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BRIEFINGS

Safeguarding UEFI Ecosystem: Firmware Supply Chain is Hard(coded)

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Who are we?

Alex Tereshkin
@AlexTereshkin

- BlackHat speaker and trainer
- Reverse engineer
- UEFI security researcher
- More...

Alex Matrosov
@matrosov

- Security REsearcher since 1997
- Conference speaker and trainer
- Breaking all shades of firmware
- codeXplorer and efiXplorer plugins
- Author "Bootkits and Rootkits" book
- More...

Adam ‘pi3’ Zabrocki
@Adam_pi3

- Phrack author
- Bughunter (Hyper-V, Linux kernel, OpenSSH, Apache, gcc SSP, more…)
- Creator and a developer of Linux Kernel Runtime Guard (LKRG)
- More…

NVIDIA Product Security Team

Outline

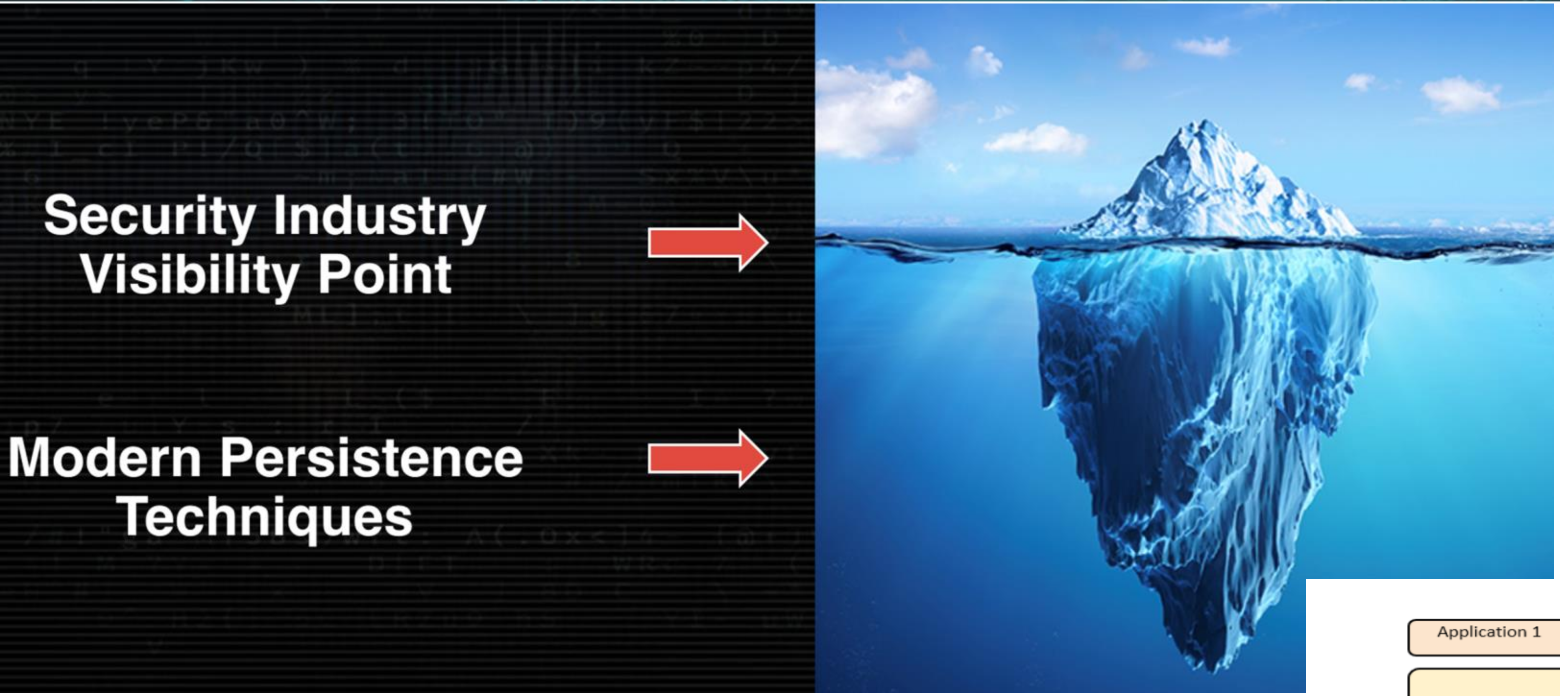
- Research Motivation

- UEFI Ecosystem Firmware Supply Chain is Hard(coded)
- Attacking (pre)EFI Ecosystem

