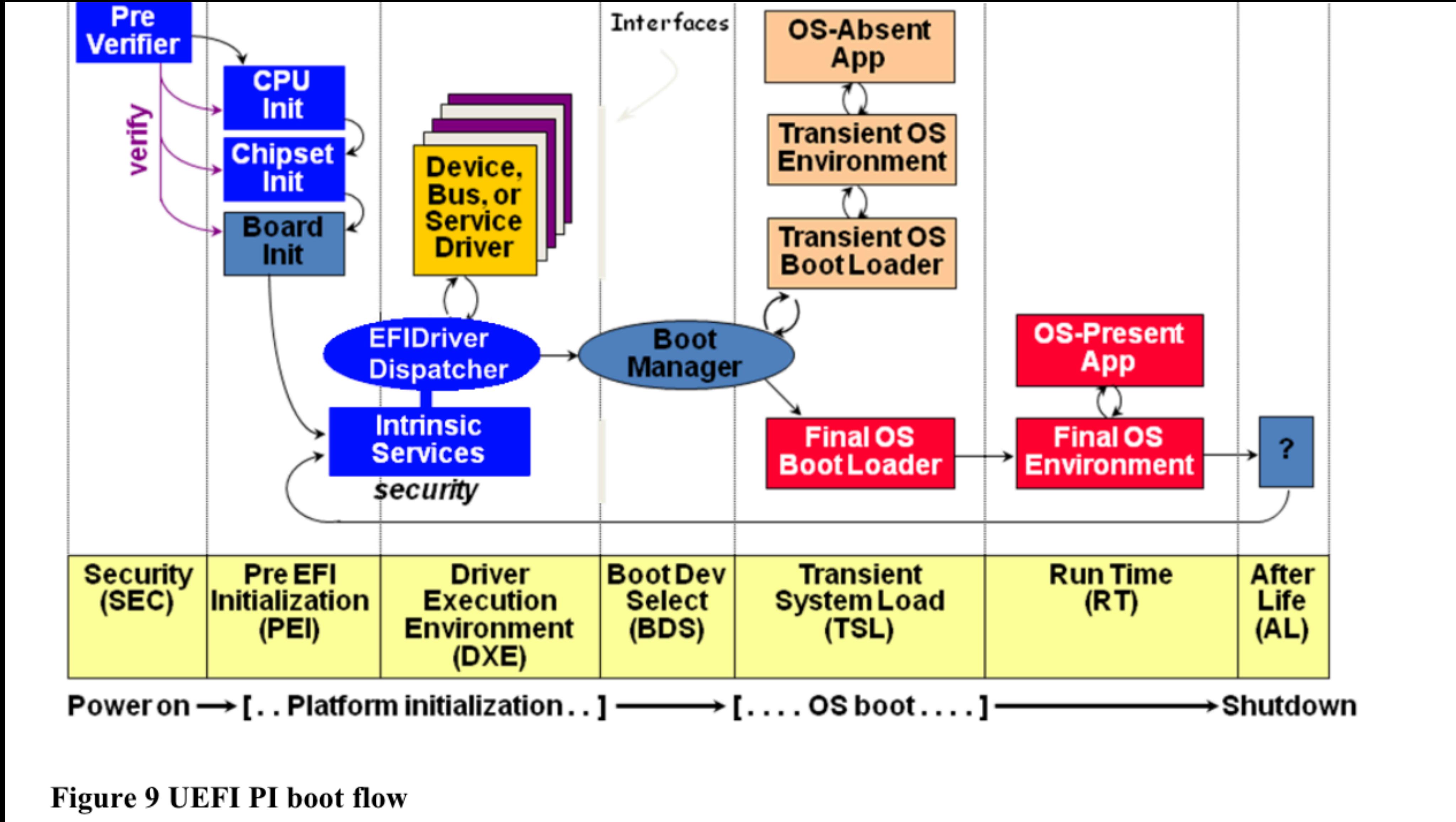


Figure 9 UEFI PI boot flow

Source:

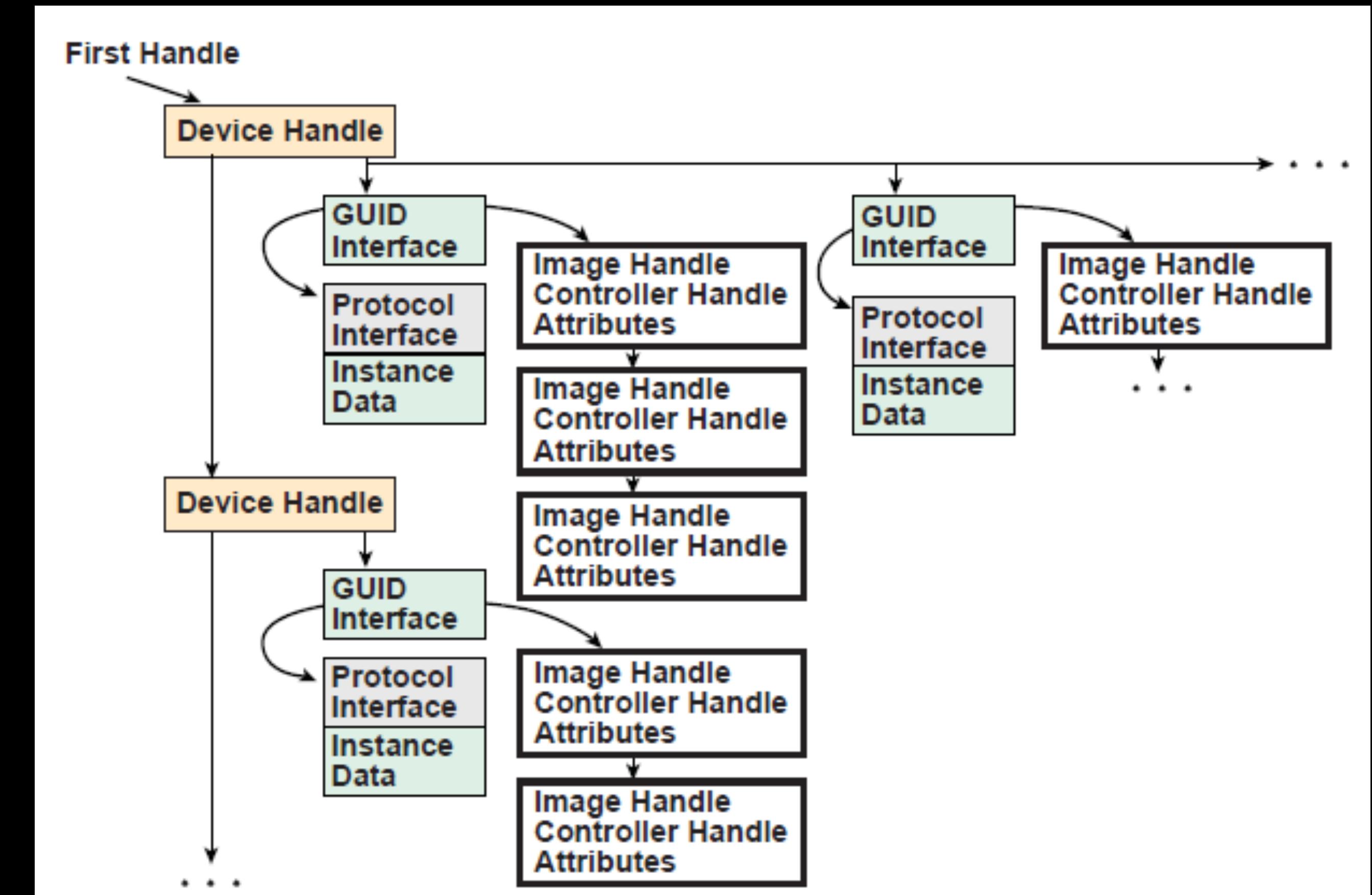
"Trusted Platforms UEFI, PI and TCG-based firmware," Vincent J. Zimmer (Intel Corporation), Shiva R. Dasari Sean P. Brogan (IBM), White Paper by Intel Corporation and IBM Corporation, September 2009

<https://www.intel.com/content/dam/doc/white-paper/uefi-pi-tcg-firmware-white-paper.pdf>

Introduction to UEFI

RE advantages of UEFI over Legacy BIOS

- Rich ecosystem of built-in functionality
- UEFI follows implementation standards with detailed and comprehensive spec [obvious caveats, it's not perfect but wow look at those diagrams. AMI never gave me a diagram </3]
- source code primarily written in C following a standardized specification —> easier to debug / disassemble
- A selection of great plugins and tools for UEFI RE + xdev:
 - [UEFITool](#)
 - [efiXplorer](#)
 - Ghidra plugins:
 - [efiSeek](#)
 - [ghidra-firmware-utils](#)
- UEFI has expansive breadth + depth —> greater attack surface



Source: “UEFI Specification, Fig.7.2 Handle Database”

https://uefi.org/specs/UEFI/2.10/07_Services_Boot_Services.html#device-handle-to-protocol-handle-mapping

Introduction to UEFI

UEFI apps/drivers + UEFI shell

- UEFI Shell: A UEFI application that provides a shell interfacing for interacting with various UEFI components (i.e. other UEFI apps and drivers, and the protocols therein)
- UEFI apps and drivers are PE/COFF executables (occasionally TE) and have a PE/COFF header
- The only difference between an UEFI app and a UEFI driver is that an app is unloaded from memory after it is run and a driver remains resident until it is unloaded

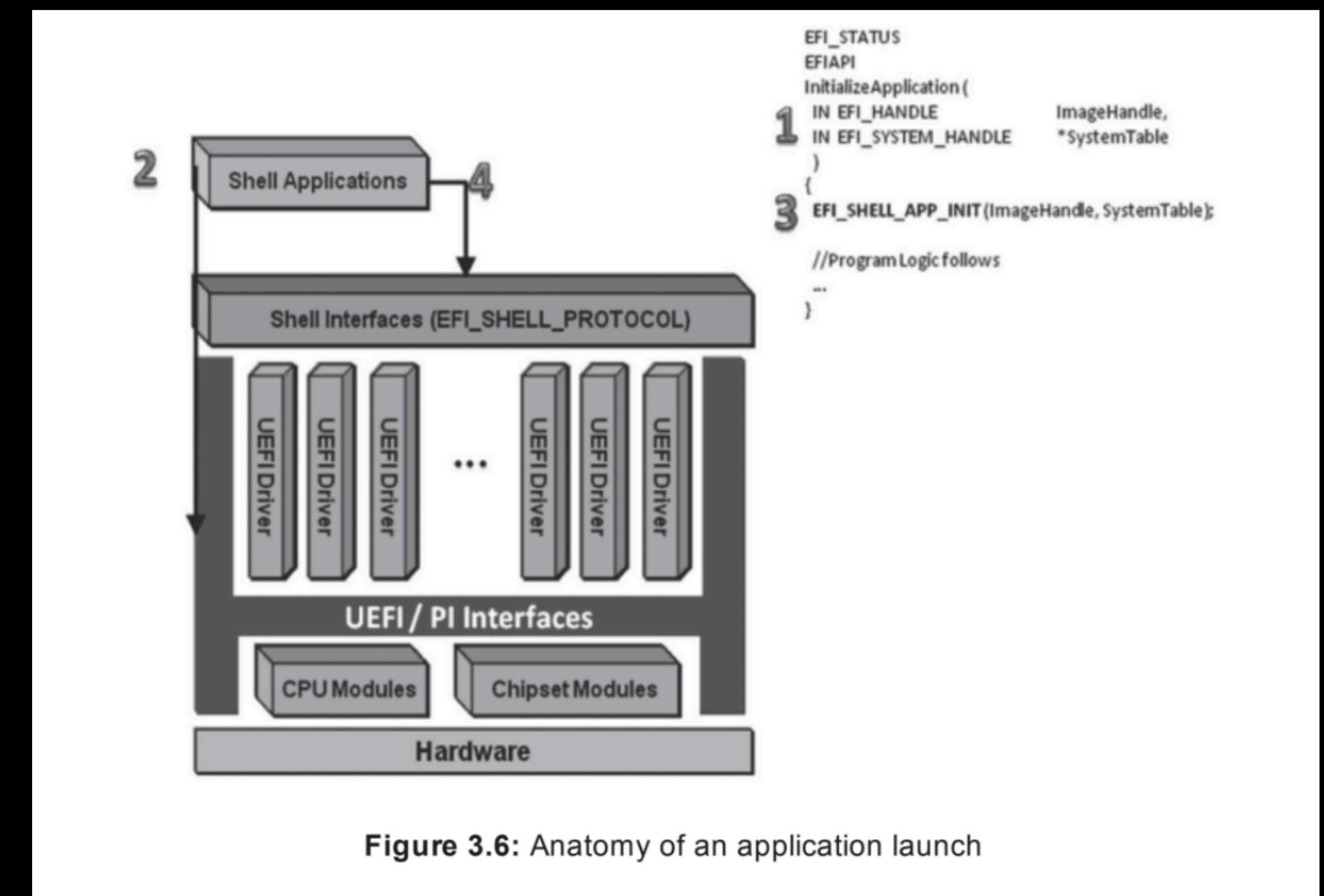


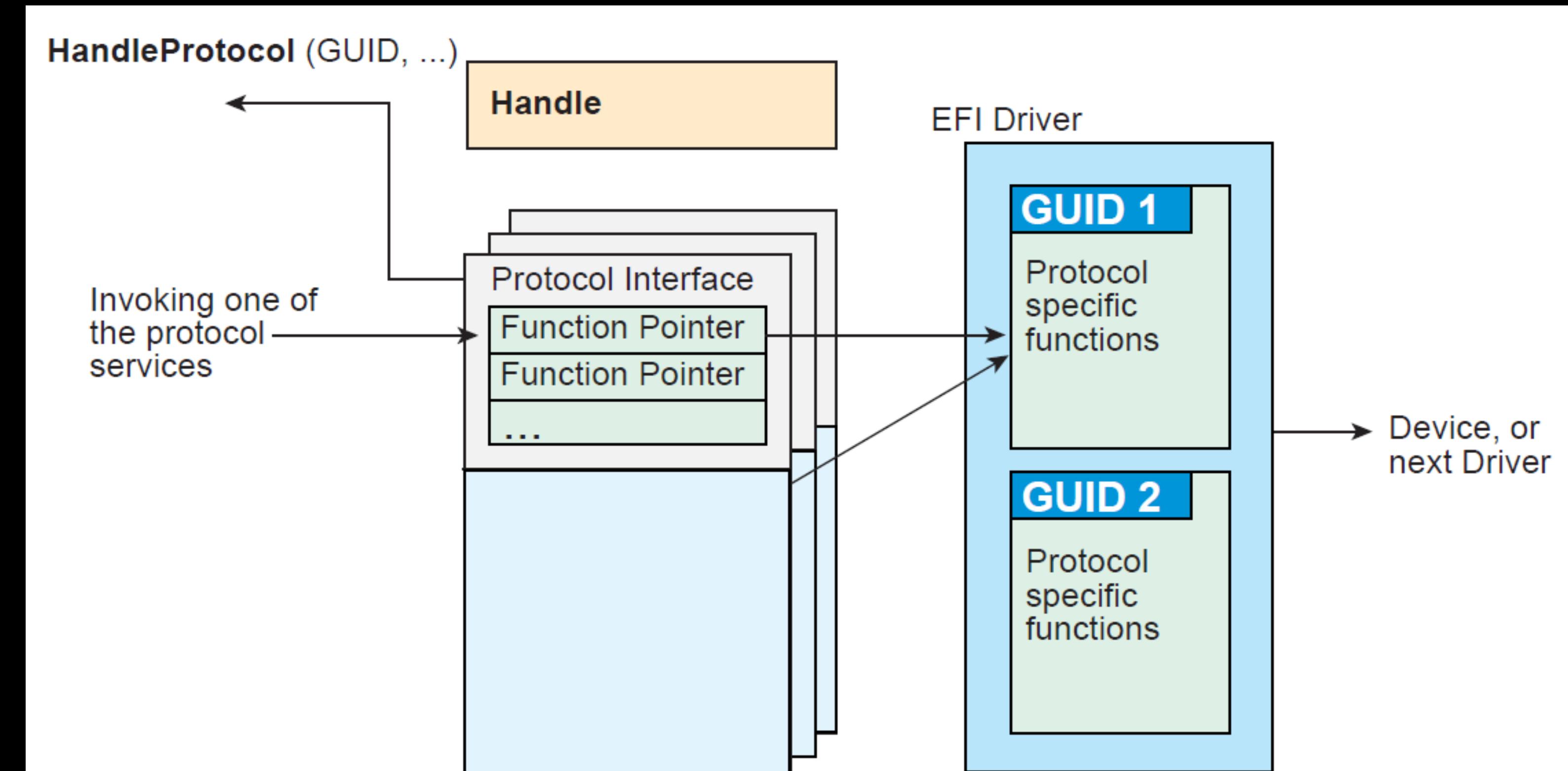
Figure 3.6: Anatomy of an application launch