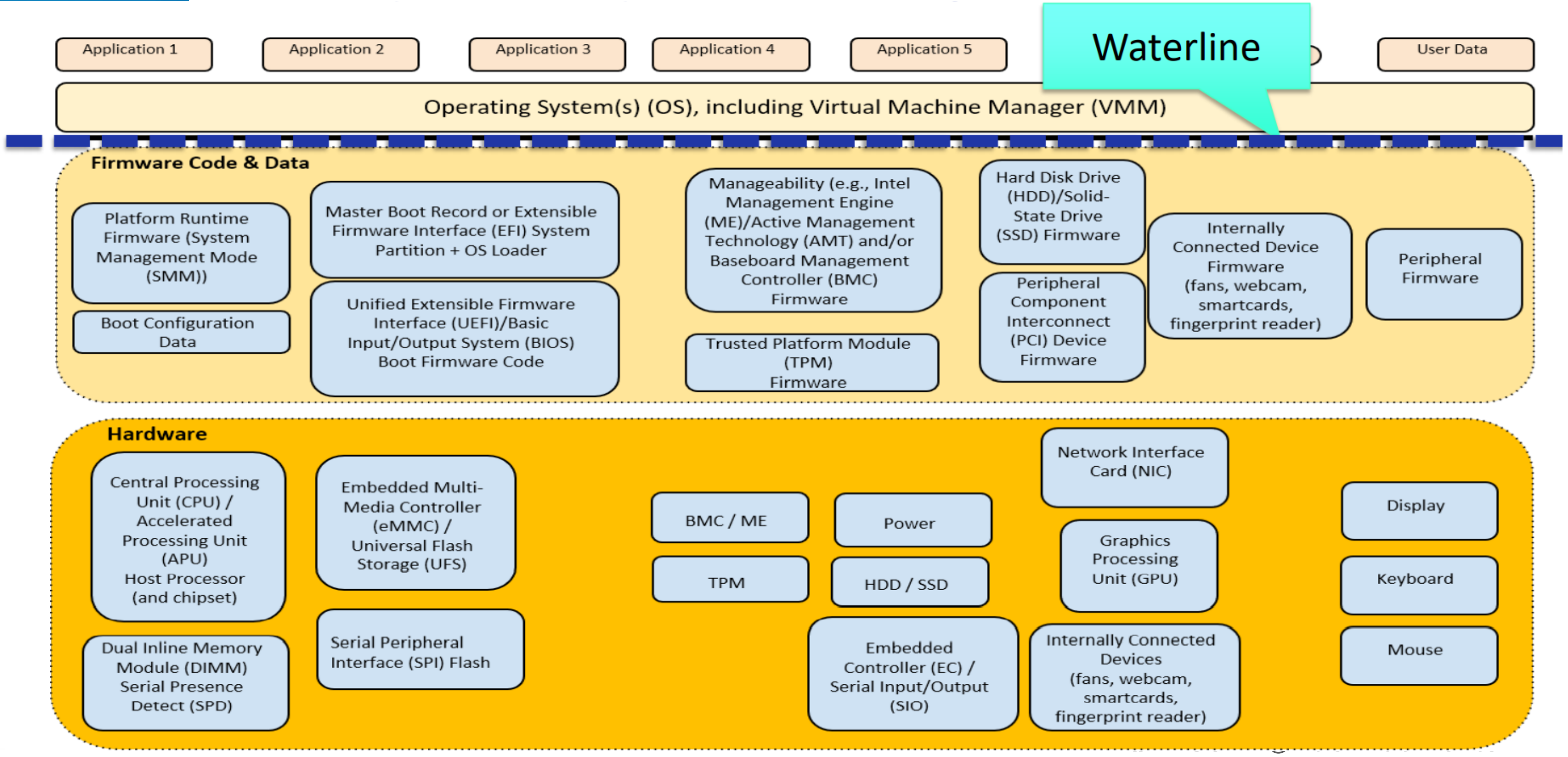
- Safeguarding UEFI Ecosystem

- Summary

Motivation for This Research



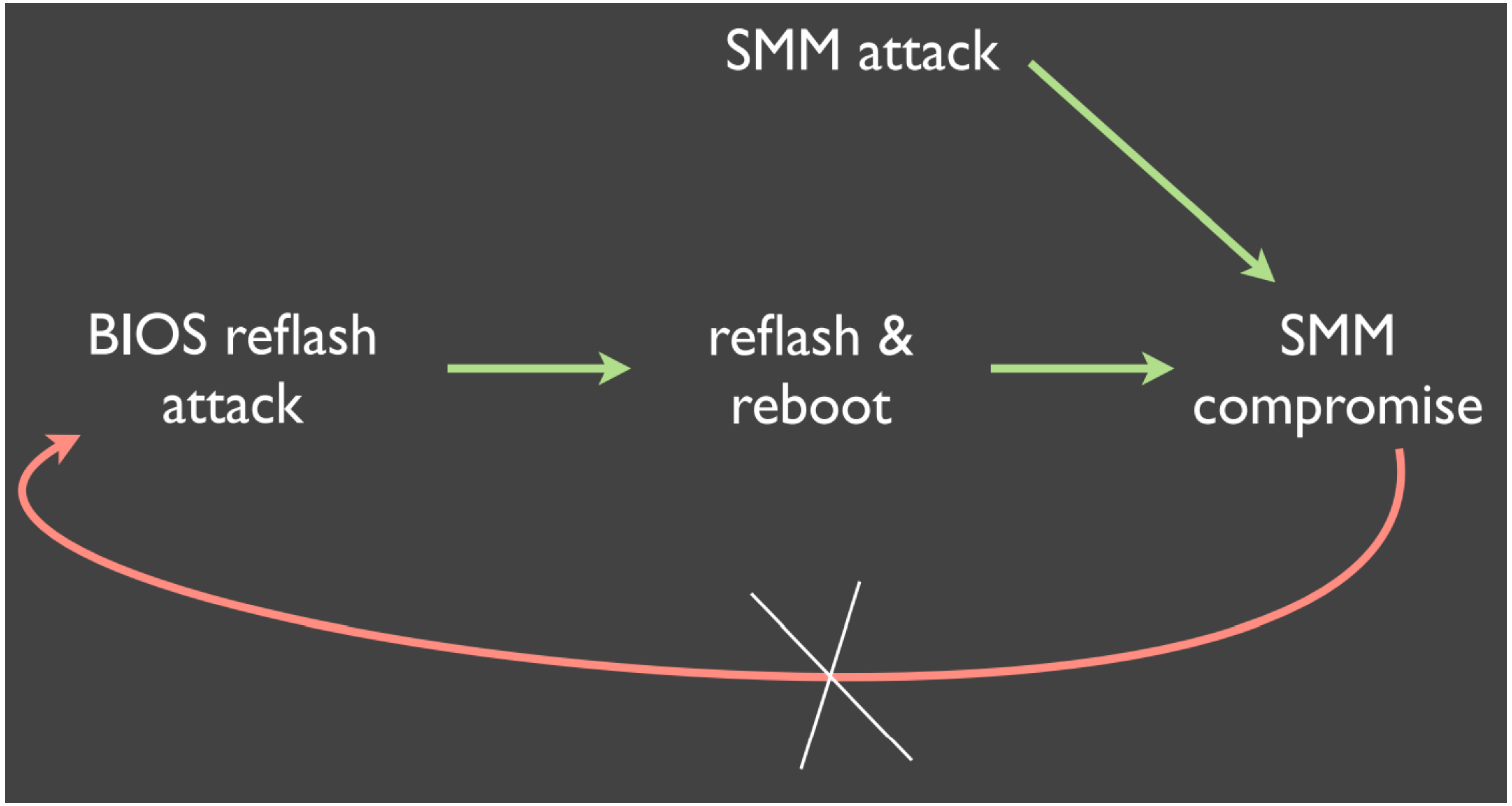
[The Evolution of Advanced Threats: REsearchers Arms Race]



[DHS-CISA-Strategy-to-Fix-Vulnerabilities-Below-the-OS-Among-Worst-Offenders]

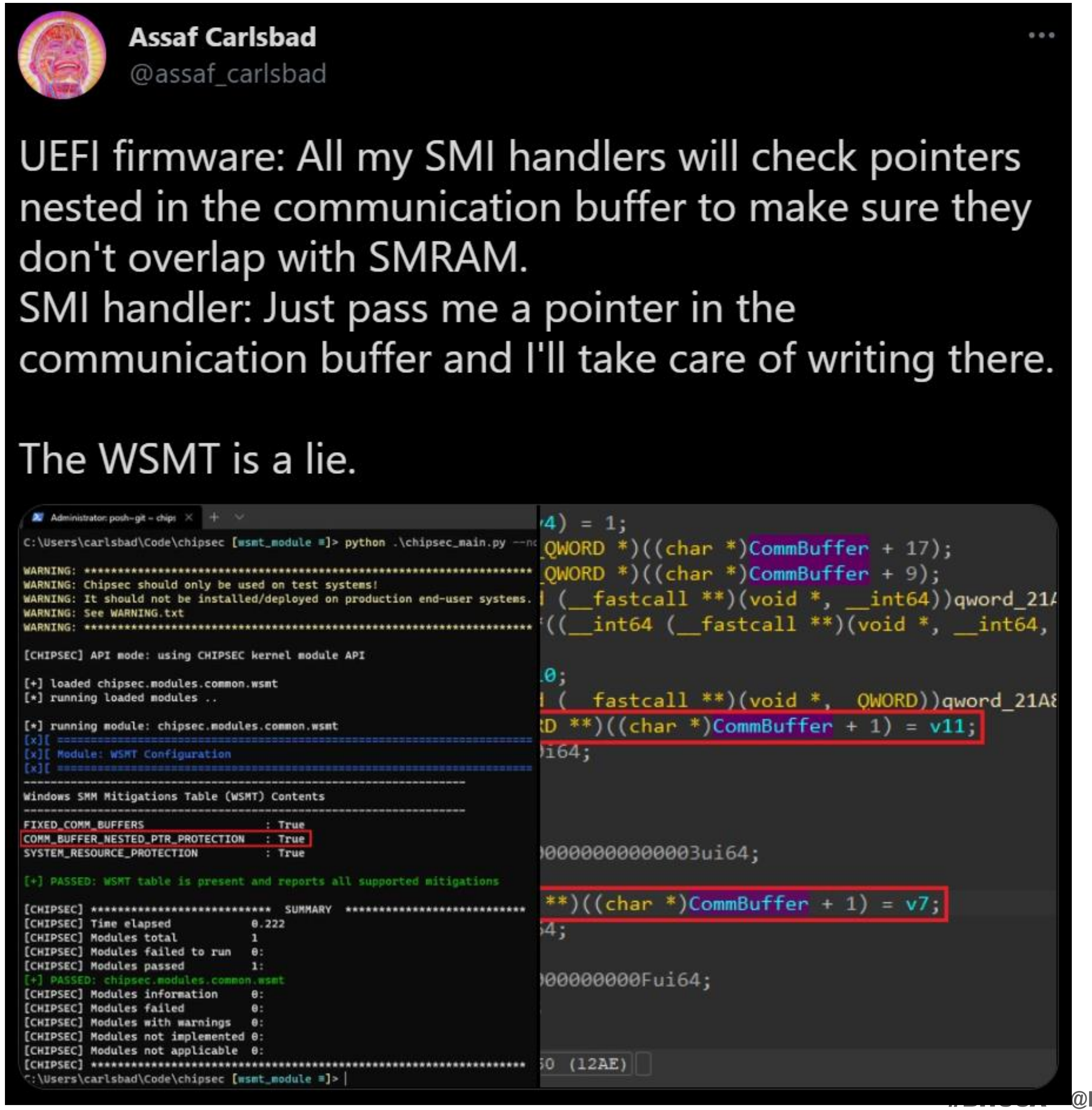
Good Old Days of Attacking BIOS

Does anything change?



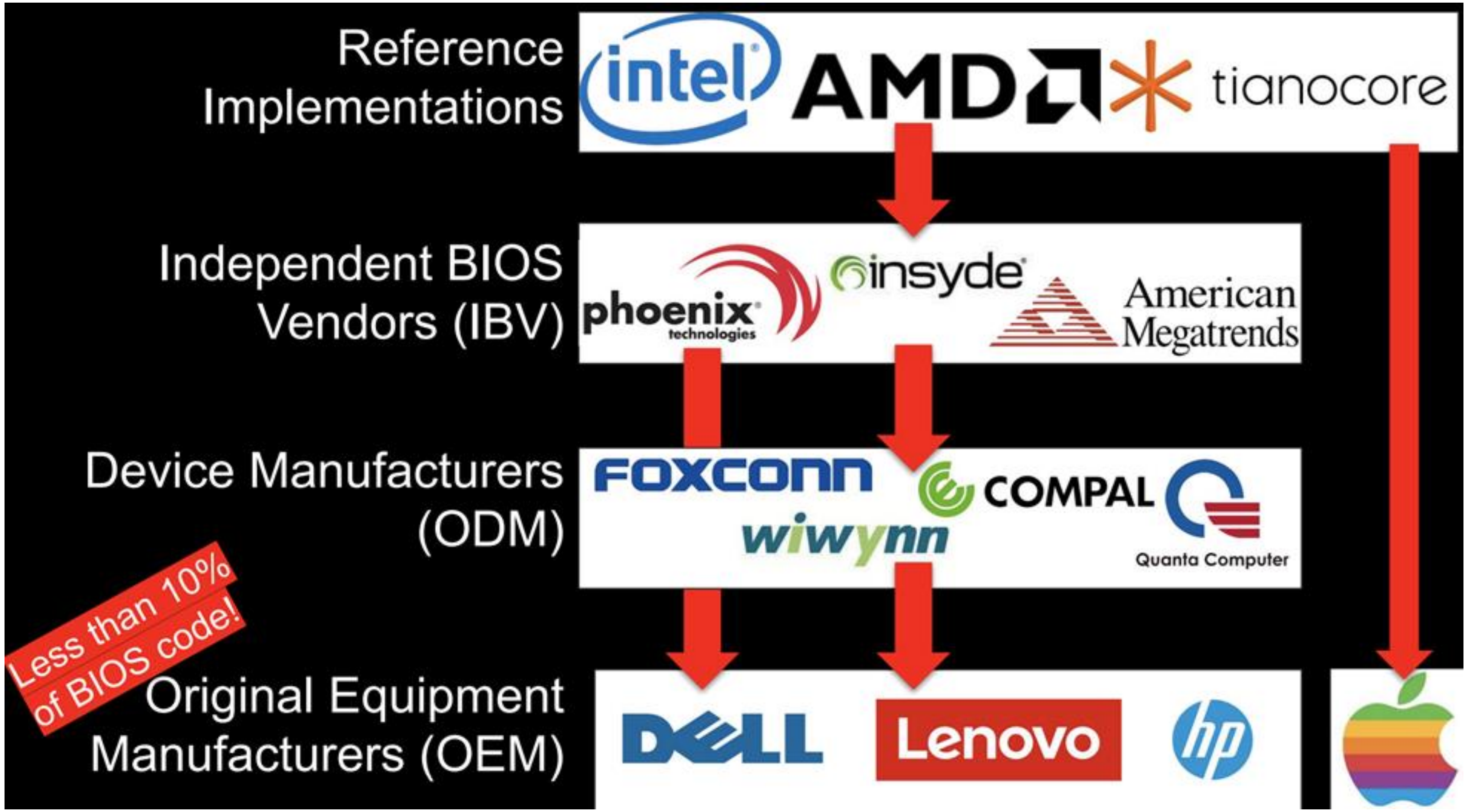
BHUSA09-Wojtczuk-AtkIntelBios-SLIDES

WSMT (Windows SMM Security Mitigation Table) has a static nature by design. Having the mitigation enabled doesn't mean this mitigation is used or configured correctly.



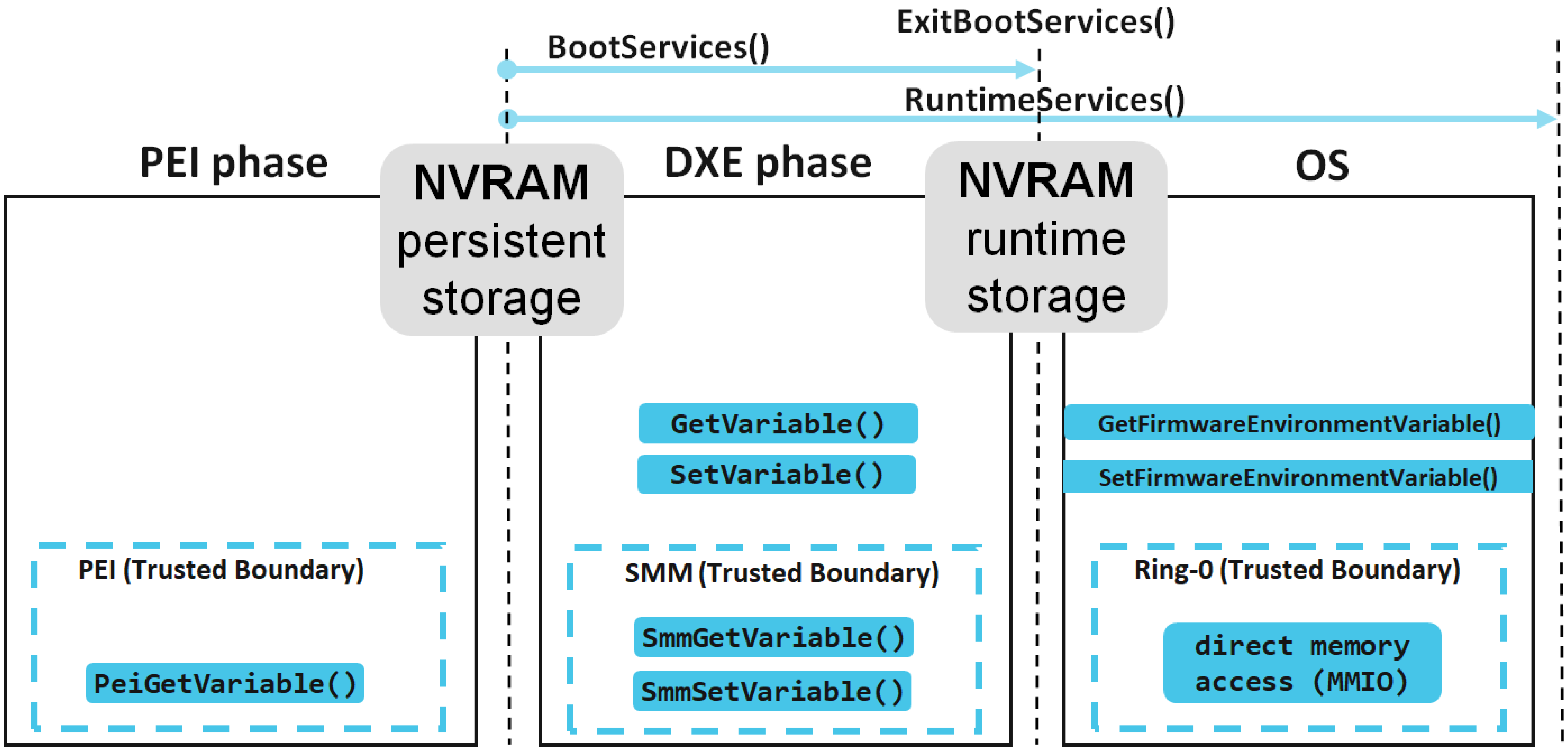
UEFI Ecosystem Firmware Supply Chain is Hard(coded)

UEFI Ecosystem Firmware Supply Chain is Hard(coded)



[Roots of Trust and Attestation | Trammell Hudson]

NVRAM Variables Access During Boot Flow



NVRAM PEI/DXE/SMM Threat Model

Attacker Model:

The local attacker uses privileged host OS access to trigger the vulnerability gaining PEI/DXE stage code execution in System Management Mode (SMM).

Potential Impact:

PEI/DXE code execution in SMM context allows potential installation of **persistent implants** in the NVRAM SPI flash region. Implant persistence across OS installations, can further **bypass Secure Boot** attacking guest VM's in bare metal cloud deployments.

NVRAM Persistence on SPI Flash

- NVRAM region is not protected by Intel Boot Guard and can be abused by attacker with physical access (supply chain vector).

BIOS region	Region	BIOS	
FA4974FC-AF1D-4E5D-BDC5-DACD6D27BAEC	Volume	FFSv2	
NVRAM	File	Raw	NVAR store
4599D26F-1A11-49B8-B91F-858745CFF824	NVAR entry	Full	StdDefaults
EfiSetupVariableGuid	NVAR entry	Full	Setup
EfiGlobalVariableGuid	NVAR entry	Full	PlatformLang
EfiGlobalVariableGuid	NVAR entry	Full	Timeout
C811FA38-42C8-4579-A9BB-60E94EDDFB…	NVAR entry	Full	AMITSESetup
90D93E09-4E91-4B3D-8C77-C82FF10E3C…	NVAR entry	Full	CpuSmm
5432122D-D034-49D2-A6DE-65A829EB4C…	NVAR entry	Full	MeSetupStorage
64192DCA-D034-49D2-A6DE-65A829EB4C…	NVAR entry	Full	IccAdvancedSetupDataVar
69ECC1BE-A981-446D-8EB6-AF0E53D06C…	NVAR entry	Full	NewOptionPolicy
D1405D16-7AFC-4695-BB12-41459D3695…	NVAR entry	Full	NetworkStackVar
EfiSetupVariableGuid	NVAR entry	Full	SdioDevConfiguration
EfiSetupVariableGuid	NVAR entry	Full	UsbSupport

- Arbitrary code execution via *GetVariable() and memory leak over SetVariable()* is common, attacker can modify persistent NVRAM storage and install fileless DXE/SMM/PEI implant (shellcode).

Most security solutions inspect only UEFI drivers!

UEFI RE Methodology: Hex-Rays+ efiXplorer

```
__int64 (__fastcall *__fastcall sub_2BC(void *a1, EFI_SYSTEM_TABLE *a2))()
{
  EFI_RUNTIME_SERVICES *v2; // rax
  EFI_BOOT_SERVICES *v3; // rbx
  __int64 i; // rax
  char v6; // cl
  char v7; // bl
  __int64 v8; // rax
  __int64 v9; // rdx
  __int64 (__fastcall *result)(); // rax
  UINTN DataSize; // [rsp+50h] [rbp+20h] BYREF
  __int64 v12; // [rsp+58h] [rbp+28h] BYREF

  v2 = a2->RuntimeServices;
  v3 = a2->BootServices;
  AgentHandle = a1;
  gST_13488 = a2;
  gBS_13490 = v3;
  gRT_134A0 = v2;
  if ( sub_38D0(&EFI_TSC_FREQUENCY_GUID_110E0, &DataSize) )
  {
    (v3->AllocatePool)(4i64, 8i64, &DataSize);
    *DataSize = sub_3C7C();
    gBS_13490->InstallConfigurationTable(&EFI_TSC_FREQUENCY_GUID_110E0, DataSize);
    v3 = gBS_13490;
  }
  qword_134A8 = *DataSize;
  (v3->LocateProtocol)(&EFI_HII_STRING_PROTOCOL_GUID_10F50, 0i64, &qword_134C0);
  gBS_13490->LocateProtocol(&EFI_HII_DATABASE_PROTOCOL_GUID_BD00, 0i64, &Interface);
  gBS_13490->LocateProtocol(&EFI_HII_CONFIG_ROUTING_PROTOCOL_GUID_BD10, 0i64, &qword_134D0);
  gBS_13490->LocateProtocol(&EFI_HII_FONT_PROTOCOL_GUID_BCD0, 0i64, &qword_134B8);
  gBS_13490->LocateProtocol(&EFI_HII_IMAGE_PROTOCOL_GUID_BD80, 0i64, &qword_134B0);
  sub_38D0(&EFI_HOB_LIST_GUID_BD60, &qword_134D8);
  sub_38D0(&DXE_SERVICES_TABLE_GUID_10EE0, &qword_134E0);
  qword_14350 = sub_B2B0(&EFI_PHYSICAL_PRESENCE_DATA_GUID_10F20, a1, &unk_BDE0, 0i64);
  dword_13CA8 = *(qword_134D8 + 12);
```