Source: "Harnessing the UEFI Shell: Moving the Platform Beyond DOS, 2nd edition,"
Vincent Zimmer, Michael Rothman and Tim Lewis

Introduction to UEFI

Protocols

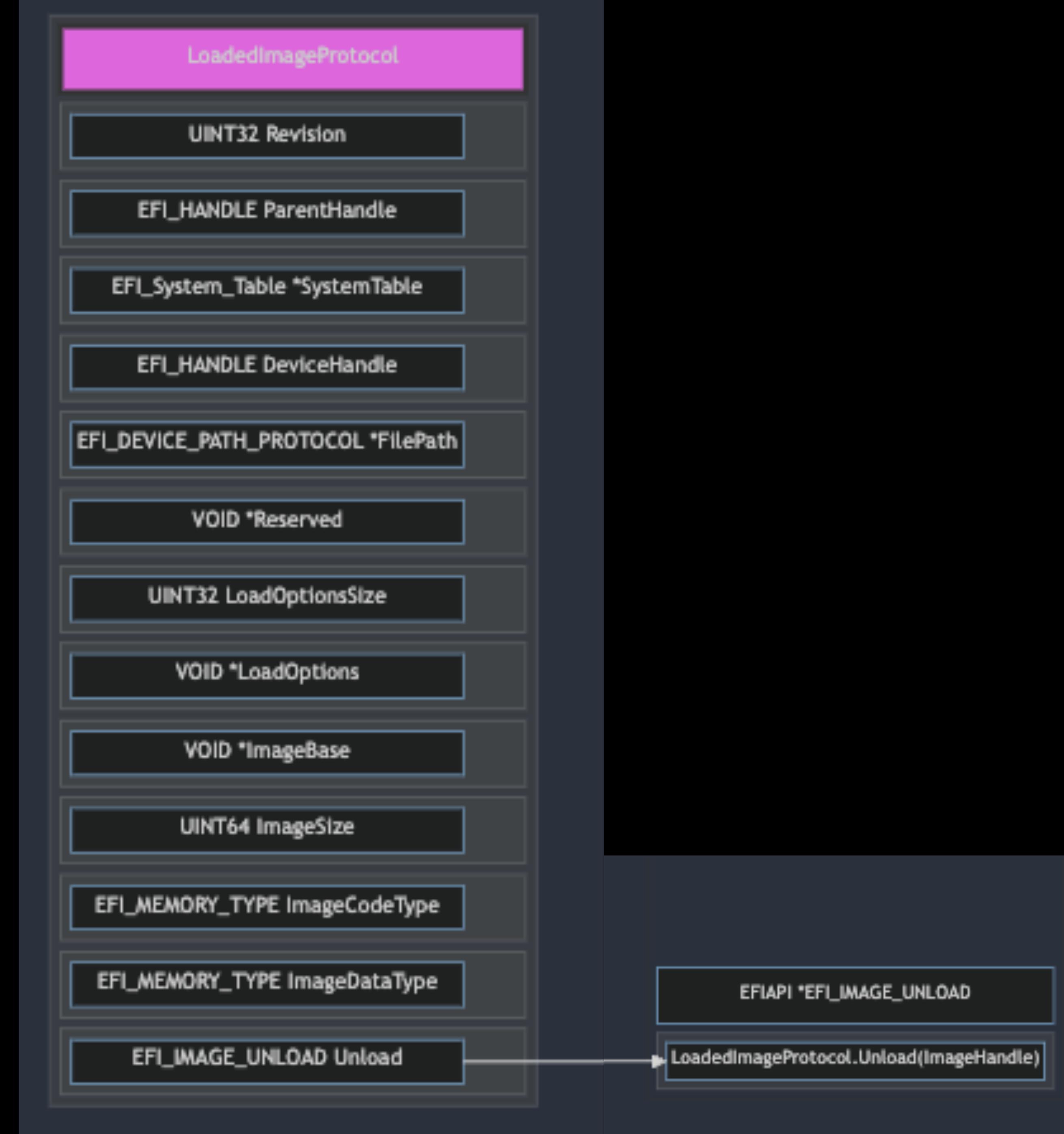
- Protocols are the keys to the empire
- UEFI is the empire
- A protocol is an interface that encapsulates data and function pointers
- Provide abstractions for hardware/firmware/OS communications
- A driver can produce one or more protocols



Source: “UEFI Specification: Fig. 2.4 Construction of a Protocol”
https://uefi.org/specs/UEFI/2.10/02_Overview.html#construction-of-a-protocol

Introduction to UEFI

Protocols Example: LoadedImageProtocol



“True translation is transparent, it does not obscure the original, does not stand in its light, but rather allows pure language, as if strengthened by its own medium, to shine even more fully on the original.”

Walter Benjamin, “The Task of the Translator,” translated by Steven Rendall, page 162.

UEFI generation 1: x86-64

UEFI generation 1: x86-64

The Specs

My winning entry in the UEFI app category of Binary Golf Grand Prix 4

- BGGP: “The goal of the Binary Golf Grand Prix is to challenge programmers to make the smallest possible binary that fits within certain constraints.”

[Source “Binary Golf Grand Prix”,
netspooky, <https://n0.lol/bggp/>

	BGGP4: REPLICATE	
	06.23.23 -> 09.08.23	
Goal	Create the smallest self-replicating file.	
	Requirements	
	A valid submission will:	
	<ul style="list-style-type: none">- Produce exactly 1 copy of itself- Name the copy "4"- Not execute the copied file- Print, return, or display the number 4	

Source: “Binary Golf Grand Prix 4,” Binary Golf Association, <https://binary.golf/>

UEFI generation 1: x86-64

Methodology

1. Write a valid working solution (a self-replicating UEFI app) in C
2. Use the C solution as a base text and translate the quine from C to assembly → Reverse engineer the C solution
3. Golf the assembly solution and shrink the size of the binary as much as possible
4. Reverse engineer, rewrite and refactor the assembly

Size of C quine: ~17,000 bytes

Final size of x86_64 asm UEFI quine: 1480 bytes

[Side note: shoutout to my friend @netspooky who I worked with on this project for teaching me PE binary mangling. Check out his fantastic write-up on his recent solution that set the new record to 420 bytes: <https://github.com/netspooky/golfclub/tree/master/uefi/bggp4>]

UEFI generation 1: x86-64

RE and development tools

- nasm
- Hex editor (xxd, hexdump)
- Ghidra, specifically using these two plugins for UEFI:
 - efiSeek: <https://github.com/DSecurity/efiSeek>
 - ghidra-firmware-utils: <https://github.com/al3xtjames/ghidra-firmware-utils>
- Radare2 for a faster option, better for disassembling and other reversing tasks near the end of the project that involved nitty gritty changes to the assembly
- QEMU and gdb for debugging/testing
- I didn't use IDA Pro for this project, it's a better tool for other projects

UEFI generation 1: x86-64

UEFI x64 - Handoff state upon program invocation

rcx - EFI_HANDLE

rdx - EFI_SYSTEM_TABLE*

rsp - <return address>

Source: UEFI Specification -
2.3.4.1. Handoff State

```
_start:  
entrypoint:  
    push rbp  
    mov rbp, rsp  
    sub rsp, 0xc0  
  
    mov [ImageHandle], rcx  
    mov [gST], rdx  
  
    mov rbx, [gST]  
    mov rbx, [rbx + 0x60]  
    mov [gBS], rbx  
    mov rax, [gST]  
    mov rax, [rax + 0x40]  
    mov [ConOut], rax
```

Program entry point - setting up stack frame, saving gST, ImageHandle
Use gST to save gBS and ConOut

UEFI Interactive Shell v2.2
EDK II
UEFI v2.70 (EDK II, 0x00010000)

Mapping table

FS0: Alias(s):HD0a1:;BLK1:
PciRoot(0x0)/Pci(0x1,0x1)/Ata(0x0)/HD(1,MBR,0xBE1AFDFA,0x3F,0xFBFC1)

BLK0: Alias(s):
PciRoot(0x0)/Pci(0x1,0x1)/Ata(0x0)
BLK2: Alias(s):
PciRoot(0x0)/Pci(0x1,0x1)/Ata(0x0)

[Press **ESC** in 3 seconds to skip **startup.nsh** or any other key to continue.

[**Shell>** fs0:
FS0:> █

Base text:
Self-replicating UEFI app
Written in C

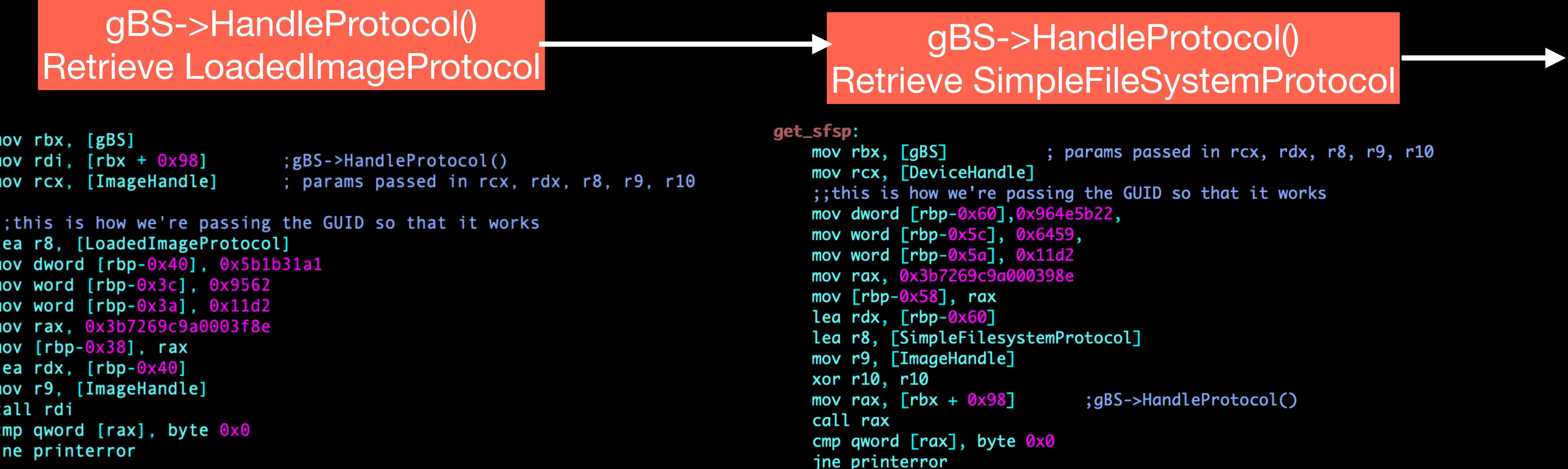
UEFI generation 1: x86-64

x64 self-replicating UEFI app - program logic breakdown



UEFI generation 1: x86-64

x64 self-replicating UEFI app - program logic breakdown



UEFI generation 1: x86-64

x64 self-replicating UEFI app - program logic breakdown

SimpleFileSystemProtocol->OpenVolume()
Retrieve Root Volume

```
get_root_volume:  
    mov rax, [SimpleFilesystemProtocol]  
    mov rax, [rax + EFI_SIMPLE_FILE_SYSTEM_PROTOCOL_OPENVOLUME_OFFSET]  
    mov rcx, [SimpleFilesystemProtocol]  
    lea rdx, [root_volume]  
    call rax  
    cmp qword [rax], byte 0x0  
    jne printerror
```

UEFI generation 1: x86-64

x64 self-replicating UEFI app - program logic breakdown



```
open_hostfile:  
    mov rax, [root_volume]  
    mov rax, [rax + EFI_FILE_PROTOCOL_OPEN_FILE_OFFSET]  
    mov rcx, [root_volume]  
    lea rdx, [hostfile]  
    lea r8, hostfilename  
    mov r9, [fileopen_mode]  
    mov r10, [hostattributes]  
    call rax  
    cmp qword [rax], byte 0x0  
    jne printerror
```

```
open_targetfile:  
    mov rax, [root_volume]  
    mov rax, [rax + EFI_FILE_PROTOCOL_OPEN_FILE_OFFSET]  
    mov rcx, [root_volume]  
    mov qword [rbp - 0x78], 0x0  
    lea rdx, [rbp-0x78]  
    lea r8, targetfilename  
    mov r9, 0x8000000000000003  
    mov qword [rsp+0x20], 0x0  
    call rax  
    cmp qword [rax], byte 0x0  
    jne printerror  
  
    mov rax, [rbp-0x78]  
    mov [targetfile], rax
```

UEFI generation 1: x86-64

x64 self-replicating UEFI app - program logic breakdown



```
allocate_tmp_buffer:  
    mov rax, [gBS]  
    mov rax, [rax + EFI_BOOTSERVICES_ALLOCATEPOOL_OFFSET]  
    mov rcx, [EFI_ALLOCATEPOOL_ALLOCATEANYPAGES]  
    mov rdx, [ImageSize]  
    lea r8, [temp_buffer]  
    call rax  
    cmp qword [rax], byte 0x0  
    jne printerror
```

```
read_hostfile:  
    mov rax, [hostfile]  
    mov rax, [rax + EFI_FILE_PROTOCOL_READ_FILE_OFFSET]  
    mov rcx, [hostfile]  
    lea rdx, [ImageSize]  
    mov r8, [temp_buffer]  
  
    call rax  
    cmp qword [rax], byte 0x0  
    jne printerror
```

UEFI generation 1: x86-64

x64 self-replicating UEFI app - program logic breakdown

FileProtocol->WriteFile()
Write buffer to target file

```
get_root_volume:  
    mov rax, [SimpleFilesystemProtocol]  
    mov rax, [rax + EFI_SIMPLE_FILE_SYSTEM_PROTOCOL_OPENVOLUME_OFFSET]  
    mov rcx, [SimpleFilesystemProtocol]  
    lea rdx, [root_volume]  
    call rax  
    cmp qword [rax], byte 0x0  
    jne printerror
```

UEFI generation 1: x86-64

x64 self-replicating UEFI app - program logic breakdown

gBS->FreePool()
Free buffer

FileProtocol->CloseFile()
Close Target File,
Close Host File +
Close Root Volume

```
free_tmp_buffer:  
    mov r13, [targetfile]  
    call close_file  
    mov rbx, [gBS]  
    mov rax, [rbx + EFI_BOOTSERVICES_FREEPOOL_OFFSET]  
    mov rcx, [temp_buffer]  
    call rax  
    cmp qword [rax], byte 0x0  
    jne printerror  
  
    mov r13, [hostfile]  
    call close_file  
    xor r13, r13  
    mov r13, [root_volume]  
    call close_file
```

```
close_file:  
    mov rax, r13  
    mov rax, [rax + EFI_FILE_PROTOCOL_CLOSE_FILE_OFFSET]  
    mov rcx, r13  
    call rax  
    cmp qword [rax], byte 0x0  
    jne printerror  
    ret
```