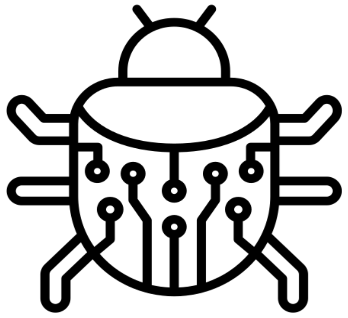
```
[efiXplorer] ============================================================
[efiXplorer] Looking for GetVariable stack/heap overflow
[efiXplorer] GetVariable_1: 0x0000000000000374, GetVariable_2: 0x00000000000004ff
[efiXplorer] GetVariable_1: 0x00000000000004ff, GetVariable_2: 0x000000000000050c
[efiXplorer] GetVariable_1: 0x000000000000050c, GetVariable_2: 0x0000000000000565
[efiXplorer] GetVariable_1: 0x0000000000000565, GetVariable_2: 0x00000000000006f3
[efiXplorer] GetVariable_1: 0x00000000000006f3, GetVariable_2: 0x0000000000000736
[efiXplorer]       overflow can occur here: 0x0000000000000736
[efiXplorer] GetVariable_1: 0x0000000000000736, GetVariable_2: 0x0000000000000960
[efiXplorer] GetVariable_1: 0x0000000000000960, GetVariable_2: 0x0000000000000c4f
[efiXplorer] GetVariable_1: 0x0000000000000c4f, GetVariable_2: 0x0000000000000c5c
[efiXplorer] GetVariable_1: 0x0000000000000c5c, GetVariable_2: 0x0000000000000c69
[efiXplorer] GetVariable_1: 0x0000000000000c69, GetVariable_2: 0x0000000000000d58
[efiXplorer] GetVariable_1: 0x0000000000000d58, GetVariable_2: 0x0000000000000ef9
[efiXplorer] GetVariable_1: 0x0000000000000ef9, GetVariable_2: 0x0000000000001337
[efiXplorer] GetVariable_1: 0x0000000000001337, GetVariable_2: 0x0000000000001344
[efiXplorer] GetVariable_1: 0x0000000000001344, GetVariable_2: 0x0000000000001351
[efiXplorer] GetVariable_1: 0x0000000000001351, GetVariable_2: 0x0000000000001396
[efiXplorer] GetVariable_1: 0x0000000000001396, GetVariable_2: 0x000000000000149b
[efiXplorer] GetVariable_1: 0x000000000000149b, GetVariable_2: 0x0000000000001530
[efiXplorer] GetVariable_1: 0x0000000000001530, GetVariable_2: 0x00000000000015d3
[efiXplorer] GetVariable_1: 0x00000000000015d3, GetVariable_2: 0x00000000000016d8
[efiXplorer] GetVariable_1: 0x00000000000016d8, GetVariable_2: 0x0000000000001729
[efiXplorer] GetVariable_1: 0x0000000000001729, GetVariable_2: 0x000000000000181d
[efiXplorer] ============================================================
[efiXplorer] Looking for SmmGetVariable stack/heap overflow
[efiXplorer] gSmmVar->SmmGetVariable calls finding via EFI_SMM_VARIABLE_PROTOCOL_GUID
[efiXplorer] gSmmVar->SmmGetVariable function finding from 0x0000000000001A60 to 0x0000000000001EE0
[efiXplorer] can't find a EFI_SMM_VARIABLE_PROTOCOL_GUID guid
[efiXplorer] less than 2 GetVariable calls found
[efiXplorer] ============================================================
```


[binarly-io/efiXplorer: IDA plugin for UEFI firmware analysis and reverse engineering automation]

DSA-2021-103: The Story of Two Buffer Overflows

- MirrorRequest:

NVRAM variable insecure memset leads to stack overflow.



- AepErrorLog:

NVRAM variable mistake in parsing routine leads to heap overflow.

DSA-2021-103: Dell PowerEdge Server Security Update for BIOS Vulnerabilities

CVE-2021-21555 (DSA-2021-103): AepErrorLog NVRAM variable

mEraseRecordShare buffer is allocated on heap.

AepErrorLog NVRAM variable is controlled by attacker.

A mistake in variable parsing leads to heap overflow resulting in execution of an attacker controlled payload.

```
__int64 __fastcall GetEraseLog__vuln()
{
  unsigned __int8 i; // [rsp+30h] [rbp-28h]
  __int64 Status; // [rsp+38h] [rbp-20h]
  UINTN DataSize; // [rsp+40h] [rbp-18h] BYREF
  char Tries; // [rsp+48h] [rbp-10h]
  BOOL v5; // [rsp+4Ch] [rbp-Ch]

  Tries = 3;
  DataSize = 0i64;
  if ( is_debug() && is_not_zero(64) )
    dbgprint(64, "%a(): Start\n", "GetEraseLog");
  do
  {
    Status = gRuntimeServices->GetVariable(L"AepErrorLog", &VendorGuid, 0i64, &DataSize, mEraseRacordShare);
    --Tries;
    v5 = Status < 0;
  }
  while ( Status < 0 && Tries );
  if ( Status >= 0 )
  {
    mEraseRacordShare[48].ch_ = 0;
    for ( i = 0; i < 0x30u; ++i )
      mEraseRacordShare[i].ResetNeeded = 0;
  }
  if ( is_debug() && is_not_zero(64) )
    dbgprint(64, "%a(): Status = %r\n", "GetEraseLog", Status);
  if ( is_debug() && is_not_zero(64) )
    dbgprint(64, "%a(): End\n", "GetEraseLog");
  return Status;
}
```

HEAP OVERFLOW if var length is > 964 bytes

DXE: CrystalRidge (C4EB3614-4986-42B9-8C0D-9FE118278908)

CVE-2021-21555: AepErrorLog NVRAM variable

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  Tries = 3;
  DataSize = 0i64;
  if ( is_debug() && is_not_zero(64) )
    dbgprint(64, "%a(): Start\n", "GetEraseLog");
  do
  {
    Status = gRuntimeServices->GetVariable(L"AepErrorLog", &VendorGuid, 0i64, &DataSize, mEraseRacordShare);
    --Tries;
  }
  while ( Status < 0 && Tries );
  if ( Status >= 0 )
  {
    mEraseRacordShare[48].ch_ = 0;
    for ( i = 0; i < 0x30u; ++i )
      mEraseRacordShare[i].ResetNeeded = 0;
  }
  if ( is_debug() && is_not_zero(64) )
    dbgprint(64, "%a(): Status = %r\n", "GetEraseLog", Status);
  if ( is_debug() && is_not_zero(64) )
    dbgprint(64, "%a(): End\n", "GetEraseLog");
  return Status;
}
```

HEAP OVERFLOW if var length is > 964 bytes

The payload is not measured and TPM PCR's are not extended.

Remote health attestation will not detect the exploitation.

DXE: CrystalRidge (C4EB3614-4986-42B9-8C0D-9FE118278908)

DSA-2021-103 (CVE-2021-21556) / INTEL-SA-00463 (CVE-2020-24486) MirrorRequest NVRAM variable

If **MirrorRequest var length** > 5, a subsequent **memset** will overwrite PEI stack with zeroes in PEI phase.

An attacker controls the length of overwritten buffer and can modify parts of saved return addresses to change execution flow which may lead to arbitrary code execution in PEI phase.

```
-000000ED                  db ? ; undefined
-000000EC                  db ? ; undefined
-000000EB var_EB           db ?
-000000EA var_EA           dd 5 dup(?)
-000000D6 var_D6           db ?
-000000D5 var_D5           db ?
-000000D4 var_D4           dw ?
-000000D2 var_D2           db ?
-000000D1 _MirrorRequest   db ?
-000000D0                  db ? ; undefined
-000000CF                  db ? ; undefined
-000000CE                  db ? ; undefined
-000000CD                  db ? ; undefined
```

```
DataSize = 5;
if ( ReadOnlyVariable2->GetVariable(
       ReadOnlyVariable2,
       L"MirrorRequest",
       &stru_FFD1F114,
       0,
       &DataSize,
       _MirrorRequest) )
{                                      // char _MirrorRequest[10]; // [esp+6AB3h] [ebp-D1h] BYREF
  memset(_MirrorRequest, 0, DataSize);
}
```

Stack buffer: will overwrite saved EIP if length is > 0xD1 bytes

PEI: UncoreInitPeim (D71C8BA4-4AF2-4D0D-B1BA-F2409F0C20D3)

CVE-2021-21556/CVE-2021-24486 (INTEL-SA-00463)

MirrorRequest NVRAM variable

If **MirrorRequest var length** > 5, a subsequent **memset** will overwrite PEI stack with zeroes, in PEI phase.

An attacker controls the length of overwritten buffer and can modify parts of saved return addresses to change execution flow which may lead to arbitrary code execution in PEI phase.