UEFI generation 1: x86-64

x64 self-replicating UEFI app - program logic breakdown



UEFI generation 1: x86-64

Golfing the solution

1. Remove unnecessary libraries and dependencies: Use the UEFI ecosystem
2. PE Binary Mangling
[netspooky's guide to PE Binary Mangling:
<https://n0.lol/a/pemangle.html>]
3. Use the protocols you want, not the wrappers with extra fluff:
e.g. OpenProtocol() is a wrapper for HandleProtocol()

```
_start:  
entrypoint:  
    push rbp  
    mov rbp, rsp  
    sub rsp, 0xc0  
  
    mov [ImageHandle], rcx  
    mov [gST], rdx  
  
    mov rbx, [gST]  
    mov rbx, [rbx + 0x60]  
    mov [gBS], rbx  
    mov rax, [gST]  
    mov rax, [rax + 0x40]  
    mov [ConOut], rax  
  
    mov rbx, [gBS]  
    mov rdi, [rbx + 0x98]           ; gBS->HandleProtocol()  
                                    ; params passed in rcx, rdx, r8, r9, r10  
    mov rcx, [ImageHandle]  
  
    ; ;this is how we're passing the GUID so that it works  
    lea r8, [LoadedImageProtocol]  
    mov dword [rbp-0x40], 0x5b1b31a1  
    mov word [rbp-0x3c], 0x9562  
    mov word [rbp-0x3a], 0x11d2  
    mov rax, 0x3b7269c9a0003f8e  
    mov [rbp-0x38], rax  
    lea rdx, [rbp-0x40]  
    mov r9, [ImageHandle]  
    call rdi  
    cmp qword [rax], byte 0x0  
    jne printerror
```

First call to gBS function HandleProtocol in my winning BGGP4 entry

```
UEFI Interactive Shell v2.2
EDK II
UEFI v2.70 (EDK II, 0x00010000)
Mapping table
FS0: Alias(s):HD0a1:;BLK1:
    PciRoot(0x0)/Pci(0x1,0x1)/Ata(0x0)/HD(1,MBR,0xBE1AFDFA,0x3F,0xFBFC1)
BLK0: Alias(s):
    PciRoot(0x0)/Pci(0x1,0x1)/Ata(0x0)
BLK2: Alias(s):
    PciRoot(0x0)/Pci(0x1,0x1)/Ata(0x0)
[Press ESC in 4 seconds to skip startup.nsh or any other key to continue.]
[Shell> fs0:
[FS0:\> ls
Directory of: FS0:\
05/02/2024 06:41           1,540  self-rep-golf.efi
05/02/2024 06:41          17,856  UEFISelfRep.efi
      2 File(s)     19,396 bytes
      0 Dir(s)
FS0:\> █
```

Final winning entry for BGGP4:
Self-replicating UEFI app
Written in x64 assembly

UEFI generation 1: x86-64

What did you learn at school today?

- Leverage the UEFI ecosystem by walking from Protocol interface to Protocol interface —> better understanding of UEFI internals and base knowledge for building better exploits
 - Building ROP chains for SMM exploits to bypass Smm_CodeCheck_En
- New knowledge of PE Binary Mangling
- Knowledge of how to write UEFI shellcode
 - even if you write an exploit in C, knowing how to write UEFI shellcode for a payload is essential

```
PE:  
header_start:  
mzheader:  
dw "MZ"  
dw 0x100 ; DOS e_magic  
  
pe_header:  
dd "PE" ; uint32_t mMagic; // PE\0\0 or 0x00004550  
dw 0x8664 ; uint16_t mMachine;  
dw 3 ; uint16_t mNumberOfSections;  
dd 0x0 ; uint32_t mTimeDateStamp;  
dd 0x0 ; uint32_t mPointerToSymbolTable;  
dd 0x0 ; uint32_t mNumberOfSymbols;  
dw sectionHeader - opt_header; uint16_t mSizeOfOptionalHeader;  
dw 0x0206 ; uint16_t mCharacteristics;  
  
opt_header:  
dw 0x20B ; uint16_t mMagic  
[0x010b=PE32, 0x020b=PE32+ (64 bit)]  
uint8_t mMajorLinkerVersion;  
uint8_t mMinorLinkerVersion;  
uint32_t mSizeOfCode;  
uint32_t mSizeOfInitializedData;  
uint32_t mSizeOfUninitializedData;  
uint32_t mAddressOfEntryPoint;  
uint32_t mBaseOfCode;  
uint32_t mImageBase;  
uint32_t mSectionAlignment;  
uint32_t mFileAlignment;  
uint16_t mMajorOperatingSystemVersion  
uint16_t mMinorOperatingSystemVersion  
uint16_t mMajorImageVersion;  
uint16_t mMinorImageVersion;  
uint16_t mMajorSubsystemVersion;  
uint16_t mMinorSubsystemVersion  
can be blank, still times 4 db 0  
uint32_t mWin32VersionValue;  
uint32_t mSizeOfImage;  
uint32_t mSizeOfHeaders;  
uint32_t mCheckSum;  
uint16_t mSubsystem;  
uint16_t mDllCharacteristics;  
uint32_t mSizeOfStackReserve;  
uint32_t mSizeOfStackCommit;  
uint32_t mSizeOfHeapReserve;  
uint32_t mSizeOfHeapCommit;  
uint32_t mLoaderFlags;  
uint32_t mNumberOfRvaAndSizes;  
  
datadirs:  
dq 0  
dq 0  
dq 0  
dq 0  
dq 0  
dq 0
```

“The translator's task consists in this: to find the intention toward the language into which the work is to be translated, on the basis of which an echo of the original can be awakened in it.”

Walter Benjamin, “The Task of the Translator,” translated by Steven Rendall, page 159.

UEFI generation 2: arm64

UEFI generation 2: arm64

The specs

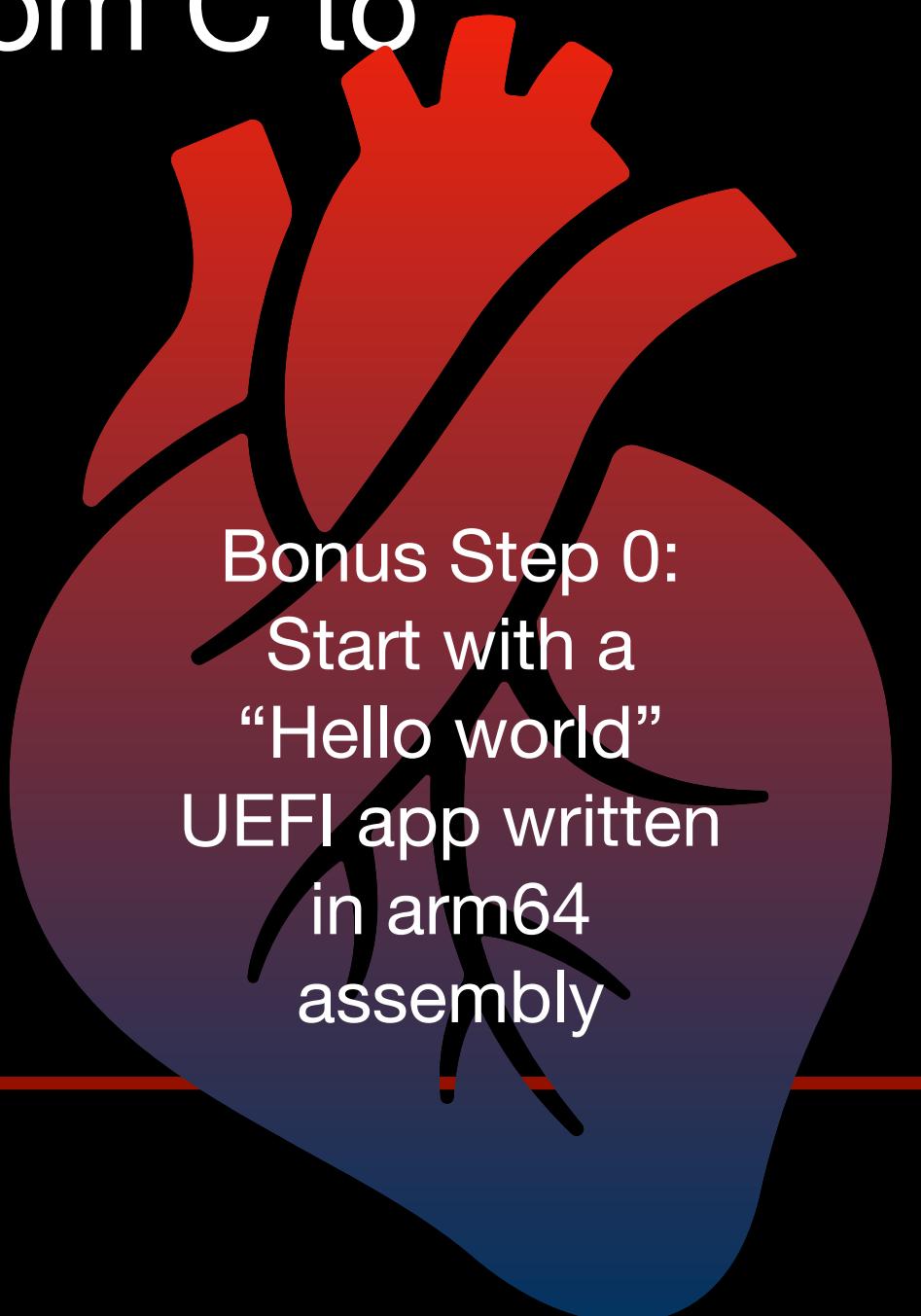
- This is not an entry for BGGP4... what are the goals of this UEFI quine?
 - Confirm that a UEFI quine is *possible* on Aarch64/ARM64 architecture
 - Translate original x64 solution to valid working solution in arm64 assembly
 - Golfing -> Optimize for small size to maximize benefit of shellcode
- What are the goals for this UEFI arm64 project?
 - Advance mastery of arm64 assembly for teaching OST2 ARM Assembly class
 - Practice writing UEFI shellcode in arm64 assembly
 - Better understand the nuances of UEFI RE and exploit dev on arm64

UEFI generation 2: arm64

Methodology

1. Recompile my valid working solution (a self-replicating UEFI app) in C with an arm64 (edk2 calls it aarch64) toolchain under the edk2 build system -> working solution to use as a base template
2. Use the C solution as a base text and translate the quine from C to assembly -> Reverse engineer the C solution
3. Reverse engineer, rewrite and refactor the assembly

The task of the translator is to be a cross-compiler?



Bonus Step 0:
Start with a
“Hello world”
UEFI app written
in arm64
assembly

UEFI generation 2: arm64

arm64 assembly building blocks: handoff state

X0 - EFI_HANDLE

X1 - EFI_SYSTEM_TABLE

X30 - Return Address

Source: UEFI Specification - 2.3.6.2. Handoff State

https://uefi.org/specs/UEFI/2.10/02_Overview.html#handoff-state-4

```
UEFI Interactive Shell v2.1
EDK II
UEFI v2.60 (EDK II, 0x00010000)
Mapping table
  FS0: Alias(s):HD0b:;BLK1:
    PciRoot(0x0)/Pci(0x1,0x0)/HD(1,MBR,0xBE1AFDFA,0x3F,0xFBFC1)
  BLK3: Alias(s):
    VenHw(F9B94AE2-8BA6-409B-9D56-B9B417F53CB3)
  BLK2: Alias(s):
    VenHw(8047DB4B-7E9C-4C0C-8EBC-DFBBAACACE8F)
  BLK0: Alias(s):
    PciRoot(0x0)/Pci(0x1,0x0)
[Press ESC in 5 seconds to skip startup.nsh or any other key to continue.
Shell> ]
```

**Base text: Self-replicating UEFI app
Written in C, cross-compiled for arm64**

“In reality, with regard to syntax, word-for-word translation completely rejects the reproduction of meaning and threatens to lead directly to incomprehensibility.”

Walter Benjamin, “The Task of the Translator,” translated by Steven Rendall, page 161.

ng: UEFISelfRep.efi

undefined8 Stack[-0xa0]:8 local_a0

UefiSelfRepMain XREF[2] : XREF[1] : FUN_C

```

00001348 fd 7b b6 a9 stp x29,x30,[sp, #local_a0]!
0000134c fd 03 00 91 mov x29,sp
00001350 e0 0f 00 f9 str ImageHandle,[sp, #local_88]
00001354 e1 0b 00 f9 str gST,[sp, #local_90]
00001358 e0 0b 40 f9 ldr ImageHandle,[sp, #local_90]
0000135c 00 30 40 f9 ldr ImageHandle,[ImageHandle, #0x60]
00001360 e0 4b 00 f9 str ImageHandle,[sp, #gBS]
00001364 20 34 86 52 mov ImageHandle,#0x31a1
00001368 60 63 ab 72 movk ImageHandle,#0x5b1b, LSL #16
0000136c e0 63 00 b9 str ImageHandle,[sp, #efiLoadedImageProtocolGuid.D...
00001370 a0 53 8d 12 mov ImageHandle,#0xfffff9562
00001374 e0 cb 00 79 strh ImageHandle,[sp, #efiLoadedImageProtocolGuid.D...
00001378 40 3a 82 52 mov ImageHandle,#0x11d2
0000137c e0 cf 00 79 strh ImageHandle,[sp, #efiLoadedImageProtocolGuid.D...
00001380 c0 f1 87 d2 mov ImageHandle,#0x3f8e
00001384 00 00 b4 f2 movk ImageHandle,#0xa000, LSL #16
00001388 20 39 cd f2 movk ImageHandle,#0x69c9, LSL #32
0000138c 40 6e e7 f2 movk ImageHandle,#0x3b72, LSL #48
00001390 e0 37 00 f9 str ImageHandle,[sp, #efiLoadedImageProtocolGuid.D...
00001394 e0 4b 40 f9 ldr ImageHandle,[sp, #gBS]
00001398 06 8c 40 f9 ldr efiOpenProtocol,[ImageHandle, #0x118]
0000139c e1 c3 01 91 add gST,sp,#0x70
000013a0 e0 83 01 91 add ImageHandle,sp,#0x60
000013a4 25 00 80 52 mov w5,#0x1
000013a8 04 00 80 d2 mov x4,#0x0
000013ac e3 0f 40 f9 ldr x3,[sp, #local_88]
000013b0 e2 03 01 aa mov x2,gST
000013b4 e1 03 00 aa mov gST,ImageHandle
000013b8 e0 0f 40 f9 ldr ImageHandle,[sp, #local_88]
000013bc c0 00 3f d6 blr efiOpenProtocol
000013c0 e0 4f 00 f9 str ImageHandle,[sp, #local_8]
000013c4 e0 4f 40 f9 ldr ImageHandle,[sp, #local_8]
000013c8 1f 00 00 f1 cmp ImageHandle,#0x0
000013cc 61 16 00 54 b.ne LAB_00001698
000013d0 e0 c3 01 91 add ImageHandle,sp,#0x70
000013d4 e1 03 00 aa mov gST,ImageHandle

```

55 uVar11 = 0;
56 efiImageHandle = ImageHandle;
57 local_8 = (*efiOpenProtocol)(ImageHandle,&efiLoadedImageProtocolGuid,efiLoadedImageProtocol,
58 ImageHandle,(EFI_HANDLE)0x0,1);
59 if (local_8 == 0) {
60 FUN_00001elc((undefined *)
61 L"EFI BootServices OpenProtocol call with loadedimageprotocol was successful: %p
62 "
63 ,&local_30,efiLoadedImageProtocol,efiImageHandle,uVar11,uVar12,
64 (ulonglong)efiOpenProtocol,in_x7);
65 local_18 = *(EFI_HANDLE *)((longlong)local_30 + 0x18);
66 local_20 = *(UINTN *)((longlong)local_30 + 0x48);
67 local_58._0_4_ = 0x964e5b22;
68 local_58._4_2_ = 0x6459;
69 local_58._6_2_ = 0x11d2;
70 local_58[8] = 0x8e;
71 local_58[9] = '9';
72 uStack_4e = '\0';
73 uStack_4d = 0xa0;
74 uStack_4c._0_1_ = 0xc9;
75 uStack_4c._1_1_ = 'i';
76 uStack_4c._2_1_ = 'r';
77 uStack_4c._3_1_ = ';';
78 efiOpenProtocol = gBS->OpenProtocol;
79 efiLoadedImageProtocol = &local_48;
80 uVar12 = 1;
81 uVar11 = 0;
82 local_8 = (*efiOpenProtocol)(local_18,(EFI_GUID *)local_58,efiLoadedImageProtocol,ImageHandle,
83 (EFI_HANDLE)0x0,1);
84 if (local_8 == 0) {
85 FUN_00001elc((undefined *)
86 L"EFI BootServices OpenProtocol call with simplefilesystemprotocol was successf
87 : %p \n"
88 ,&local_30,efiLoadedImageProtocol,ImageHandle,uVar11,uVar12,
89 (ulonglong)efiOpenProtocol,in_x7);
90 }
91 pcVar6 = *(code **)((longlong)local_48 + 8);
92 puVar1 = &local_60;
93 local_8 = (*pcVar6)(local_48);
94 if (local_8 == 0) {

arm64 UEFI quine

RE and xdev

arm64 UEFI quine

RE and xdev

```

str     ImageHandle,[sp, #local_8]
ldr     ImageHandle,[sp, #local_8]
cmp     ImageHandle,#0x0
b.ne   LAB_00001698
add     ImageHandle,sp,#0x70
mov     gST,ImageHandle
adrp   ImageHandle,0x4000
add     ImageHandle=>u_EFI_BootServices_OpenProtocol_c...
bl     Print
ldr     ImageHandle,[sp, #loadedImageProtocol]
ldr     ImageHandle,[ImageHandle, #0x18]
str     ImageHandle,[sp, #local_18]
ldr     ImageHandle,[sp, #loadedImageProtocol]
ldr     ImageHandle,[ImageHandle, #0x48]
str     ImageHandle,[sp, #local_20]
mov     ImageHandle,#0x5b22
movk   ImageHandle,#0x964e, LSL #16
str     ImageHandle,[sp, #local_58]
mov     ImageHandle,#0x6459
strh   ImageHandle=>DAT_00006459,[sp, #local_54]
mov     ImageHandle,#0x11d2
strh   ImageHandle,[sp, #local_52]
mov     ImageHandle,#0x398e
movk   ImageHandle,#0xa000, LSL #16
movk   ImageHandle,#0x69c9, LSL #32
movk   ImageHandle,#0x3b72, LSL #48
str     ImageHandle,[sp, #local_50]
ldr     ImageHandle,[sp, #gBS]
ldr     efiOpenProtocol,[ImageHandle, #0x118]
add     gST,sp,#0x58
add     ImageHandle,sp,#0x48
mov     w5,#0x1
mov     x4,#0x0
ldr     efiImageHandle,[sp, #local_88]

```

```

62    if (local_8 == 0) {
63      Print((undefined *)
64        L"EFI BootServices OpenProtocol call with loadedimageproto
65          &loadedImageProtocol,efiLoadedImageProtocol,efiImageHandle
66            (ulonglong)efiOpenProtocol,in_x7);
67      local_18 = loadedImageProtocol->DeviceHandle;
68      local_20 = loadedImageProtocol->ImageSize;
69      local_58._0_4_ = 0x964e5b22;
70      local_58._4_2_ = 0x6459;
71      local_58._6_2_ = 0x11d2;
72      local_58[8] = 0x8e;
73      local_58[9] = '9';
74      uStack_4e = '\0';
75      uStack_4d = 0xa0;
76      uStack_4c._0_1_ = 0xc9;
77      uStack_4c._1_1_ = 'i';
78      uStack_4c._2_1_ = 'r';
79      uStack_4c._3_1_ = ';';
80      efiOpenProtocol = gBS->OpenProtocol;
81      ppvVar7 = &local_48;
82      uVar13 = 1;
83      uVar12 = 0;
84      local_8 = (*efiOpenProtocol)(local_18,(EFI_GUID *)local_58,ppvVa
85                                );
86      if (local_8 == 0) {
87        Print((undefined *)
88          L"EFI BootServices OpenProtocol call with simplefilesyst
89          "
90          ,&loadedImageProtocol,ppvVar7,ImageHandle,uVar12,uVar13,
91          );
92      pcVar8 = *(code **)((longlong)local_48 + 8);
93      puVar1 = &local_60;
94      local_8 = (*pcVar8)(local_48).

```

The screenshot shows a debugger interface with two panes. The left pane displays assembly code for an arm64 UEFI quine. The right pane shows the corresponding C decompiled code.

```

ldr    ImageHandle,[sp, #gBS]
ldr    efiOpenProtocol,[ImageHandle, #0x118]
add    gST,sp,#0x70
add    ImageHandle,sp,#0x60
mov    w5,#0x1
mov    x4,#0x0
ldr    x3,[sp, #local_88]
mov    x2,gST
mov    gST,ImageHandle
ldr    ImageHandle,[sp, #local_88]
blr    efiOpenProtocol
str    ImageHandle,[sp, #local_8]
ldr    ImageHandle,[sp, #local_8]
cmp    ImageHandle,#0x0
b.ne  LAB_00001698
add    ImageHandle,sp,#0x70
mov    gST,ImageHandle
adrp   ImageHandle,0x4000
add    ImageHandle=>u_EFI_BootServices_OpenProtocol_c...
bl     Print
ldr    ImageHandle,[sp, #loadedImageProtocol]
ldr    ImageHandle,[ImageHandle, #0x18]
str    ImageHandle,[sp, #local_18]
ldr    ImageHandle,[sp, #loadedImageProtocol]
ldr    ImageHandle,[ImageHandle, #0x48]
str    ImageHandle,[sp, #local_20]
mov    ImageHandle,#0x5b22
movk   ImageHandle,#0x964e, LSL #16
str    ImageHandle,[sp, #local_58]
mov    ImageHandle,#0x6459
strh   ImageHandle=>DAT_00006459,[sp, #local_54]
mov    ImageHandle,#0x11d2
strh   ImageHandle,[sp, #local_52]
mov    ImageHandle,#0x398e

```

```

41    EFI_STATUS local_8;
42
43    gBS = gST->BootServices;
44    efiLoadedImageProtocolGuid.Data1 = 0x5b1b31a1;
45    efiLoadedImageProtocolGuid.Data2 = 0x9562;
46    efiLoadedImageProtocolGuid.Data3 = 0x11d2;
47    efiLoadedImageProtocolGuid.Data4[0] = 0x8e;
48    efiLoadedImageProtocolGuid.Data4[1] = '?';
49    efiLoadedImageProtocolGuid.Data4[2] = '\0';
50    efiLoadedImageProtocolGuid.Data4[3] = 0xa0;
51    efiLoadedImageProtocolGuid.Data4[4] = 0xc9;
52    efiLoadedImageProtocolGuid.Data4[5] = 'i';
53    efiLoadedImageProtocolGuid.Data4[6] = 'r';
54    efiLoadedImageProtocolGuid.Data4[7] = ';';
55    efiOpenProtocol = gBS->OpenProtocol;
56    efiLoadedImageProtocol = &loadedImageProtocol;
57    uVar13 = 1;
58    uVar12 = 0;
59    efiImageHandle = ImageHandle;
60    local_8 = (*efiOpenProtocol)(ImageHandle,&loadedImageProtocol,
61                                ImageHandle,(EFI_HANDLE)0x0,1);
62    if (local_8 == 0) {
63        Print((undefined *)
64                  L"EFI BootServices OpenProtocol call with loadedimageproto
65                  &loadedImageProtocol,efiLoadedImageProtocol,efiImageHandle
66                  (ulonglong)efiOpenProtocol,in_x7);
67        local_18 = loadedImageProtocol->DeviceHandle;
68        local_20 = loadedImageProtocol->ImageSize;
69        local_58._0_4_ = 0x964e5b22;
70        local_58._4_2_ = 0x6459;
71        local_58._6_2_ = 0x11d2;
72        local_58[8] = 0x8e;
73        local_58[9] = '9';
74        uStack_40 = '\0';

```

arm64 UEFI quine

RE and xdev

The image shows a debugger interface with two panes. The left pane displays assembly code, and the right pane displays the corresponding C decompiled code. The assembly code is in ARM64 syntax, and the C code is annotated with line numbers.

```
mov    ImageHandle,#0x31a1
movk   ImageHandle,#0x5b1b, LSL #16
str    ImageHandle,[sp, #efiLoadedImageProtocolGuid.D...
mov    ImageHandle,#0xfffff9562
strh   ImageHandle,[sp, #efiLoadedImageProtocolGuid.D...
mov    ImageHandle,#0x11d2
strh   ImageHandle,[sp, #efiLoadedImageProtocolGuid.D...
mov    ImageHandle,#0x3f8e
movk   ImageHandle,#0xa000, LSL #16
movk   ImageHandle,#0x69c9, LSL #32
movk   ImageHandle,#0x3b72, LSL #48
str    ImageHandle,[sp, #efiLoadedImageProtocolGuid.D...
ldr    ImageHandle,[sp, #gBS]
ldr    efiOpenProtocol,[ImageHandle, #0x118]
add    gST,sp,#0x70
add    ImageHandle,sp,#0x60
mov    w5,#0x1
mov    x4,#0x0
ldr    x3,[sp, #local_88]
mov    x2,gST
mov    gST,ImageHandle
ldr    ImageHandle,[sp, #local_88]
blr    efiOpenProtocol
str    ImageHandle,[sp, #local_8]
ldr    ImageHandle,[sp, #local_8]
cmp    ImageHandle,#0x0
b.ne   LAB_00001698
add    ImageHandle,sp,#0x70
mov    gST,ImageHandle
adrp   ImageHandle,0x4000
add    ImageHandle=>u_EFI_BootServices_OpenProtocol_c... = u"EFI BootServices OpenProtocol
bl    Print
ldr    ImageHandle,[sp, #local_30]
ldr    ImageHandle,[ImageHandle, #0x18]
```

```
41    gBS = gST->BootServices;
42    efiLoadedImageProtocolGuid.Data1 = 0x5b1b31a1;
43    efiLoadedImageProtocolGuid.Data2 = 0x9562;
44    efiLoadedImageProtocolGuid.Data3 = 0x11d2;
45    efiLoadedImageProtocolGuid.Data4[0] = 0x8e;|
46    efiLoadedImageProtocolGuid.Data4[1] = '?';
47    efiLoadedImageProtocolGuid.Data4[2] = '\0';
48    efiLoadedImageProtocolGuid.Data4[3] = 0xa0;
49    efiLoadedImageProtocolGuid.Data4[4] = 0xc9;
50    efiLoadedImageProtocolGuid.Data4[5] = 'i';
51    efiLoadedImageProtocolGuid.Data4[6] = 'r';
52    efiLoadedImageProtocolGuid.Data4[7] = ';';
53    efiOpenProtocol = gBS->OpenProtocol;
54    efiLoadedImageProtocol = &local_30;
55    uVar12 = 1;
56    uVar11 = 0;
57    efiImageHandle = ImageHandle;
58    local_8 = (*efiOpenProtocol)(ImageHandle,&efiLoadedImageProtocolGuid,efiLoadedImageProtocol,
                                     ImageHandle,(EFI_HANDLE)0x0,1);
59    if (local_8 == 0) {
60        Print((undefined *)
61            L"EFI BootServices OpenProtocol call with loadedimageprotocol was successful: %p
62            &local_30,efiLoadedImageProtocol,efiImageHandle,uVar11,uVar12,(ulonglong)efiOpenP
63            in_x7);
64        local_18 = *(EFI_HANDLE *)((longlong)local_30 + 0x18);
65        local_20 = *(UINTN *)((longlong)local_30 + 0x48);
66        local_58._0_4_ = 0x964e5b22;
67        local_58._4_2_ = 0x6459;
68        local_58._6_2_ = 0x11d2;
69        local_58[8] = 0x8e;
70        local_58[9] = '9';
71        uStack_4e = '\0';
72        uStack_Ad = 0x0;
```

arm64 UEFI quine

RE and xdev

Listing: UEFISelfRep_Aarch64_v1.efi

```

00001380 04 00 80 d2    mov    x4,#0x0
00001384 e3 0f 40 f9    ldr    x3,[sp, #local_78]
00001388 e2 03 00 aa    mov    x2,param_1
0000138c 20 00 00 b0    adrp   param_1,0x6000
00001390 01 20 00 91    add    param_2=>EfiLoadedImageProtocolGuid,param_1,#0x8
00001394 e0 0f 40 f9    ldr    param_1,[sp, #local_78]
00001398 c0 00 3f d6    blr    x6
0000139c e0 47 00 f9    str    param_1,[sp, #local_8]
000013a0 e0 47 40 f9    ldr    param_1,[sp, #local_8]
000013a4 1f 00 00 f1    cmp    param_1,#0x0
000013a8 81 15 00 54    b.ne   LAB_00001658
000013ac e0 83 01 91    add    param_1,sp,#0x60
000013b0 e1 03 00 aa    mov    param_2,param_1
000013b4 00 00 00 f0    adrp   param_1,0x4000
000013b8 00 c0 33 91    add    param_1=>u_EFI_BootServices_OpenProtocol_ca_00...
000013bc 88 02 00 94    bl    FUN_00001ddc
000013c0 e0 33 40 f9    ldr    param_1,[sp, #Stack[-0x30]]
000013c4 00 0c 40 f9    ldr    param_1,[param_1, #0x18]
000013c8 e0 3b 00 f9    str    param_1,[sp, #local_20]
000013cc e0 33 40 f9    ldr    param_1,[sp, #Stack[-0x30]]
000013d0 00 24 40 f9    ldr    param_1,[param_1, #0x48]
000013d4 e0 37 00 f9    str    param_1,[sp, #local_28]
000013d8 e0 33 40 f9    ldr    param_1,[sp, #Stack[-0x30]]
000013dc 00 00 01 91    add    param_1,param_1,#0x40
000013e0 e0 27 00 f9    str    param_1,[sp, #local_48]
000013e4 e0 23 01 91    add    param_1,sp,#0x48
000013e8 e1 03 00 aa    mov    param_2,param_1
000013ec 00 00 00 f0    adrp   param_1,0x4000
000013f0 00 60 36 91    add    param_1=>u_Base_Address_of_Image:_sp_00004d98...
000013f4 7a 02 00 94    bl    FUN_00001ddc
000013f8 e0 43 40 f9    ldr    param_1,[sp, #local_10]
000013fc 06 8c 40 f9    ldr    x6,[param_1, #0x118]
00001400 e0 63 01 91    add    param_1,sp,#0x58
00001404 20 00 30 92    w5,#0x1
00001408 01 00 30 92    x4,#0x0
0000140c e3 0f 40 f9    ldr    x3,[sp, #local_78]
00001410 e2 03 00 aa    mov    ppvVar6,param_1
00001414 20 00 00 b0    adrp   param_1,0x6000
00001418 01 60 00 91    add    param_2=>EfiSimpleFileSystemProtocolGuid,param...
0000141c e0 3b 40 f9    ldr    param_1,[sp, #local_20]
00001420 c0 00 3f d6    blr    x6
00001424 e0 47 00 f9    str    param_1,[sp, #local_8]
00001428 e0 47 40 f9    ldr    param_1,[sp, #local_8]