```
-000000ED                 db ? ; undefined
-000000EC                 db ? ; undefined
-000000EB var_EB          db ?
-000000EA var_EA          dd 5 dup(?)
-000000D6 var_D6          db ?
-000000D5 var_D5          db ?
-000000D4 var_D4          dw ?
-000000D2 var_D2          db ?
-000000D1 _MirrorRequest  db ?
-000000D0                 db ? ; undefined
-000000CF                 db ? ; undefined
-000000CE                 db ? ; undefined
-000000CD                 db ? ; undefined
```

The payload is not measured and TPM PCR's are not extended.

Remote health attestation will not detect the exploitation.

```
DataSize = 5;
if ( ReadOnlyVariable2->GetVariable(
       ReadOnlyVariable2,
       L"MirrorRequest",
       &stru_FFD1F114,
       0,
       &DataSize,
       _MirrorRequest) )
{                                   // char _MirrorRequest[10]; // [esp+6AB3h] [ebp-D1h] BYREF
  memset(_MirrorRequest, 0, DataSize);
}
```

Stack buffer: will overwrite saved EIP if length is > 0xD1 bytes

PEI: UncoreInitPeim (D71C8BA4-4AF2-4D0D-B1BA-F2409F0C20D3)

Attacking (pre)EFI Ecosystem

Pre-EFI Initialization and NVRAM variables

- PEI code also reads configuration data from NVRAM variables
- By design, NVRAM is considered read only in PEI stage
- EFI variables are as good attack surface for PEI as they are for DXE
- The API for reading EFI vars is a bit different for PEI though

```
#define EFI_PEI_READ_ONLY_VARIABLE2_PPI_GUID \
  { 0x2ab86ef5, 0xecb5, 0x4134, { 0xb5, 0x56, 0x38, 0x54, 0xca, 0x1f,
0xe1, 0xb4 } }

typedef
EFI_STATUS
(EFIAPI *EFI_PEI_GET_VARIABLE2)(
  IN CONST  EFI_PEI_READ_ONLY_VARIABLE2_PPI *This,
  IN CONST  CHAR16                          *VariableName,
  IN CONST  EFI_GUID                        *VariableGuid,
  OUT       UINT32                          *Attributes,
  IN OUT    UINTN                           *DataSize,
  OUT       VOID                            *Data OPTIONAL
  );
```

Scan for this GUID to quickly locate PEI code that reads NVRAM variables (and potentially has vulns that have to be fixed)

Pre-EFI Initialization and NVRAM variables

```
(*PeiServices)->LocatePpi(PeiServices, &gEfiPeiReadOnlyVariable2PpiGuid, 0, 0, &ReadOnlyPpi);
ZeroMem(syscg_stack, 2048);
ReadOnlyPpi->GetVariable(ReadOnlyPpi, L"syscg", &gSsaBiosVariablesGuid, 0, &DataSize, syscg_stack);
syscg = AllocatePool(DataSize);
memcpy_0(syscg, syscg_stack, DataSize);
```

This is an example of EFI var reading from UncoreInitPeim.efi running on Grantley, and there are problems.

How to know when your Uncore is up to no good

```
(*PeiServices)->LocatePpi(PeiServices, &gEfiPeiReadOnlyVariable2PpiGuid, 0, 0, &ReadOnlyPpi);
ZeroMem(syscg_stack, 2048);
ReadOnlyPpi->GetVariable(ReadOnlyPpi, L"syscg", &gSsaBiosVariablesGuid, 0, &DataSize, syscg_stack);
syscg = AllocatePool(DataSize);
memcpy_0(syscg, syscg_stack, DataSize);
```

- No status check after `GetVariable()`
- `DataSize` may become larger than 2048 bytes if `GetVariable()` call fails with `EFI_BUFFER_TOO_SMALL` (that is, if "syscg" NVRAM variable is longer than 2048 bytes)
- No check for a return value of `AllocatePool()`
- `memcpy()` will not overflow `syscg`, but may copy some stack memory to it

This is not particularly useful but looks like this code may be full of surprises. Let's see what it does *next*.

Hey Uncore, GetVariable() API is dangerous when called in a loop

It may change DataSize and you overflow your buffer on the next iteration with an attacker-controlled data if you don’t check the returned state:

This code reads a chain of EFI variables. Each var contains a name of the next one in the beginning of the data.

```
CHAR16 ChunkName[6]; // [esp+810h] [ebp-14h] BYREF
ReadOnlyPpi->GetVariable(ReadOnlyPpi, SourceVarName, SourceVarGuidPtr, 0, &DataSize, NextChunkNameAndData);

ZeroMem(ChunkName, 12);
memcpy_0(ChunkName, NextChunkNameAndData, 10);
memcpy_0(ImageBase, &NextChunkNameAndData[10], DataSize - 10);
for ( result = StrCmp(ChunkName, &Zero); result; result = StrCmp(ChunkName, &Zero) )
{
  ImageBase = ImageBase + DataSize - 10;
  ReadOnlyPpi->GetVariable(ReadOnlyPpi, ChunkName, SourceVarGuidPtr, 0, &DataSize, NextChunkNameAndData);
  ZeroMem(ChunkName, 12);
  memcpy_0(ChunkName, NextChunkNameAndData, 10);
  if ( DataSize != 10 )
  {
    memcpy_0(ImageBase, &NextChunkNameAndData[10], DataSize - 10);
    FlushFlashRegion();
  }
}
```

Hey Uncore, GetVariable() API is dangerous when called in a loop

It may change DataSize and you overflow your buffer on the next iteration with an attacker-controlled data if you don't check the returned state:

DataSize is not reinitialized before GetVariable(). Therefore, DataSize value is controlled by an attacker.

```
CHAR16 ChunkName[6]; // [esp+810h] [ebp-14h] BYREF
ReadOnlyPpi->GetVariable(ReadOnlyPpi, SourceVarName, SourceVarGuidPtr, 0, &DataSize, NextChunkNameAndData);
ZeroMem(ChunkName, 12);
memcpy_0(ChunkName, NextChunkNameAndData, 10);
memcpy_0(ImageBase, &NextChunkNameAndData[10], DataSize - 10);
for ( result = StrCmp(ChunkName, &Zero); result; result = StrCmp(ChunkName, &Zero) )
{
  ImageBase = ImageBase + DataSize - 10;
  ReadOnlyPpi->GetVariable(ReadOnlyPpi, ChunkName, SourceVarGuidPtr, 0, &DataSize, NextChunkNameAndData);
  ZeroMem(ChunkName, 12);
  memcpy_0(ChunkName, NextChunkNameAndData, 10);
  if ( DataSize != 10 )
  {
    memcpy_0(ImageBase, &NextChunkNameAndData[10], DataSize - 10);
    FlushFlashRegion();
  }
}
```

This may be large

Hey Uncore, GetVariable() API is dangerous when called in a loop

It may change DataSize and you overflow your buffer on the next iteration with an attacker-controlled data if you don’t check the returned state:

ChunkName is a stack buffer. When GetVariable encounters a large var (length > DataSize), DataSize is overwritten with the actual length. On the next iteration a stack overflow occurs when GetVariable() assumes ChunkName length is at least DataSize bytes.

```
CHAR16 ChunkName[6]; // [esp+810h] [ebp-14h] BYREF
ReadOnlyPpi->GetVa  iable(ReadOnlyPpi, SourceVarName, SourceVarGuidPtr, 0, &DataSize, NextChunkNameAndData);

ZeroMem(ChunkNam    );
memcpy_0(ChunkName,   xtChunkNameAndData, 10);
memcpy_0(ImageBase,    xtChunkNameAndData[10], DataSize - 10);
for ( result = StrCm    unkName, &Zero); result; result = StrCmp(ChunkName, &Zero) )
{
  ImageBase = ImageBas    DataSize - 10;
  ReadOnlyPpi->GetVaria    (ReadOnlyPpi, ChunkName, SourceVarGuidPtr, 0, &DataSize, NextChunkNameAndData);
  ZeroMem(ChunkName, 12
  memcpy_0(ChunkName, Ne    unkNameAndData
  if ( DataSize != 10 )
  {
    memcpy_0(ImageBase, &Ne    unkNameAndDa    0], DataSize - 10);
    FlushFlashRegion();
  }
}
```

This stack buffer is overflowed. We don’t have stack cookies or ASLR in PEI code.

We don’t even need to exploit this stack overflow to make our unsigned code execute during PEI.

This *feature* was designed to run arbitrary unsigned code blobs stored in EFI variables!

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Yes, this is a reference code.

Uncore features unsigned module loading

This walks the EFI var chain starting from variable “toolh” and builds a contiguous 32bit PE image.

The payload may be 100kb in size or even more, available NVRAM space is the limit.

This executes the PE entry point.