```

arm64 UEFI RE

```

37  EFI_LOADED_IMAGE_PROTOCOL *pEStack_30;
38  UINTN local_28;
39  EFI_HANDLE local_20;
40  UINT64 local_18;
41  EFI_BOOT_SERVICES *local_10;
42  EFI_STATUS local_8;
43
44  local_10 = param_2->BootServices;
45  local_50 = (EFI_FILE_PROTOCOL *)0x0;
46  local_58 = 0;
47  local_18 = 0;
48  pEVar17 = local_10->OpenProtocol;
49  ppvVar6 = &pEStack_30;
50  uVar13 = 1;
51  uVar13 = 0;
52  pvVar9 = param_1;
53  local_8 = (*pEVar17)(param_1,&EfiLoadedImageProtocolGuid,ppvVar6,param_1,(EF
54  if (local_8 == 0) {
55      FUN_00001ddc((undefined *)
56          L"EFI BootServices OpenProtocol call with loadedimageprotocol
57          "
58          ,&pEStack_30,ppvVar6,pvVar9,uVar13,uVar15,(ulonglong)pEVar17,
59  local_20 = pEStack_30->DeviceHandle;
60  local_28 = pEStack_30->ImageSize;
61  local_48 = &pEStack_30->ImageBase;
62  FUN_00001ddc((undefined *)L"Base Address of Image: %p \n",&local_48,ppvVar
63  , (ulonglong)pEVar17,in_x7);
64  pEVar17 = local_10->OpenProtocol;
65  Interface = &local_38;
66  uVar15 = 1;
67  uVar13 = 0;
68  local_8 = (*pEVar17)(local_20,&EfiSimpleFileSystemProtocolGuid,Interface,p
69  ,1);
70  if (local_8 == 0) {
71      FUN_00001ddc((undefined *)
72          L"EFI BootServices OpenProtocol call with simplefilesystemp
73          : %p \n"
74          ,&pEStack_30,Interface,param_1,uVar13,uVar15,(ulonglong)pEVar17
75  }
76  pEVar6 = local_38->OpenVolume;
77  ppEVar1 = &local_40;
78  local_8 = (*pEVar6)(local_38,ppEVar1);
79  if (local_8 == 0) {

```

UEFI generation 2: arm64

RE and development tools

- Write the assembly program and build it with the edk2 build system
 - This was easiest option because I wrote this on an arm64 machine (an M1 MacBook Pro) but the bindings for arm64 with the native Xcode Tools command line tools are for *Darwin* arm64 and for generating Mach-O arm64 binaries
 - UEFI apps and drivers are predominately PE files (and occasionally TE) that don't use the Darwin bindings
 - The edk2 build system finally came through and was up to this task of generating arm64 UEFI apps
- For an assembler with solid UEFI support, there is the ARM-specific flavor of FASM: FASMARM: <https://arm.flatassembler.net/>
 - [Note FASMARM only supports 32-bit and 64-bit ARM architectures up until v8; valid solution for ARM32 builds but not arm64 builds)
- Hex editor (xxd, hexdump)
- Ghidra with [efiSeek](#) and [ghidra-firmware-utils](#)
- radare2 for disassembly
- QEMU and gdb for debugging/testing

UEFI Interactive Shell v2.1

EDK II

UEFI v2.60 (EDK II, 0x00010000)

Mapping table

FS0: Alias(s):HD0b:;BLK1:
PciRoot(0x0)/Pci(0x1,0x0)/HD(1,MBR,0xBE1AFDFA,0x3F,0xFBFC1)

BLK3: Alias(s):
VenHw(F9B94AE2-8BA6-409B-9D56-B9B417F53CB3)

BLK2: Alias(s):
VenHw(8047DB4B-7E9C-4C0C-8EBC-DFBAAACACE8F)

BLK0: Alias(s):
PciRoot(0x0)/Pci(0x1,0x0)

[Press **ESC** in 3 seconds to skip **startup.nsh** or any other key to continue.

[Shell> fs0:

FS0:\> █

**Final arm64 quine:
Self-replicating UEFI app**

Written in arm64 assembly

```
/Users/nika/uefi_testing/edk2/MdePkg/Library/BaseLib/DivU64x32Remainder.c
```

```
1  /** @file
2   Math worker functions.
3
4   Copyright (c) 2006 - 2008, Intel Corporation. All rights reserved.<BR>
5   SPDX-License-Identifier: BSD-2-Clause-Patent
6
7  */
8
9 #include "BaseLibInternals.h"
10
11 /**
12  Divides a 64-bit unsigned integer by a 32-bit unsigned integer and generates
13  a 64-bit unsigned result and an optional 32-bit unsigned remainder.
14
```

arm64 UEFI debugging

qemu & gdb

```
0x78760ac8 <DivU64x32Remainder>      stp    x29, x30, [sp, #-48]!
0x78760acc <DivU64x32Remainder+4>     mov    x29, sp
0x78760ad0 <DivU64x32Remainder+8>     str    x0, [sp, #40]
0x78760ad4 <DivU64x32Remainder+12>    str    w1, [sp, #36]
0x78760ad8 <DivU64x32Remainder+16>    str    x2, [sp, #24]
0x78760adc <DivU64x32Remainder+20>    bl    0x7875e678 <DebugAssertEnabled>
0x78760ae0 <DivU64x32Remainder+24>    and    w0, w0, #0xff
0x78760ae4 <DivU64x32Remainder+28>    cmp    w0, #0x0
0x78760ae8 <DivU64x32Remainder+32>    b.eq   0x78760b10 <DivU64x32Remainder+72> // b.none
0x78760aec <DivU64x32Remainder+36>    ldr    w0, [sp, #36]
0x78760af0 <DivU64x32Remainder+40>    cmp    w0, #0x0
0x78760af4 <DivU64x32Remainder+44>    b.ne   0x78760b10 <DivU64x32Remainder+72> // b.any
0x78760af8 <DivU64x32Remainder+48>    adrp   x0, 0x78761000 <CpuBreakpoint+912>
0x78760afc <DivU64x32Remainder+52>    add    x2, x0, #0xe0
```

```
exec No process In:
(No debugging symbols found in UEFI_bb_disk/UefiQuineAarch64.efi)
(gdb) info files
Symbols from "/Users/nika/uefi-task-of-the-translator/Aarch64_UEFI_exploits/UEFI_bb_disk/UefiQuineAarch64.efi".
Local exec file:
`/Users/nika/uefi-task-of-the-translator/Aarch64_UEFI_exploits/UEFI_bb_disk/UefiQuineAarch64.efi', file type pei-aarch64-little.
Entry point: 0x1000
0x000000000001000 - 0x0000000000005000 is .text
0x0000000000005000 - 0x0000000000006000 is .data
0x0000000000006000 - 0x0000000000007000 is .reloc
(gdb) add-symbol-file ~/uefi_testing/edk2/Build/BareBonesPkg/DEBUG_GCC/Aarch64/UefiQuineAarch64.debug 0x7875e000 -s .data 0x78762000
add symbol table from file "/Users/nika/uefi_testing/edk2/Build/BareBonesPkg/DEBUG_GCC/Aarch64/UefiQuineAarch64.debug" at
  .text_addr = 0x7875e000
  .data_addr = 0x78762000
(y or n) y
Reading symbols from /Users/nika/uefi_testing/edk2/Build/BareBonesPkg/DEBUG_GCC/Aarch64/UefiQuineAarch64.debug...
(gdb)
```

UEFI generation 2: arm64

What did you learn at school today?

- Leverage the UEFI ecosystem by walking from Protocol interface to Protocol interface → better understanding of UEFI internals and base knowledge for building better exploits
 - Building ROP chains for arm64 exploits
 - Learning how to set up debugging for arm64 UEFI apps/drivers
 - Knowledge of how to write UEFI shellcode for arm64
 - Expanded repertoire of knowledge and skills for UEFI exploit dev
 - Additional working payloads for arm64 UEFI exploits

UEFI generation 3: EBC

EBC - EFI Byte Code

Why EBC?

- EBC was a natural fit as the final architecture to choose for this project because of the inherent variability/malleability of natural indexing and the EBC spec itself
- EBC aims to become something of a tower of Babel: a platform-agnostic architecture specification for PCI option ROM implementation; it uses natural-indexing to adjust the width of its instructions (32-bit or 64-bit) depending on the architecture of the host
- EBC is an intermediate language (like LLVM byte code, Java byte code, [insert your favorite byte code here]) and it is run in the EFI Byte Code Virtual Machine (EBCVM)
- If a compiler is a translator, then EBC could be considered the holy scripture [per Benjamin's metaphor]...

“For to some degree all great writings, but above all holy scripture, contain their virtual translation between the lines. The interlinear version of the holy scriptures is the prototype or ideal of all translation.”

Walter Benjamin, “The Task of the Translator,” translated by Steven Rendall, page 165.

UEFI generation 3: EBC

UEFI EBC architecture details

- EBCVM uses 8 general purposes registers:
 - R0-R7
- EBCVM has 2 dedicated registers:
 - IP (instruction pointer)
 - F (Flags register)
- Natural indexing: uses a natural unit to calculate offsets of data relative to a base address, where a natural unit is defined as:
 - Natural unit == sizeof (void *)

Table 22.4 Index Encoding

Bit #	Description
N	Sign bit (sign), most significant bit
N-3..N-1	Bits assigned to natural units (w)
A..N-4	Constant units (c)
0..A-1	Natural units (n)

As shown in the Table above for a given encoded index, the most significant bit (bit N) specifies the sign of the resultant offset after it has been calculated. The sign bit is followed by three bits (N-3..N-1) that are used to compute the width of the natural units field (n). The value (w) from this field is multiplied by the index size in bytes to determine the actual width (A) of the natural units field (n). Once the width of the natural units field has been determined, then the natural units (n) and constant units (c) can be extracted. The offset is then calculated at runtime according to the following equation:

```
Offset = (c + n * (sizeof (VOID *))) * sign
```

Source: “UEFI Spec, Chapter 22: EFI Byte Code Virtual Machine,”
https://uefi.org/specs/UEFI/2.10/22_EFI_Bit_Code_Virtual_Machine.html#natural-indexing

EBC - EFI Byte Code

If EBC is so great then why haven't I heard of it?

- Only one compiler specifically designed to target valid EBC binaries: the proprietary Intel C compiler for EBC
- This proprietary Intel C compiler for EBC was available for the low price of \$995 [to my knowledge, it is no longer available; now the page on the Intel Products site redirects to an IoT toolkit for \$2399]
- Open-source options are available ... sort of
 - `fasm-ebc` is the closest open-source version to the Intel C compiler for EBC but it can't handle edge cases for encoding instructions with natural-indexing [see this issue in the *archived* `fasm-ebc` GitHub repo:]
- Very few in-the-wild reference EBC images
- EBC is technically “no longer part of the spec”
 - Chapter 22 doesn’t exist. Chapter 22 never existed.

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EBC - EFI Byte Code

If EBC is a dead ISA with little to no reference implementations why are you talking about it now?

- What if there were legacy/deprecated features lingering in a codebase for years...
- What if IBVs/OEMs were slow to patch platform firmware and remove legacy/deprecated features...
- EBC interpreter is still part of the main branch in Tianocore's edk2
- IBVs/OEMs fork edk2, along with the EBC interpreter...
 - ... then a lot of machines might have the EBC interpreter, and can run EBC binaries
- Just because this feature is hardly (if ever) used, doesn't mean it can't be leveraged
- To be continued... [ongoing project, updates to be presented at REcon 2024 and in VX-Underground Black Mass, vol. 2]

```
1  /** @file
2   * Contains code that implements the virtual machine.
3   *
4   * Copyright (c) 2006 - 2018, Intel Corporation. All rights reserved.
5   * SPDX-License-Identifier: BSD-2-Clause-Patent
6   */
7
8
9  #include "EbcInt.h"
10 #include "EbcExecute.h"
11 #include "EbcDebuggerHook.h"
```

UEFI generation 3: EBC

RE and development tools

- Open-source version of the EBC compiler: fasm-ebc
<https://github.com/pbatard/fasmg-ebc>
- Hex editor (xxd, hexdump)
- ebcvm: <https://github.com/yabits/ebcvm>
- Ghidra with efiSeek and ghidra-firmware-utils and an EBC plugin:
 - <https://github.com/meromwolff/Ghidra-EFI-Byte-Code-Processor/>

UEFI Exploit Dev

What do they say about programming in C code? It's like smoking a cigarette in a swimming pool full of gasoline. OK, enough of the jokes and back to the blog.

Source: Vincent Zimmer, “EFI Byte Code,” Saturday, August 1, 2015,
<https://vzimmer.blogspot.com/2015/08/efi-byte-code.html>

UEFI Exploit dev

Well, how did I get here?

- My research on this began after I kept running into the same problem at work: I was *finding* UEFI vulnerabilities, but I didn't know how to write exploits for UEFI
- This talk is an overview of my experience learning UEFI exploit dev; it's ongoing, I welcome feedback. [If you work in or do research in this space, please come talk to me afterwards. I'm here to learn just like all of you.]
- How did I learn to write UEFI exploits?
 - 1. Reverse engineering and replicating the techniques of other PoCs [Translating PoC's, if you will]
 - 2. Learning about UEFI by writing UEFI apps and drivers [How do you learn a language? How do you learn to write UEFI exploits? Exploit dev is like learning a language: it requires practice and accepting that you'll fail many times before you communicate what you want to say (e.g. pwn a target)]

SMM Callout Exploit dev

Reverse Engineering earlier malware/PoCs

- How does one start writing an exploit for a new system/an unfamiliar target?
- Understand the target:
 - Build foundational knowledge (RTFM - the UEFI spec, Beyond BIOS, Rootkits and Bootkits)
 - Find previous notable work in UEFI exploit development/malware, and read, re-read the base text
 - “Translate a base text” : Try to translate the same exploit technique on a different vulnerable target
 - e.g. Use cr4sh’s SMM callout PoC for a vulnerability in SystemSmmAhciAspiLegacyRt (“Exploiting SMM callout vulnerabilities in Lenovo firmware”, <http://blog.cr4.sh/2016/02/exploiting-smm-callout-vulnerabilities.html>], as a template for writing an SMM callout exploit for a vulnerability in an IdeBusDxe driver

UEFI Exploit dev

Reverse Engineering earlier malware/PoCs

- There is no ROP Emporium for UEFI specifically, and there are very few examples of UEFI-specific CTF challenges [Notable exception: SMM Cowsay from UIUCTF 2022, which we'll return to] that you can use for practice
- But there are good resources for learning all of the skills you'll need to write UEFI exploits
 - No exploit dev roadmap?
Honey, that's what I call a make-your-own-adventure CTF

UEFI Exploit dev

Make-your-own-adventure CTF

- (OST2) Architecture 4021: Introductory UEFI
<https://ost2.fyi/Arch4021>
- (OST2) Architecture 4001: x86-64 Intel Firmware Attack & Defense
<https://ost2.fyi/Arch4001>
- (OST2) Hardware 1101: Intel SPI Analysis
<https://ost2.fyi/HW1101>
- UEFI-Lessons by Kostr: <https://github.com/Kostr/UEFI-Lessons/>
- Tools
 - Chipsec: <https://chipsec.github.io/>
 - UEFITool: <https://github.com/LongSoft/UEFITool>

UEFI Exploit dev: SMM Callouts

Started from ring -2 now we're calling out to an attacker-controlled region of memory

SMM Callout

?????

```
1 EFI_STATUS __fastcall ChildSwSmiHandler(
2     EFI_HANDLE DispatchHandle,
3     const void *Context,
4     char *CommBuffer,
5     UINTN *CommBufferSize)
6 {
7     EFI_STATUS v5; // rbx
8     EFI_STATUS v6; // rax
9     UINTN v7; // rbx
10    EFI_STATUS result; // rax
11    INTN v9; // rsi
12    EFI_STATUS v10; // r12
13    EFI_HANDLE Buffer; // [rsp+30h] [rbp-40h] BYREF
14    UINTN BufferSize; // [rsp+38h] [rbp-38h] BYREF
15    UINTN NoHandles; // [rsp+40h] [rbp-30h] BYREF
16    EFI_LOADED_IMAGE_PROTOCOL *EfiLoadedImageProtocol; // [rsp+48h] [rbp-28h] BYREF
17    EFI_ACPI_SUPPORT_PROTOCOL *EfiAcpiSupportProtocol; // [rsp+50h] [rbp-20h] BYREF
18    void *Table; // [rsp+58h] [rbp-18h] BYREF
19    UINTN Handle[2]; // [rsp+60h] [rbp-10h] BYREF
20    EFI_ACPI_TABLE_VERSION Version; // [rsp+A0h] [rbp+30h] BYREF
21
22    if ( !CommBuffer || !CommBufferSize )
23        return 0i64;
24    if ( *(_DWORD *)CommBuffer == 1 )
25    {
26        Buffer = 0i64;
27        if ( gBS->LocateHandleBuffer(ByProtocol, &EFI_ATATA_PASS_THRU_PROTOCOL_GUID, 0i64, &NoHandles, (EFI_HANDLE **)&Buffer)
28        {
29            v5 = 0x8000000000000000Eui64;
30        }
31    }
32 }
```

UEFI Exploit dev: SMM Callouts

Started from ring -2 now we're calling out to an attacker-controlled region of memory

- So... you found an SMM callout vulnerability in a combined SMM/DXE driver. Now what?
- Well... How does an exploit for an SMM callout work?
 - What process is it disrupting or manipulating or interfering with?
 - What is the starting state of the UEFI firmware's environment before and after a successful SMM callout exploit?
- What are the critical data structures to know?
 - SMRAM
 - EFI Boot Services Table & EFI Runtime Services Table
 - EFI System Table
 - SMMC

SMM (System Management Mode)

Overview

- The most privileged x86 processor mode — ring -2 [we're going to ignore ME, but yes that's ring -3, good job]
- The processor enters SMM only when a System Management Interrupt (SMI) is invoked
- SMIs have the highest priority of all interrupts — higher priority than NMIs (non-maskable interrupts) and MIs (maskable interrupts)
- SMM is meant to act as a privileged and *separate* (read isolated) processor mode for handling critical system functionality that needs to proceed uninterrupted (i.e. power management, etc.)
- SMM code and data reside in SMRAM

SMM (System Management Mode)

SMRAM

- SMM code and data (meaning SMI handler code and data) is stored in SMRAM
- SMRAM = a protected region of a processor's address space, dedicated to storing SMM code and data
- SMRAM is locked (or it should be) during Platform Initialization (PI), so that SMM code and data in SMRAM are not accessible by code outside of SMRAM
 - SMRAM code should not be reachable by code running in kernel space or userspace
- Entering SMM is triggered by an SMI, which includes *saving execution context of code running outside of SMRAM*
- After execution of SMI handler code, RSM instruction triggers the restoration of the initial saved state

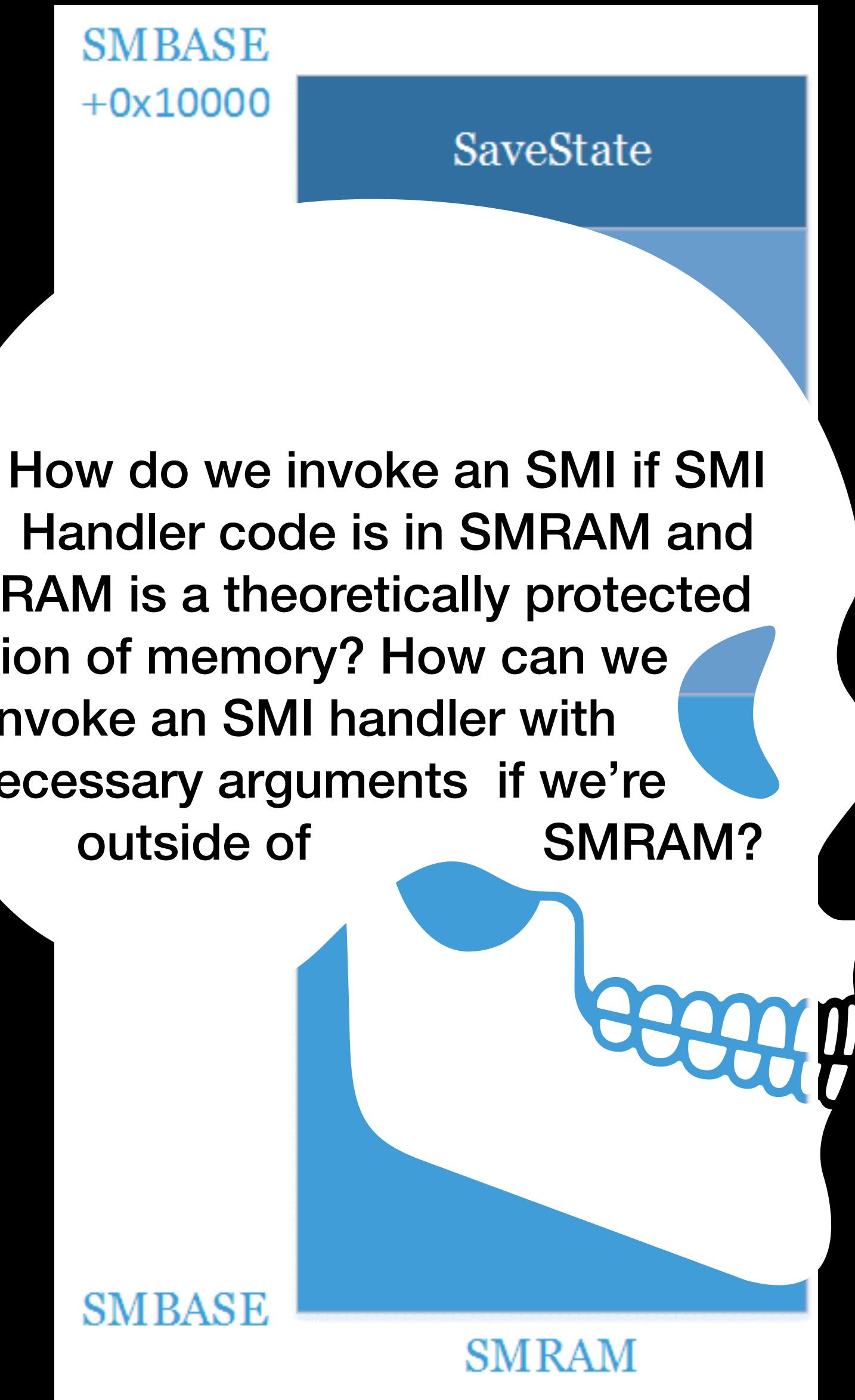


Image credit:

"Through the SMM Class and a Vulnerability Found There." Bruno Pujos,
January 14, 2020, Synactiv
<https://www.synactiv.com/en/publications/through-the-smm-class-and-a-vulnerability-found-there.html>

SMM (System Management Mode)

The Communication Buffer

- SMM_Core_Private_Data structure:
 - Used as a shared buffer for data during communication between SMRAM/non-SMRAM
 - Easily identifiable by “smmc” signature in memory
- EFI_SMM_Communicate Protocol requires that the Smm Communicate Buffer has the following structure:
 - GUID of SmiHandler you want to communicate with
 - The size of the data you’re sending to the SMI handler
 - The data

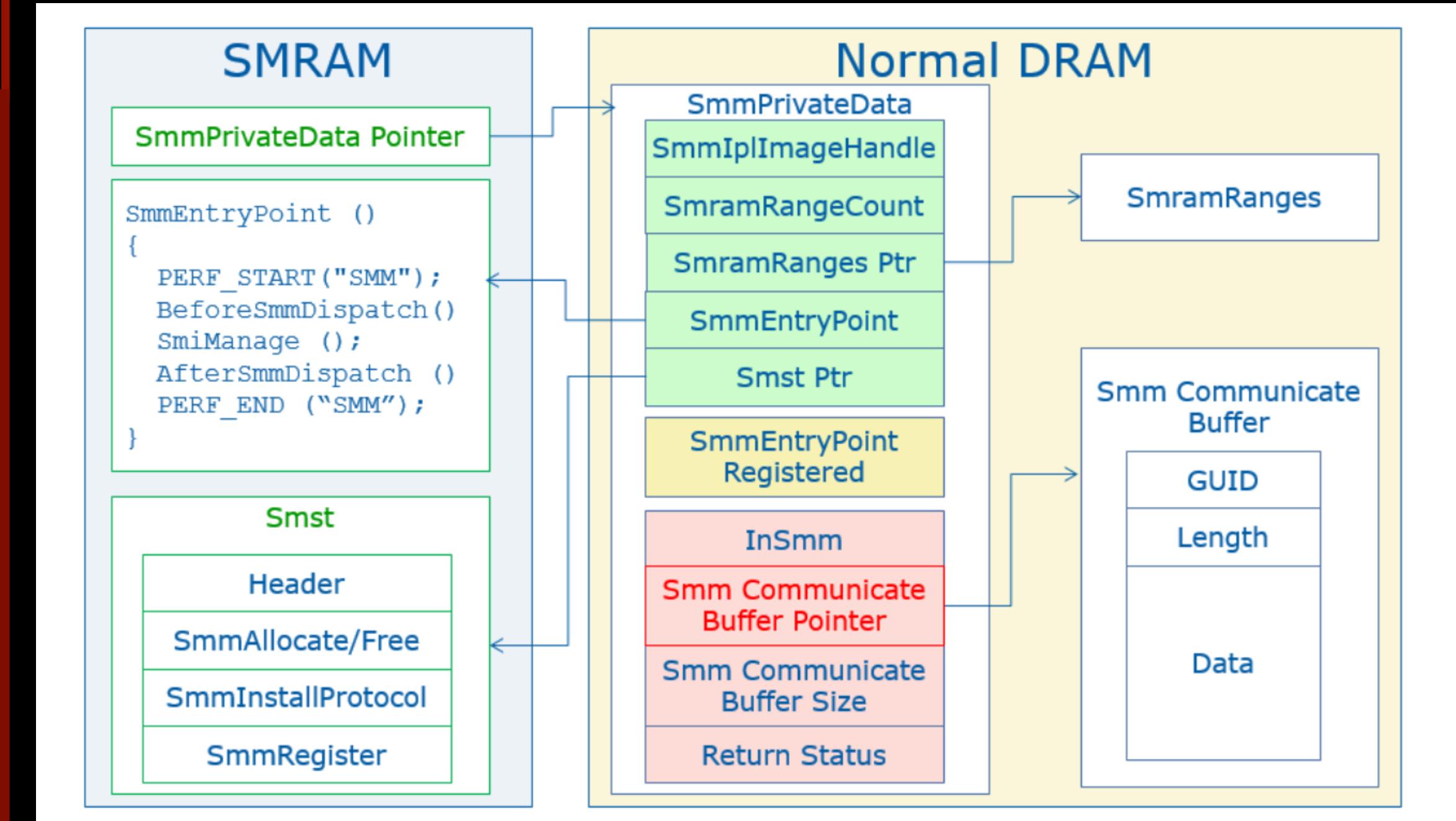


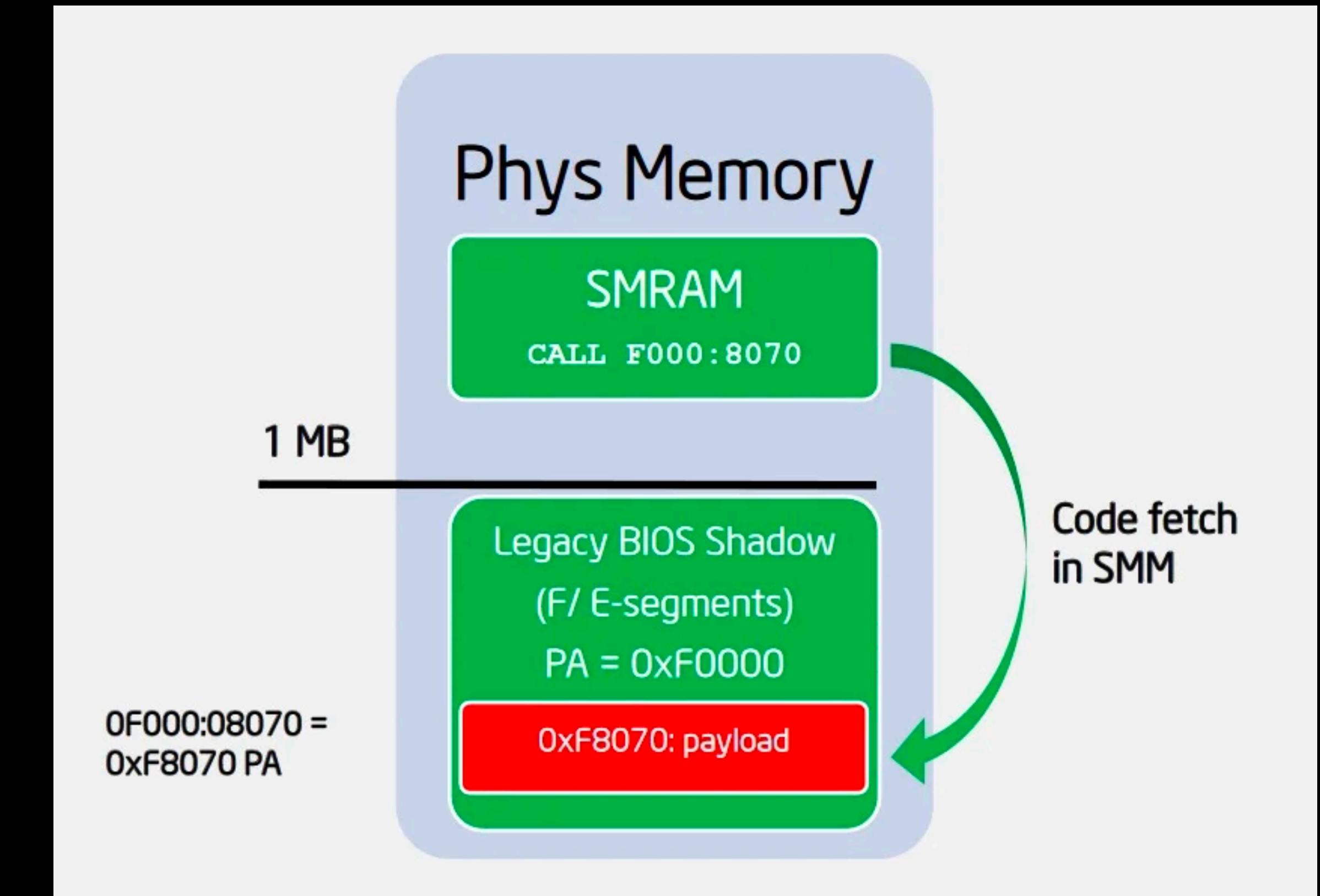
Figure 2 – SMM Communication

Source:
“A Tour Beyond BIOS Secure SMM Communication in the EFI Developer Kit II”
Jiewen Yao, Vincent J. Zimmer, Star Zeng, Intel, April 26, 2016

SMM Callouts

How

- When code running in SMM (so SMI handler code) reaches out to a data structure/code located *outside* of SMRAM, an SMM callout vuln can arise
- SMRAM == ****safe**** (relatively)
- **EFI_BOOT_SERVICES** and **EFI_RUNTIME_SERVIES** == data structures that are located outside of SMRAM
 - Code in either of these data structures can be attacker controlled!