```
TotalConfigs = *(syscg + 0x10);
EvLoadTool(host, syscg, &ConfigIndex, &ImageBase);
if ( TotalConfigs )
{
  ConfigIndex = 0;
  do
  {
    EvLoadConfig(ConfigIndex, host, syscg, TotalConfigs, &v14);

    Entry = GetPEEntry(host, ImageBase);
    Entry(Ppi, v6);
    sub_FFE6667E(host);
    result = ++ConfigIndex;
  }
  while ( ConfigIndex < TotalConfigs );
}
else
{
  Entry = GetPEEntry(host, ImageBase);
  Entry(Ppi, 0);
  return sub_FFE6667E(host);
}
```

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TotalConfigs = *(syscg + 0x10);
EvLoadTool(host, syscg, &ConfigIndex, &ImageBase);
if ( TotalConfigs )

  ConfigIndex = 0;
  do
  {
    EvLoadConfig(ConfigIndex, host, syscg, TotalConfigs, &v14);

     Entry = GetPEEntry(host, ImageBase);
     Entry(Ppi, v6);
     sub_FFE6667E(host);
     result = ++ConfigIndex;
   }
   while ( ConfigIndex < TotalConfigs );
}
else
{
   Entry = GetPEEntry(host, ImageBase);
   Entry(Ppi, 0);
   return sub_FFE6667E(host);
}
```

Uncore features unsigned module loading

This walks the EFI var chain starting from variable “toolh” and builds a contiguous 32bit PE image.

The payload may be 100kb in size or even more, available NVRAM space is the limit.

This executes the PE entry point.

```
TotalConfigs = *(syscg + 0x10);
EvLoadTool(host, syscg, &ConfigIndex, &ImageBase);
if ( TotalConfigs )

  ConfigIndex = 0;
  do
  {
    EvLoadConfig(ConfigIndex, host, syscg, TotalConfigs, &v14);

     Entry = GetPEEntry(host, ImageBase);
     Entry(Ppi, v6);
     sub_FFE6667E(host);
     result = ++ConfigIndex;
   }
   while ( ConfigIndex < TotalConfigs );
}
else
{
   Entry = GetPEEntry(host, ImageBase);
   Entry(Ppi, 0);
   return sub_FFE6667E(host);
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```

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EvLoadTool(host, syscg, &ConfigIndex, &ImageBase);
if ( TotalConfigs )
{
  ConfigIndex = 0;
  do
  {
    EvLoadConfig(ConfigIndex, host, syscg, TotalConfigs, &v14);

    Entry = GetPEEntry(host, ImageBase);
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    result = ++ConfigIndex;
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}
else
{
  Entry = GetPEEntry(host, ImageBase);
  Entry(Ppi, 0);
  return sub_FFE6667E(host);
}
```

The loaded unsigned code is not measured, TPM PCRs are not extended.

Remote health attestation will not detect the exploitation.

What is the purpose of this feature?

This was intended to be used for debugging or testing purposes.

Intel guidance is this feature is not supposed to be enabled if a physical presence has not been established.

BIOS vendors are supposed to implement their own code for establishing physical presence. For example, a physical jumper setting may be used.

If this feature is not used by OEM vendors then this feature should not be compiled in.

What is the purpose of this feature?

This was intended to be used for debugging or testing purposes.

Intel guidance is this feature is not supposed to be enabled if a physical presence has not been established.

BIOS vendors are supposed to implement their own code for establishing physical presence. For example, a physical jumper setting may be used.

This is what a poor implementation looks like:

```
char IsPhysicalPresenceEstablished()
{
  return 1;
}
```

Not all BIOS vendors are oblivious to the guidelines

Dell has permanently disabled a setup knob setting for this feature, making the module loading code unreachable.

Good job!

How did it happen?

1. Intel implemented a dummy function for a physical presence which always returns TRUE. Should have put “return FALSE”.
2. IBVs have been told by Intel to implement the code which checks for physical jumpers etc.
3. Instead, IBVs just reused Intel’s reference code implementation without making any changes to the relevant code. Now Grantley+ server platforms have this presence check effectively disabled because of this.

"Reference implementations" often become the defacto implementation — due care with proper (safe) defaults should be the norm.

Actual bug is here

```
char IsPhysicalPresenceEstablished()
{
  return 1;
}
```

CVE-2021-0114: Intel’s response

- BSSA Target-Based Loader is a Design for Manufacturing (DFx) feature intended to be used on manufacturing lines.
- Intel's Implementation and Security Guidelines state this feature is not intended to be included in production use, but if it is included then it must be further secured. A suggested method is to confirm physical presence and would vary by different motherboards and systems each requiring their own implementation.
- Transparency is part of our security first pledge. Intel has published an Intel® BSSA DFT Advisory (INTEL-SA-00525) and has developed updated reference UEFI Firmware for potentially affected platforms which includes a physical presence check that always returns False thus necessitating IBV's to complete the implementation for a specific motherboard or system if they included this DFx feature in production.

Looking up the details

Let’s look up the GUID for “toolh” and “syscg” EFI variables used by this feature.

https://edk2.groups.io › devel › message

Re: [edk2-platforms][PATCH V1 01/37] CoffeelakeSiliconPkg: Add ...

+gSsaBiosVariablesGuid = {**0x43eeffe8**, 0xa978, 0x41dc, {0x9d, 0xb6, 0x54, 0xc4, 0x27, 0xf2, 0x7e, 0x2a}} +gSsaBiosResultsGuid = {0x8f4e928, 0xf5f, 0x46d4, ...

Looking up the details

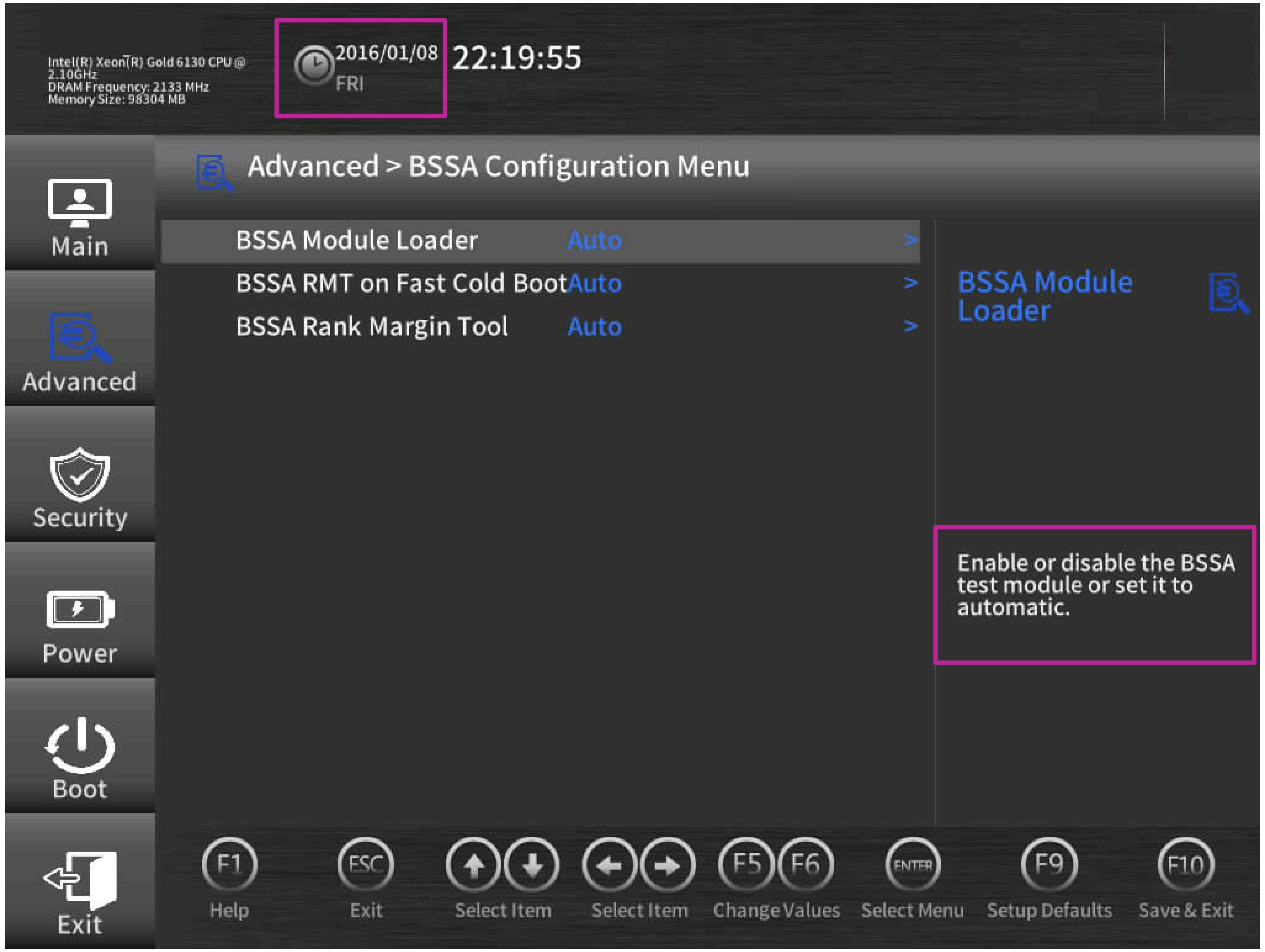
https://edk2.groups.io/g/devel/message/46002

```
+## Include/SsaCommonConfig.h
+gSsaPostcodeHookGuid  = {0xADF0A27B, 0x61A6, 0x4F18, {0x9E, 0xAC, 0x46, 0x87, 0xE7, 0x9E, 0x6F, 0xBB}}
+gSsaBiosVariablesGuid  = {0x43eeffe8, 0xa978, 0x41dc, {0x9d, 0xb6, 0x54, 0xc4, 0x27, 0xf2, 0x7e, 0x2a}}
+gSsaBiosResultsGuid  = {0x8f4e928, 0xf5f, 0x46d4, {0x84, 0x10, 0x47, 0x9f, 0xda, 0x27, 0x9d, 0xb6}}
...
+##
+## SystemAgent
+##
+gSsaBiosCallBacksPpiGuid  =  {0x99b56126, 0xe16c, 0x4d9b, {0xbb, 0x71, 0xaa, 0x35, 0x46, 0x1a, 0x70, 0x2f}}
+gSsaBiosServicesPpiGuid    =  {0x55750d10, 0x6d3d, 0x4bf5, {0x89, 0xd8, 0xe3, 0x5e, 0xf0, 0xb0, 0x90, 0xf4}}
```

So, the *feature* is called "SSA".