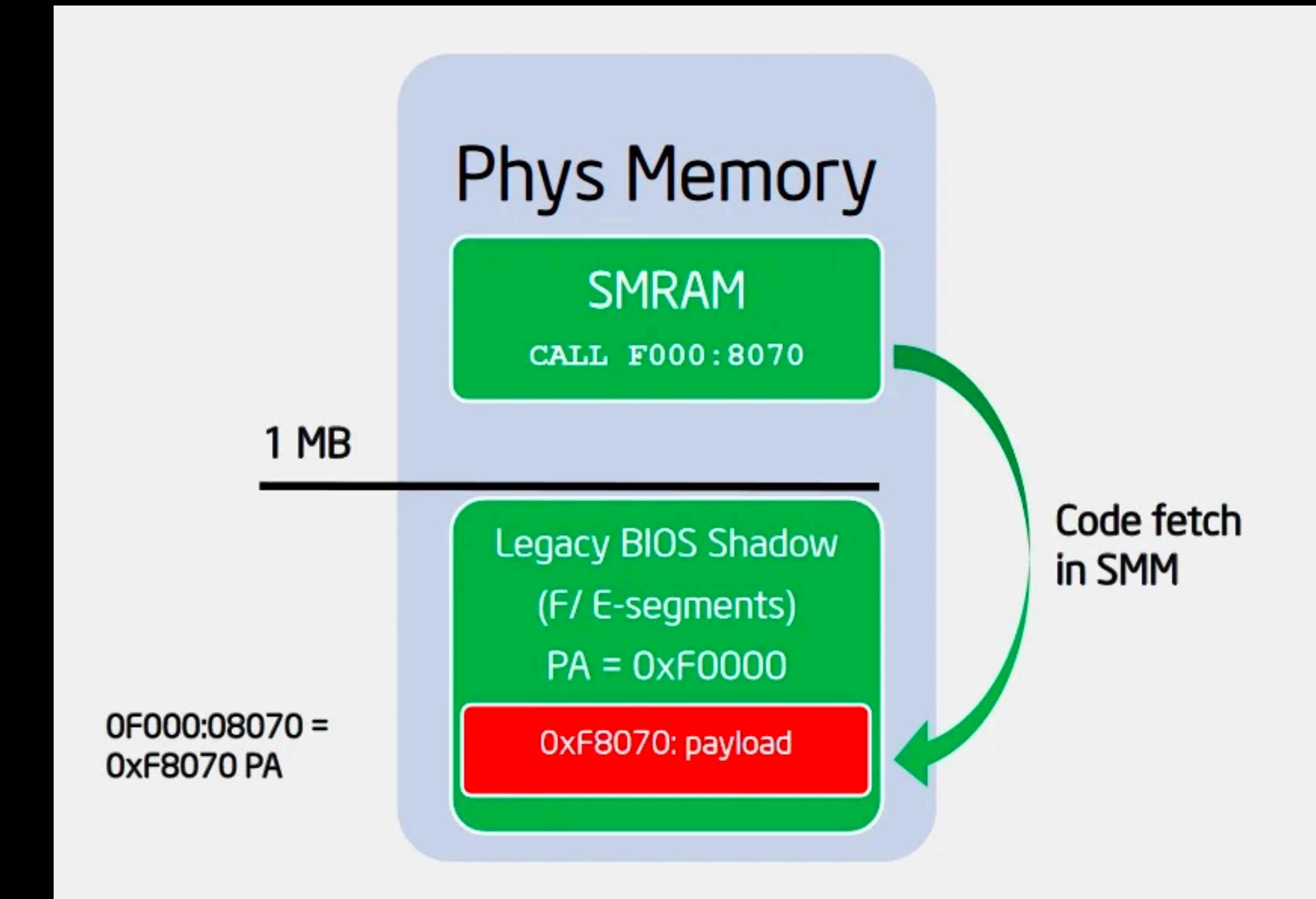


Source: “A New Class of Vulnerabilities in SMI Handlers,”
Figure 1 – Schematic overview of an SMM callout, source: [CanSecWest 2015](#)

SMM Callouts

why should I care?

- A successful SMM exploit could allow an attacker arbitrary code execution within the most privileged execution level (ring -2) of the OS
- Ring -2 code execution would effectively bypass security protections at all other execution levels and allow an attacker to install a persistent malicious firmware backdoor or implant.



Source: “A New Class of Vulnerabilities in SMI Handlers,”
Figure 1 – Schematic overview of an SMM callout, source: CanSecWest 2015

SMM Callout

```
1 EFI_STATUS __fastcall ChildSwSmiHandler(
2     EFI_HANDLE DispatchHandle,
3     const void *Context,
4     char *CommBuffer,
5     UINTN *CommBufferSize)
6 {
7     EFI_STATUS v5; // rbx
8     EFI_STATUS v6; // rax
9     UINTN v7; // rbx
10    EFI_STATUS result; // rax
11    INTN v9; // rsi
12    EFI_STATUS v10; // r12
13    EFI_HANDLE Buffer; // [rsp+30h] [rbp-40h] BYREF
14    UINTN BufferSize; // [rsp+38h] [rbp-38h] BYREF
15    UINTN NoHandles; // [rsp+40h] [rbp-30h] BYREF
16    EFI_LOADED_IMAGE_PROTOCOL *EfiLoadedImageProtocol; // [rsp+48h] [rbp-28h] BYREF
17    EFI_ACPI_SUPPORT_PROTOCOL *EfiAcpiSupportProtocol; // [rsp+50h] [rbp-20h] BYREF
18    void *Table; // [rsp+58h] [rbp-18h] BYREF
19    UINTN Handle[2]; // [rsp+60h] [rbp-10h] BYREF
20    EFI_ACPI_TABLE_VERSION Version; // [rsp+A0h] [rbp+30h] BYREF
21
22    if ( !CommBuffer || !CommBufferSize )
23        return 0i64;
24    if ( *(_DWORD *)CommBuffer == 1 )
25    {
26        Buffer = 0i64;
27        if ( gBS->LocateHandleBuffer(ByProtocol, &EFI_ATATA_PASS_THRU_PROTOCOL_GUID, 0i64, &NoHandles, (EFI_HANDLE **)&Buffer) )
28        {
29            v5 = 0x8000000000000000Eui64;
30        }
31    }
32 }
```

SwSmi Handler executing code in SMRAM

Necessary conditions for callout:
CommBuffer != NULL
CommBufferSize != NULL
first DWORD of CommBuffer == 1

SwSmi Handler calling out to function in *attacker-controlled* EFI_BOOT_SERVICES table

000013A1 ChildSwSmiHandler:27 (13A1)

SMM Callout

```
1 EFI_STATUS __fastcall ChildSwSmiHandler(
2     EFI_HANDLE DispatchHandle,
3     const void *Context,
4     char *CommBuffer,
5     UINTN *CommBufferSize)
6 {
7     EFI_STATUS v5; // rbx
8     EFI_STATUS v6; // rax
9     UINTN v7; // rbx
10    EFI_STATUS result; // rax
11    INTN v9; // rsi
12    EFI_STATUS v10; // r12
13    EFI_HANDLE Buffer; // [rsp+30h] [rbp-40h] BYREF
14    UINTN BufferSize; // [rsp+38h] [rbp-38h] BYREF
15    UINTN NoHandles; // [rsp+40h] [rbp-30h] BYREF
16    EFI_LOADED_IMAGE_PROTOCOL *EfiLoadedImageProtocol; // [rsp+48h] [rbp-28h] BYREF
17    EFI_ACPI_SUPPORT_PROTOCOL *EfiAcpiSupportProtocol; // [rsp+50h] [rbp-20h] BYREF
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19    UINTN Handle[2]; // [rsp+60h] [rbp-10h] BYREF
20    EFI_ACPI_TABLE_VERSION Version; // [rsp+A0h] [rbp+30h] BYREF
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22    if ( !CommBuffer || !CommBufferSize )
23        return 0i64;
24    if ( *(_DWORD *)CommBuffer == 1 )
25    {
26        Buffer = 0i64;
27        if ( gBS->LocateHandleBuffer(ByProtocol, &EFI_ATATA_PASS_THRU_PROTOCOL_GUID, 0i64, &NoHandles, (EFI_HANDLE **)&Buffer)
28        {
29            v5 = 0x8000000000000000Eui64;
30        }
31    }
32 }
```

Hell yeah

SMM callout exploit dev

Methodology overview, v.1

Adapted from base text: “[Exploiting SMM callout vulnerabilities in Lenovo firmware](#)” by cr4sh

Since SMI Handler is making a call *out* of SMRAM to a function in this data structure -- EFI_BOOT_SERVICES -- and EFI_BOOT_SERVICES can be attacker-controlled, an attacker would need to do the following to exploit this SMM callout and achieve arbitrary code execution in ring -2.

1. Identify the location of the EFI_BOOT_SERVICES data structure in memory
2. Determine the SW SMI which triggers the execution of the callout in vulnerable driver
3. Allocate space for shellcode in memory + save address of shellcode for use in step 4
4. Set the address of the LocateHandleBuffer function within the EFI_BOOT_SERVICES table to point to the address of shellcode (overwrite function pointer of LocateHandleBuffer to redirect code flow)
5. Trigger the SW SMI using the identified SW SMI number identified in step 2.
6. Attacker shellcode is executed in ring -2

SMM Callout exploit v. 1

SMM Callout v.1

Chipsec

- Back to the drawing board

github.com/chipsec/chipsec/issues/461

chipsec / chipsec

Type to search

Code Issues 52 Pull requests 6 Discussions Actions Projects 3 Wiki Sec

ARM support? #461

Open ismaws opened this issue on Oct 20, 2018 · 4 comments

ismaws commented on Oct 20, 2018

This is not an issue, more of a future-release / other tools question:
Does chipsec have any plans to support non-intel architectures?
Are there any other tools specific to check secure cfg or AMD/ARM architectures? also, are there other tools that complement chipsec in its current scope?

ErikBjorge commented on Oct 20, 2018 Member

We do have plans for adding the ability to test other architectures to CHIPSEC. Part of this will require restructuring the driver and configuration file layout and updating the detection process. We also need a simple method for tagging modules so they run only under the appropriate configurations. I am sure we will find other issues as we start to add these features.
If you would like we can discuss potential changes in this issue for now. At some point we may need to track plan/progress on the wiki or some other location.

UEFI Exploit dev: SMM Callouts

Started from ring -2 now we're calling out to an attacker-controlled region of memory

~*There are no binary exploitation mitigations present in the vulnerable SMM/DXE driver but Chipsec won't run on the host machine so now we're reversing the swsmb function in Chipsec and replicating its functionality in C *~

SMM callout exploit dev

Methodology overview, v.2

Since SMI Handler is making a call *out* of SMRAM to a function in this data structure -- EFI_BOOT_SERVICES -- and EFI_BOOT_SERVICES can be attacker-controlled, an attacker would need to do the following to exploit this SMM callout and achieve arbitrary code execution in ring -2.

1. Identify the location of the EFI_BOOT_SERVICES data structure in memory
2. Determine the SW SMI which triggers the execution of the callout in vulnerable driver
3. Allocate space for shellcode in memory + save address of shellcode for use in step 4
4. Set the address of the LocateHandleBuffer function within the EFI_BOOT_SERVICES table to point to the address of shellcode (overwrite function pointer of LocateHandleBuffer to redirect code flow)
5. Trigger the SW SMI using the identified SW SMI number identified in step 2.
 - A. Set up communication buffer
 - B. SmmCommunicate()
 - C. Write to I/O ports 0xb2 and 0xb3
6. Attacker shellcode is executed in ring -2

```
[FS0:\> load SmmCalloutDriver.efi
Locate Handle Buffer address: 000000007EED0110
Locate Handle Buffer offset: 000000007EED0108
EFI SYSTEM TABLE pointer address: 7E5EC018
EFI BOOT SERVICES TABLE pointer address is: 7EEF6F60

EFI_LOADED_IMAGE_PROTOCOL pointer address is: 7EED0118

Found Runtime Data address range in memory map: 000000007E4ED000 - 000000007E5ED000 of size 000000000100000
Found Runtime Code address range in memory map: 000000007E5ED000 - 000000007E6ED000 of size 000000000100000
potential smmc found at: 7E6CB140
potential smmc found at: 7E6CB140
Testing smmc_loc value, found at: 7E6CB140
Vulnerable gBS function pointer LocateHandleBuffer is at: 7EEF7098
Testing ... confirming gBS function pointer LocateHandleBuffer is at: 7EEF7098
Vulnerable gBS LocateHandleBuffer function handler is at: 7EED70AF
Size of shellcode 000000000000091
shellcode address: 7EED0143
alt shellcode address: 000000007EED00E0
SMM Base2 protocol is located at 7E6CB0E0
SMM communication protocol is located at 7E6CB400
```

SMM Callout v. 2 Chipsec? Never heard of her.

UEFI Exploit dev: SMM Callouts

where's my exploit uWu

- I found this vulnerability on a time-boxed pentesting engagement at work
- I wrote my first two versions of the PoC and was ready to try it
- On the last day of testing, the other consultants on my team found a vulnerability and successfully exploited it!
- ... which ended up bricking the device.
- So while the client was happy and we delivered high-impact findings, I wrote a PoC that I haven't tested yet on real hardware. More importantly, I don't have a demo video



```
[FS0:\> load SmmCalloutDriver.efi
Locate Handle Buffer address: 000000007EED0110
Locate Handle Buffer offset: 000000007EED0108
EFI SYSTEM TABLE pointer address: 7E5EC018
EFI BOOT SERVICES TABLE pointer address is: 7EEF6F60

EFI_LOADED_IMAGE_PROTOCOL pointer address is: 7EED0118

Found Runtime Data address range in memory map: 000000007E4ED000 - 000000007E5ED000 of size 0000000000100000
Found Runtime Code address range in memory map: 000000007E5ED000 - 000000007E6ED000 of size 0000000000100000
potential smmc found at: 7E6CB140
potential smmc found at: 7E6CB140
Testing smmc_loc value, found at: 7E6CB140
Vulnerable gBS function pointer LocateHandleBuffer is at: 7EEF7098
Testing ... confirming gBS function pointer LocateHandleBuffer is at: 7EEF7098
Vulnerable gBS LocateHandleBuffer function handler is at: 7EED70AF
Size of shellcode 000000000000091
shellcode address: 7EED0143
alt shellcode address: 000000007EED00E0
SMM Base2 protocol is located at 7E6CB0E0
SMM communication protocol is located at 7E6CB400
AllocatePool for Smm Comm Buffer successful, located at: 7E5B5018
Testing smm_comm_buffer_offset address: 7E6CB178
Testing smm_comm_buffer_sz_offset address: 7E6CB180
comm buffer data is located at address: 7EED00CC
SmmComm Communicate call returned status: 0x0000000F DataSize is: 1C
Testing ... confirming gBS function pointer LocateHandleBuffer now points to shellcode at: 7EED0143
Testing ... confirming gBS function pointer LocateHandleBuffer now points to shellcode at: 7EED0143
Testing ... confirming gBS function pointer LocateHandleBuffer again points to original address of LocateHandleBuffer() function at: 7EED70AF
Image 'FS0:\SmmCalloutDriver.efi' error in StartImage: Access Denied
```

SMM Callout v. 2 Chipsec? Never heard of her.

UEFI Exploit dev: SMM Callouts

where's my exploit uWu

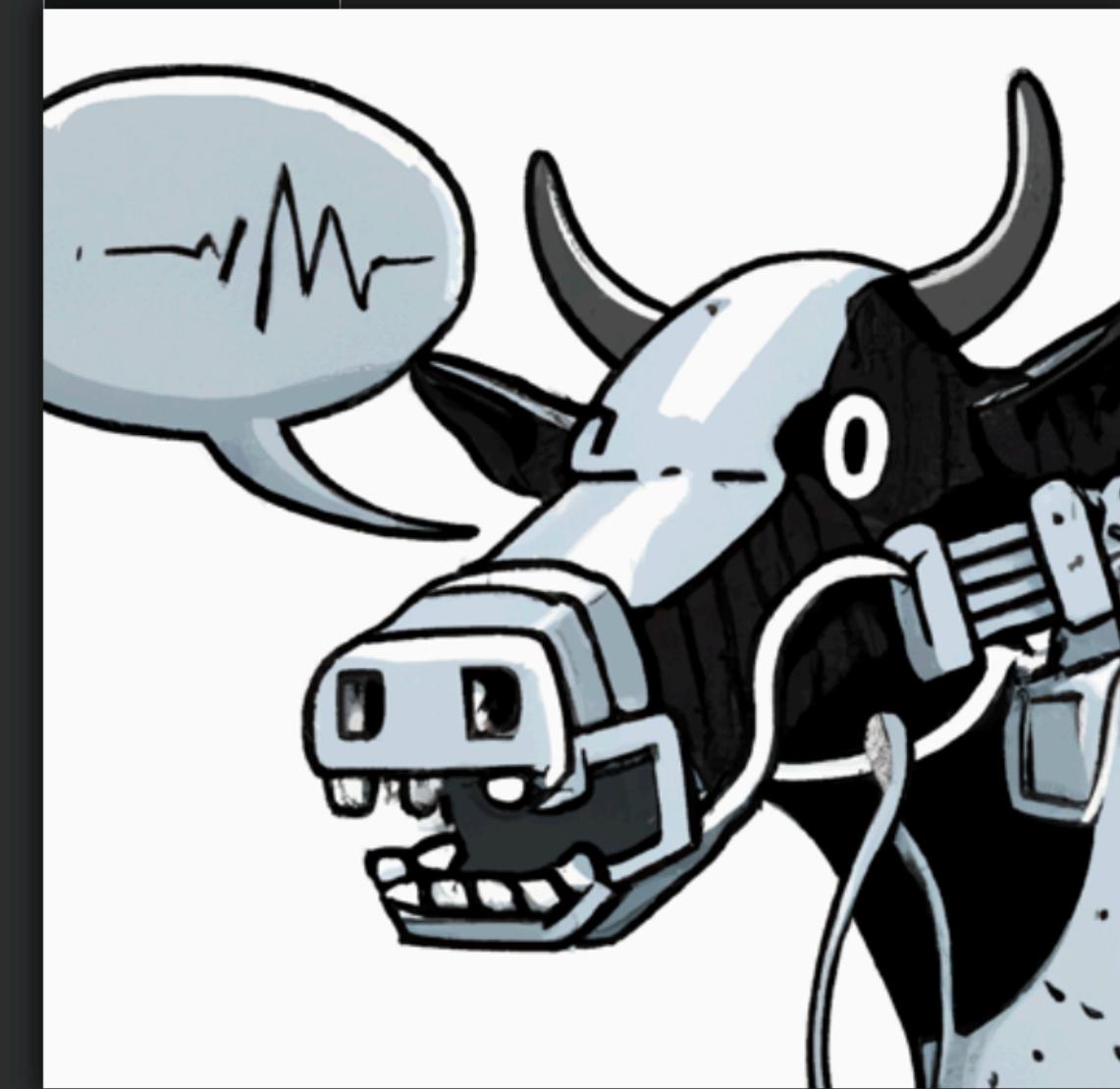
- This vulnerability is also present in Fujitsu Lifebook e449/e459, version
 - Possibly viable option for hardware testing?
 - Only available option for acquiring the device promptly was on Craigslist...
- However, the exploit I wrote initially was for a relatively simple case
- There were none of the typical mitigations that make SMM callout vulnerabilities more difficult to exploit (though not dramatically so), e.g. SMM_CODE_CHK_EN

```
PS C:\Users\ic3\fwhunt> py.exe ./fwhunt_scan_analyzer.py scan-firmware --rules_dir C:\Users\ic3\FwHunt\rules\ C:\Users\ic3\Desktop\FT  
S_BIOSAdminPackLIFEBOOKE459E449_107_1250951\ DOS\ESRV107.ROM  
Scanner result IntelAlderLakeLeak (variant: default) No threat detected  
Scanner result BRLY-MsileakBootGuardKeys (variant: default) No threat detected  
Scanner result MsileakFwCapsuleKeys (variant: default) No threat detected  
Scanner result OemUnlockKeyLeak (variant: default) No threat detected  
[I] Specify volume_guids in IntelAlderLakeLeak or use scan command  
[I] Specify volume_guids in BRLY-MsileakBootGuardKeys or use scan command  
[I] Specify volume_guids in MsileakFwCapsuleKeys or use scan command  
[I] Specify volume_guids in OemUnlockKeyLeak or use scan command  
[I] Specify volume_guids in BlackLotusBootkit or use scan command  
[I] Specify volume_guids in ESPecker or use scan command  
Scanner result BRLY-2022-021 (variant: SecureBootEnforce-SecureBoot variant) No threat detected (BdsDxe)  
Scanner result BRLY-2022-021 (variant: SecureBoot-RestoreBootSettings variant) No threat detected (BdsDxe)  
Scanner result BRLY-2021-015 (variant: default) FwHunt rule has been triggered and threat detected! (IdeBusDxe)  
Scanner result BRLY-2021-020 (variant: default) FwHunt rule has been triggered and threat detected! (IdeBusDxe)  
Scanner result BRLY-2021-009 (variant: variant1) No threat detected (AhciBusDxe)  
Scanner result BRLY-2021-009 (variant: variant2) No threat detected (AhciBusDxe)  
Scanner result BRLY-2021-016 (variant: default) FwHunt rule has been triggered and threat detected! (AhciBusDxe)  
Scanner result BRLY-2021-018 (variant: default) FwHunt rule has been triggered and threat detected! (AhciBusDxe)  
Scanner result BRLY-2021-025 (variant: default) No threat detected (AhciBusDxe)  
Scanner result BRLY-2021-026 (variant: default) No threat detected (AhciBusDxe)  
Scanner result BRLY-2021-010 (variant: variant1) No threat detected (NvmExpressDxe)  
Scanner result BRLY-2021-010 (variant: variant2) No threat detected (NvmExpressDxe)  
Scanner result BRLY-2021-017 (variant: default) FwHunt rule has been triggered and threat detected! (NvmExpressDxe)  
Scanner result BRLY-2021-030 (variant: default) No threat detected (NvmExpressDxe)  
Scanner result BRLY-2021-031 (variant: default) No threat detected (UsbCoreDxe)  
Scanner result BRLY-2021-027 (variant: default) FwHunt rule has been triggered and threat detected! (FvbServicesRuntimeDxe)  
Scanner result BRLY-2022-025 (variant: Protocol installation in FwBlockServiceSmm) No threat detected (FvbServicesRuntimeDxe)  
Scanner result BRLY-2022-025 (variant: Protocol usage in FvbServicesRuntimeDxe) No threat detected (FvbServicesRuntimeDxe)  
Scanner result BRLY-2022-026 (variant: Protocol installation in FwBlockServiceSmm) No threat detected (FvbServicesRuntimeDxe)  
Scanner result BRLY-2022-026 (variant: Protocol usage in FvbServicesRuntimeDxe) No threat detected (FvbServicesRuntimeDxe)  
Scanner result BRLY-2021-011 (variant: variant1) FwHunt rule has been triggered and threat detected! (FwBlockServiceSmm)  
Scanner result BRLY-2021-011 (variant: variant2) No threat detected (FwBlockServiceSmm)  
Scanner result BRLY-2022-017 (variant: default) No threat detected (FwBlockServiceSmm)  
Scanner result BRLY-2022-018 (variant: default) No threat detected (FwBlockServiceSmm)  
Scanner result BRLY-2022-024 (variant: default) No threat detected (FwBlockServiceSmm)  
Scanner result BRLY-2022-025 (variant: Protocol installation in FwBlockServiceSmm) No threat detected (FwBlockServiceSmm)  
Scanner result BRLY-2022-025 (variant: Protocol usage in FvbServicesRuntimeDxe) No threat detected (FwBlockServiceSmm)  
Scanner result BRLY-2022-026 (variant: Protocol installation in FwBlockServiceSmm) No threat detected (FwBlockServiceSmm)  
Scanner result BRLY-2022-026 (variant: Protocol usage in FvbServicesRuntimeDxe) No threat detected (FwBlockServiceSmm)  
Scanner result BRLY-2022-023 (variant: default) No threat detected (PnpSmm)  
Scanner result BRLY-2021-028 (variant: default) No threat detected (HddPassword)  
Scanner result BRLY-2021-029 (variant: default) No threat detected (HddPassword)  
Scanner result BRLY-2021-023 (variant: default) No threat detected (StorageSecurityCommandDxe)  
Scanner result BRLY-2021-024 (variant: default) No threat detected (StorageSecurityCommandDxe)  
Scanner result BRLY-2021-022 (variant: default) No threat detected (Int15ServiceSmm)  
Scanner result BRLY-2021-012 (variant: default) No threat detected (SdHostDriver)
```

UEFI Exploit dev: SMM Callouts

where's my exploit uWu

- This vulnerability is also present in Fujitsu Lifebook e449/e459, version
 - Possibly viable option for hardware testing?
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SMM Cowsay 1 - 442 points
"cybernetic talking cow"
systems smm

One of our engineers thought it would be a good idea to write Cowsay inside SMM. Then someone outside read out the trade secret (a.k.a. flag) stored at physical address 0x44440000, and since it could only be read from SMM, that can only mean one thing: it... was a horrible idea.

```
$ stty raw -echo isig; nc smm-cowsay-1.chal.uiuc.tf 1337
```

author: YiFei Zhu

[Download](#)

UEFI Exploit dev

Make-your-own-adventure CTF continued

- While testing and demo-ing the PoC on real hardware was not realistically feasible, there is that one CTF challenge I mentioned...
- SMM Cowsay parts 1, 2 and 3 from UIUCTF 2022: [archived 2022 CTF]: <https://2022.uiuc.tf/challenges>
- [Shoutout to the author of this challenge, Yifei Zhu (@zhuyifei1999 on GitHub)]: This CTF challenge has 3 levels of difficulty
 - SMM Cowsay I: has 0 SMM exploit mitigations applied
 - SMM Cowsay II: 1 mitigation
 - SMM Cowsay III: 2 mitigations (ASLR and SMM_CODE_CHK_EN)

Challenge 0 Solves ×



SMM Cowsay 3 - 500 points
"Mona Lisa as a cow"
systems smm extreme

We fired that engineer. Unfortunately, other engineers refused to touch this code, but instead suggested to integrate some ASLR code found online. Additionally, we hardened the system with SMM_CODE_CHK_EN and kept DEP on. Now that we have the monster combination of ASLR+DEP, we should surely be secure, right?

```
$ stty raw -echo isig; nc smm-cowsay-3.chal.uiuc.tf 1337
```

author: YiFei Zhu

UEFI Exploit dev: SMM Callouts

Mitigations: SMM_CODE_CHK_EN

- SMM_CODE_CHK_EN: SMM Callout mitigation that aims to prevent SMM Callouts
 - If SMM_CODE_CHK_EN is enabled, then SMM code must be located within ranges defined by SMRR (System-Management Range Register); if SMM code is executed outside of this range, unrecoverable exception is triggered
 - Recall: Entering SMM is triggered by an SMI, which includes *saving execution context of code running outside of SMRAM*
 - After execution of SMI handler code, RSM instruction triggers the restoration of the initial saved state
 - What if we just... polluted the SMI save state with a ROP chain and bypassed SMM_CODE_CHK_EN?

UEFI Exploit dev: SMM Callouts

Mitigations: SMM_CODE_CHK_EN

- **Requires building a ROP chain and calculating SMBASE**
- Run ropper on your target UEFI driver, find some gadgets, build your exploit
- A few resources on bypassing SMM_CODE_CHK_EN with ROP:
 - Binarly: “The Dark Side of UEFI: A technical Deep-Dive into Cross-Silicon Exploitation”
<https://www.binarly.io/blog/the-dark-side-of-uefi-a-technical-deep-dive-into-cross-silicon-exploitation>
 - Syntactiv: “Code Checkmate in SMM” by Bruno Pujos: <https://www.synacktiv.com/en/publications/code-checkmate-in-smm>
 - cr4sh: “Exploiting AMI Aptio firmware on example of Intel NUC”
<http://blog.cr4.sh/2016/10/exploiting-ami-aptio-firmware.html>
 - Many more examples

UEFI Exploit Dev

tips + tricks

- It's helpful to think about UEFI as a separate ecosystem between the OS and onboard (i.e. SPI flash chip-resident) firmware. It operates like an intermediary OS in and of itself. Thus, in order to write effective UEFI-targeting exploits, we have to understand how to manipulate data structures within UEFI.
- The offsets of data structures in UEFI are consistent, so if we know which data structure + protocol we want to target, we can write a test program to find those offsets, then define them with macros in our final exploit
 - e.g. BootServices-> HandleProtocol is at offset 0x98 in the EFI_BOOT_SERVICES table
- We will have easy access to data structures right away:
 - e.g. on x64, EFI_SYSTEM_TABLE * is in RDX and EFI_IMAGE_HANDLE is in RCX upon program invocation
- We can also target other data structures/protocols (i.e. EFI_FILE_PROTOCOL for file operations, EFI_SIMPLE_FILESYSTEM_PROTOCOL for filesystem operations, etc.) to hook/inject our payload
- Binary exploit mitigations (i.e. ASLR, stack canaries, etc.) are not used consistently in UEFI firmware implementations (sometimes not even at all), so once you understand the UEFI ecosystem (even vaguely) then writing exploits is pretty straightforward

Challenges/hurdles for UEFI Exploit Dev

Honey, you bricked the machine.

- The edk2 build system and I have a blood feud
- QEMU and the Sisyphean task of UEFI firmware testing/debugging in emulators
- Chipsec does not work on M-series Mac machines, so the de-facto platform firmware testing framework both doesn't work on architectures and can't be used for testing/developing exploits for other architectures
- Debugging on real hardware has its own challenges:
 - It can be cost-prohibitive – you will brick machines, you will break things. That's how these things go.
 - Documentation may not be available for the architecture you want to target (i.e. arm64 or EBC)

UEFI Exploit Dev is amazing and here's why

I love UEFI it's my favorite

- Exploit mitigations that are common on modern OSes (i.e. ASLR, DEP, stack canaries, etc.) aren't always implemented or implemented fully on UEFI BIOS firmwares
- If binary exploit mitigations are applied, bypass techniques aren't unfamiliar (i.e. ROP/JOP chains for bypassing SMM Code_Check_En)
- UEFI is a complex ecosystem -> error-prone and incomplete coverage of applied protections
- UEFI is so expansive and unexplored that it offers an environment for creativity in research and exploit development
- Firmware + hardware + low-level exploit dev + cross-architecture exploits == <3

“Just as fragments of a vessel, in order to be fitted together, must correspond to each other in the tiniest details but need not resemble each other, so translation, instead of making itself resemble the meaning of the original, must lovingly, and in detail, fashion in its own language a counterpart to the original's mode of intention, in order to make both of them recognizable as fragments of a vessel, as fragments of a greater language.”

Walter Benjamin, “The Task of the Translator,” translated by Steven Rendall, page 161.

Q & A

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