And the payload is probably called "SystemAgent"

Looking up the details



BSSA was available since at least 2016

Table 50. MRC Progress Codes

Post Code (Hex)	Upper Nibble				Lower Nibble				Description
	8h	4h	2h	1h	8h	4h	2h	1h	
B0	1	0	1	1	0	0	0	0	Detect DIMM population
B1	1	0	1	1	0	0	0	1	Set DDR4 frequency
B2	1	0	1	1	0	0	1	0	Gather remaining SPD data
B3	1	0	1	1	0	0	1	1	Program registers on the memory controller level
B4	1	0	1	1	0	1	0	0	Evaluate RAS modes and save rank information
B5	1	0	1	1	0	1	0	1	Program registers on the channel level
B6	1	0	1	1	0	1	1	0	Perform the JEDEC defined initialization sequence
B7	1	0	1	1	0	1	1	1	Train DDR4 ranks
1	0	0	0	0	0	0	0	1	Train DDR4 ranks
2	0	0	0	0	0	0	1	0	Train DDR4 ranks – Read DQ/DQS training
3	0	0	0	0	0	0	1	1	Train DDR4 ranks – Receive enable training
4	0	0	0	0	0	1	0	0	Train DDR4 ranks – Write DQ/DQS training
5	0	0	0	0	0	1	0	1	Train DDR4 ranks – DDR channel training done
B8	1	0	1	1	1	0	0	0	Initialize CLTT/OLTT
B9	1	0	1	1	1	0	0	1	Hardware memory test and init
BA	1	0	1	1	1	0	1	0	Execute software memory init
BB	1	0	1	1	1	0	1	1	Program memory map and interleaving
BC	1	0	1	1	1	1	0	0	Program RAS configuration
BE	1	0	1	1	1	1	1	0	Execute BSSA RMT
BF	1	0	1	1	1	1	1	1	MRC is done

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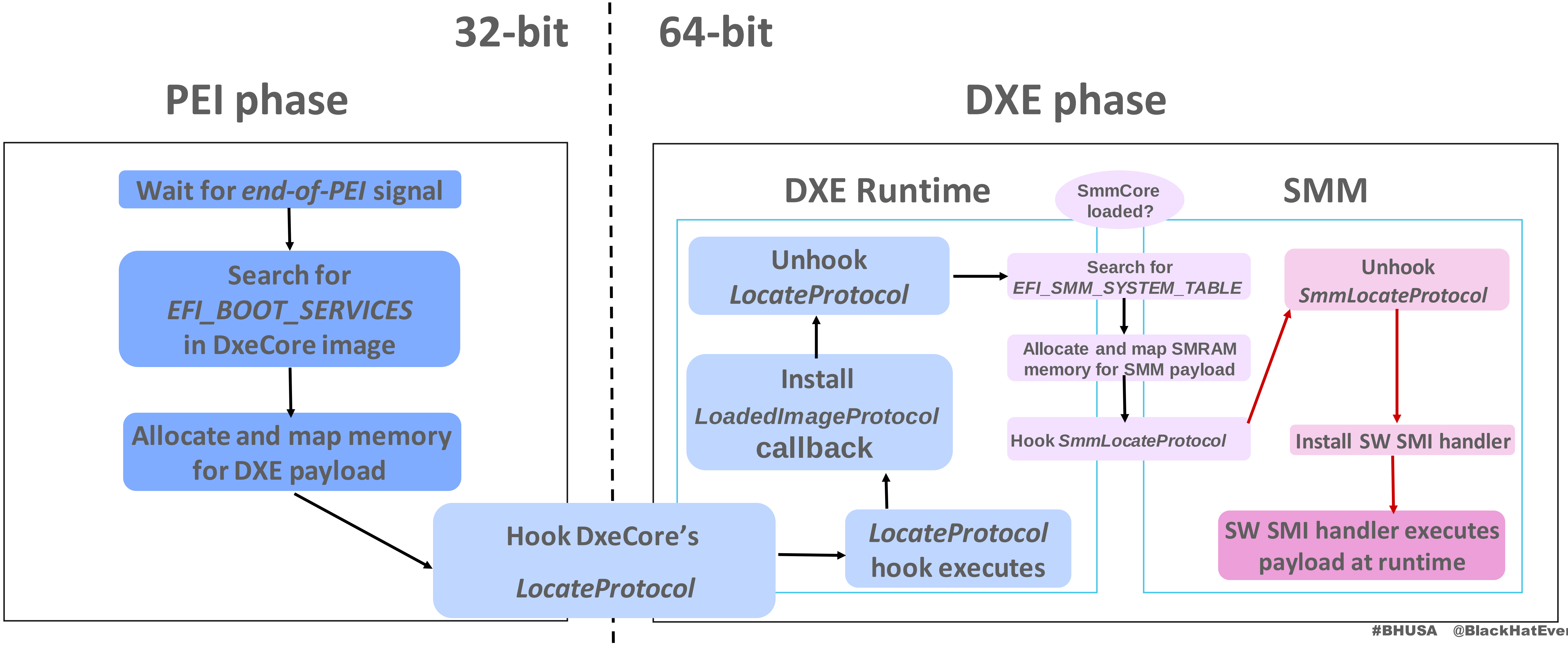
[Intel® Server System M50CYP1UR TPS]

Payload Example: Escalate from PEI to SMM



DEMO TIME

Safeguarding UEFI Ecosystem

Let's briefly talk about

EFI Development Kit (EDK II)...

Let’s briefly talk about

EFI Development Kit (EDK II)...

... I mean CVE-2021-28216 ;-)

EFI Development Kit (EDK II)…

- An open-source implementation of the Unified Extensible Firmware Interface (UEFI) support by the community (TianoCore)

- EDK II is advertised as a modern, feature-rich, cross-platform firmware development environment for the UEFI and UEFI Platform Initialization (PI) specifications

- EDK II supports tons of platforms including:
  - Intel
  - AMD
  - ARM
  - Ampere
  - HiSilicon
  - BeagleBoard
  - Marvell
  - Raspbery Pi
  - RISC-V
  - Socionext
  - NXP
  - More…

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One bug…
… to rule them all !

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For example, CVE-2021-28216

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  - More…

One bug…
… to rule them all !

CVE-2021-28216

```
//
// Update S3 boot records into the basic boot performance table.
//
VarSize = sizeof (PerformanceVariable);
Status = VariableServices->GetVariable (
                           VariableServices,
                           EFI_FIRMWARE_PERFORMANCE_VARIABLE_NAME,
                           &gEfiFirmwarePerformanceGuid,
                           NULL,
                           &VarSize,
                           &PerformanceVariable
                           );
if (EFI_ERROR (Status)) {
  return Status;
}
BootPerformanceTable = (UINT8*) (UINTN)
PerformanceVariable.BootPerformanceTablePointer;  //
// Dump PEI boot records
//
FirmwarePerformanceTablePtr = (BootPerformanceTable + sizeof
(BOOT_PERFORMANCE_TABLE));
GuidHob   = GetFirstGuidHob
(&gEdkiiFpdtExtendedFirmwarePerformanceGuid);
```

```
  while (GuidHob != NULL) {
    FirmwarePerformanceData  = GET_GUID_HOB_DATA (GuidHob);
    PeiPerformanceLogHeader  = (FPDT_PEI_EXT_PERF_HEADER  *)
FirmwarePerformanceData;
    CopyMem (FirmwarePerformanceTablePtr,
FirmwarePerformanceData  + sizeof (FPDT_PEI_EXT_PERF_HEADER),

(UINTN)(PeiPerformanceLogHeader->SizeOfAllEntries));
    GuidHob = GetNextGuidHob
(&gEdkiiFpdtExtendedFirmwarePerformanceGuid,  GET_NEXT_HOB
(GuidHob));
    FirmwarePerformanceTablePtr  +=
(UINTN)(PeiPerformanceLogHeader->SizeOfAllEntries);
  }  //
  // Update Table length.
  //
  ((BOOT_PERFORMANCE_TABLE  *) BootPerformanceTable)-
>Header.Length = (UINT32)((UINTN)FirmwarePerformanceTablePtr  -
(UINTN)BootPerformanceTable);
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(UINTN)(PeiPerformanceLogHeader->SizeOfAllEntries));
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(UINTN)(PeiPerformanceLogHeader->SizeOfAllEntries);
 } //
 // Update Table length.
 //
 ((BOOT_PERFORMANCE_TABLE  *) BootPerformanceTable)-
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(UINTN)BootPerformanceTable);
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CVE-2021-28216

Arbitrary overwrite

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                    &PerformanceVariable
                    );
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PerformanceVariable.BootPerformanceTablePointer;  //
// Dump PEI boot records
//
  FirmwarePerformanceTablePtr = (BootPerformanceTable + sizeof
(BOOT_PERFORMANCE_TABLE));
  GuidHob   = GetFirstGuidHob
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Arbitrary overwrite

Semi-controllable write-what-where

CVE-2021-28216

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                   );
if (EFI_ERROR (Status)) {
  return Status;
}
BootPerformanceTable = (UINT8*) (UINTN)
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// Dump PEI boot records
//
FirmwarePerformanceTablePtr = (BootPerformanceTable + sizeof
(BOOT_PERFORMANCE_TABLE));
GuidHob   = GetFirstGuidHob
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Arbitrary overwrite

Semi-controllable write-what-where

The payload is not measured and TPM PCR's are not extended.

Remote health attestation will not detect the exploitation.

Let's briefly talk about exploitability...

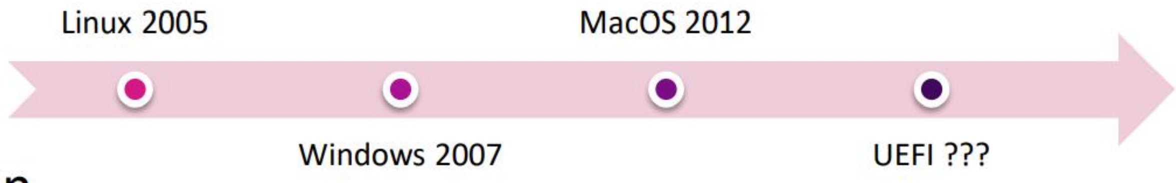
... Let's talk about mitigations and hardening...

... below the OS

“The popularity of UEFI and its lack of memory protection enforcements attract exploitation.”

BAD NEWS: There are no ways to apply Vulnerability Mitigations below the OS

Address
Space
Layout
Randomization



MORE BAD NEWS: Most criminal and advanced threat actors exploit Vulnerabilities Below the OS that affect UEFI

EVEN MORE BAD NEWS: In general, existing memory protections (NX) are not enforced due to vendor non-compliance

[DHS-CISA-Strategy-to-Fix-Vulnerabilities-Below-the-OS-Among-Worst-Offenders]

EFI Development Kit (EDK II) documentation...

Compatbility with other features

	Stack Guard	NULL Ptr	Heap Guard	Mem Profile	NX Stack	NX/RO Mem	Image Protect	Static Paging	SMI Profile	SMM Profile
Stack Guard	N/A	V	V	V	V	V	V	V	V	V
NULL Pointer	V	N/A	V	V	V	V	V	V	V	V
Heap Guard	V	V	N/A	V	V	V	V	N	V	V
Mem Profile	V	V	V	N/A	V	V	V	V	V	V
NX Stack	V	V	V	V	N/A	V	V	V	V	V
NX/RO Memory	V	V	V	V	V	N/A	V	V	V	V
Image Protect	V	V	V	V	V	V	N/A	V	V	V
SMM Static Paging (*)	V	V	N	V	V	V	V	N/A	V	N
SMI Profile (*)	V	V	V	V	V	V	V	V	N/A	V
SMM Profile (*)	V	V	V	V	V	V	V	N	V	N/A

Production Feature	Debug Feature

- **BLUE** means a production feature which might be enabled in the final production.
- **YELLOW** means a debug feature which need be disabled in the final production.
- **"V"** means 2 features can be enabled together.
- **"N"** means 2 feature must not be enabled together.
- **(*)** means this feature is for System Management Mode (SMM) only.
- **No (*)** means this feature can be enabled for DXE or SMM.

https://edk2-docs.gitbook.io/a-tour-beyond-bios-mitigate-buffer-overflow-in-ue/summary

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Mem Profile	V	V	V	N/A	V	V	V	V	V	V
NX Stack	V	V	V	V	N/A	V	V	V	V	V
NX/RO Memory	V	V	V	V	V	N/A	V	V	V	V
Image Protect	V	V	V	V	V	V	N/A	V	V	V
SMM Static Paging (*)	V	V	N	V	V	V	V	N/A	V	N
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"May" → not mandatory

Moreover…

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EFI Development Kit (EDK II) documentation…

- Stack canaries
- DEP
- ASLR
- NULL Pointers

- Limitations

EFI Development Kit (EDK II) documentation...

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Current EDK II uses `/GS-` for MSVC and `-fno-stack-protector` for GCC. The stack check feature is disabled by default. The reason is that EDK II does not link against any compiler provided libraries. If `/G`

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- ## NULL Pointers

Zero address is considered as an invalid address in most programs. However, in x86 systems, the zero address is valid address in legacy BIOS because the 16bit interrupt vector table (IVT) is at address zero. In current UEFI firmware, zero address is always mapped.

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- ## Limitations

The guard in Pre-EFI Initialization (PEI) phase is not supported yet, because most Intel® Architecture (IA) platforms only supports 32bit PEI and paging is not enabled.
From technical perspective, we can add paging-based guard after the permanent memory is initialized in PEI. Stack guard, heap guard or NULL pointer detection can be enabled.

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The Unified Extensible Firmware Interface (UEFI) [www.uefi.org] specification allows "Stack may be marked as non-executable in identity mapped page tables." UEFI also defines

allocation need 12K memory. The heap guard feature will increase memory consumption and may cause memory out of resource. Especially, the System Management Mode (SMM) code runs in the limited System Management Mode RAM (SMRAM) (4M or 8M).

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The current EDK II code does not support address space random

We have observed the performance downgrade in UEFI Shell,

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For heap pool detection, we cannot enable both underflow and overflow detection in one image, because the guard page must be 4K aligned and the allocated pool is either adjacent to head guard page or tail guard page.

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In practice, mitigations & hardening are rarely (if ever) enabled…

What about EDR / XDR / ATP ?

- **Dramatically limited comparing to OS solutions…**

… however, it's (very) slowly changing

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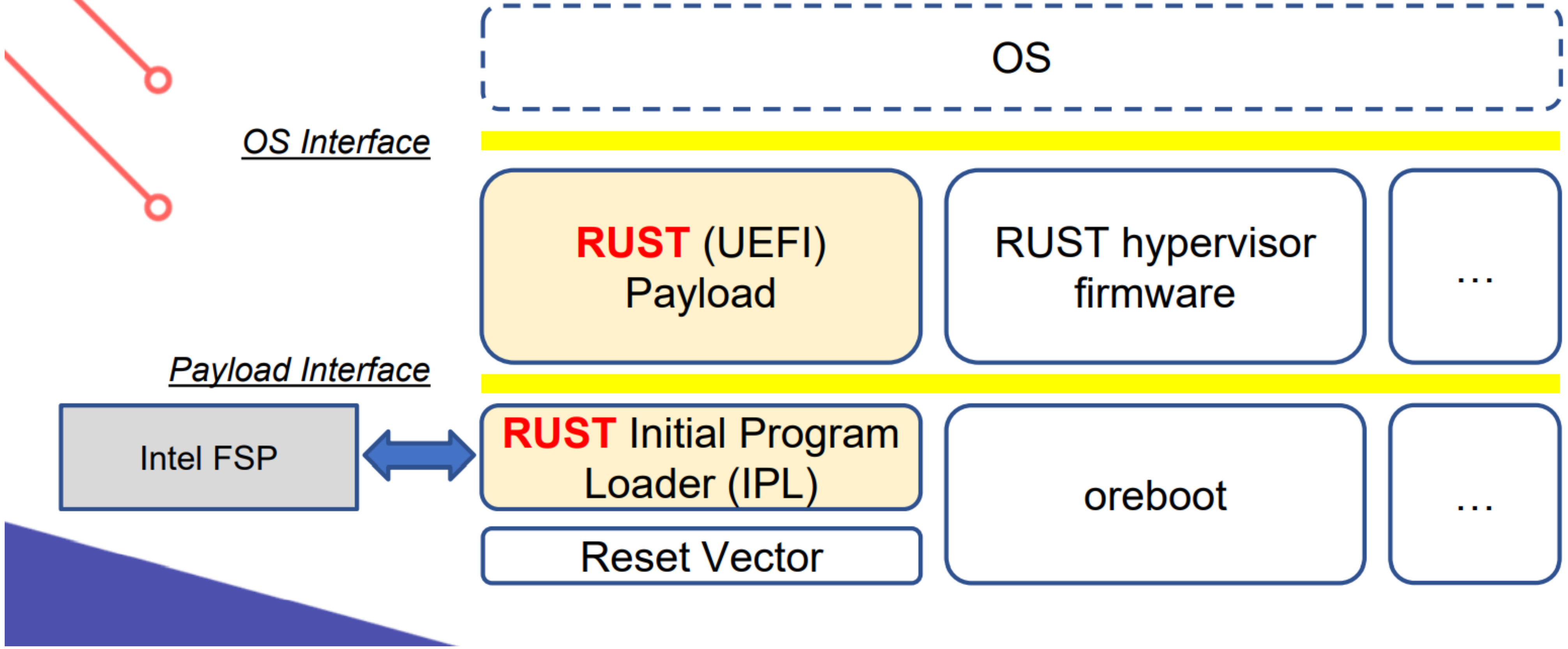
Are we completely lost?

Using Type Safe languages to Develop Critical Code

Thought and Current work



[OSFC2020_Rust_EFI_Yao_Zimmer_NDK4Dme.pdf]

[rust-osdev/uefi-rs: Rust wrapper for UEFI]

[edk2-staging/RustPkg at edkii-rust · tianocore/edk2-staging]

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- **RedHat and LKRG project**
  - for helping to discover at scale potentially vulnerable vendors and notify them
- **Dell**
  - for the great collaboration during disclosure process and very professional feedback

Questions?