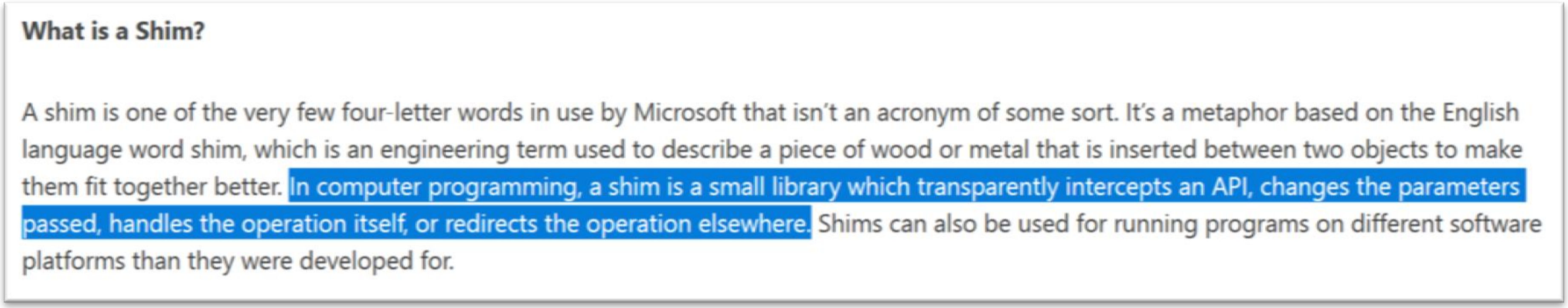
Kernel Shim Engine for fun and not so much (but still a little?) profit

Or how to write a super long title for nothing :)

Who am i?

- Gaby - @pwissenlit
- RE engineer at Quarkslab (fr)
- Play with Windows Internals
- Attending BlackHoodie for the third time
  - And will probably do it again and again and again

Shim Engine



What is a Shim?

A shim is one of the very few four-letter words in use by Microsoft that isn't an acronym of some sort. It's a metaphor based on the English language word shim, which is an engineering term used to describe a piece of wood or metal that is inserted between two objects to make them fit together better. In computer programming, a shim is a small library which transparently intercepts an API, changes the parameters passed, handles the operation itself, or redirects the operation elsewhere. Shims can also be used for running programs on different software platforms than they were developed for.

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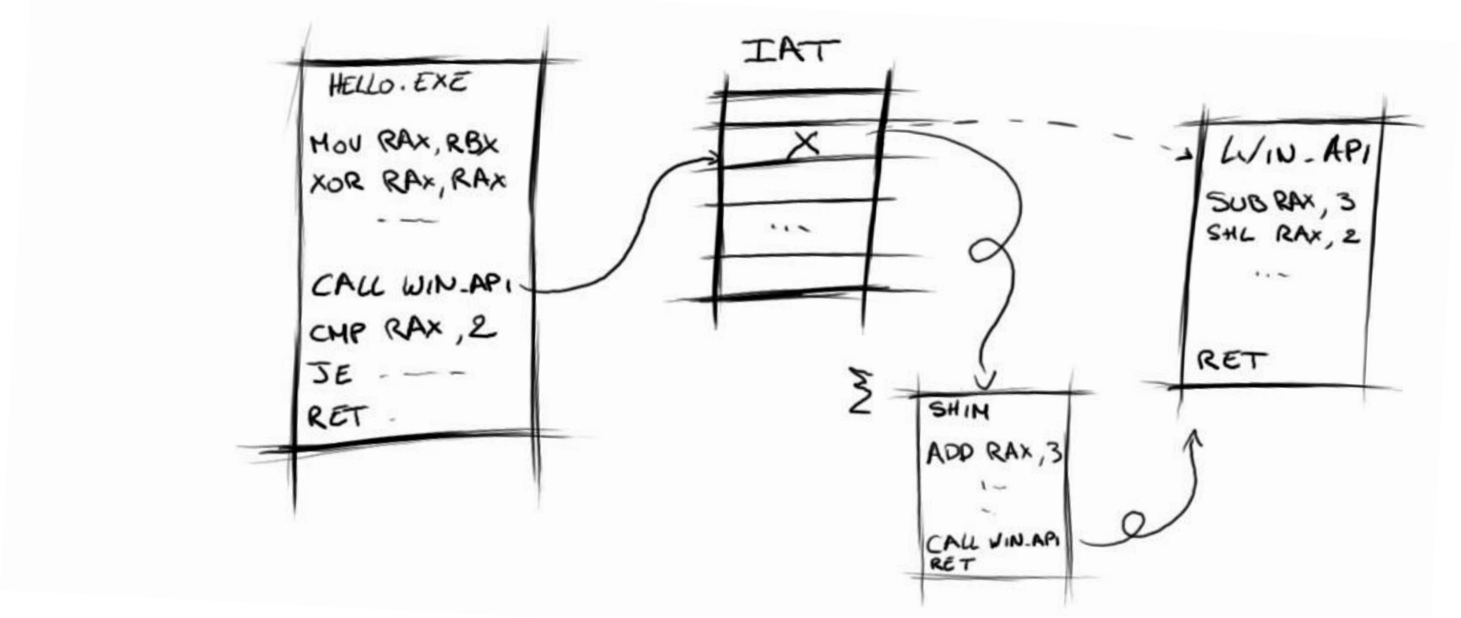
- A.k.a Windows Application Compatibility
- Mechanisms to ensure retro-compatibility for 3rd party apps
- Exist since Windows XP

Shim Engine

- Hot patch import address table (IAT) when app is loaded
- Redirect exec flow before calling the external function



Useful if the API behaviour changed from what you were expecting

Kernel Shim Engine

- Since Windows 8.1
- Same idea – but in kernel!
- Not really known for some reasons
  - Only two (badass) guys talked about it (AFAIK)…
    - Alex Ionescu - Recon 2016
    - Geoff Chappell - (awesome) blog on windows internals

What does it do?

- Can be applied on drivers and devices
- Can hook:
  - Import address table (IAT)
  - I/O request packet (IRP)
  - Driver callbacks
    - DRIVER_OBJECT’s DriverUnload, DriverStartIo, etc.
    - DRIVER_EXTENSION’s AddDevice, etc.
- Applied when the driver is loaded

-> Great way to ensure persistence :DDD

- Cf. Ionescu’s slides at recon 2k16

What do we do?

Keylogger (speedrun)

- Need to hook the keyboard driver
  - i8042ptr.sys driver
- Class Service Callback routine
  - Retrieve the keystrokes
- IRP_MJ_DEVICE_CONTROL callback
  - Set the class service callback routine during the driver init

-> Let's shim that callback <-

BTW how do we write a shim?

Recipe for an easy keylogger at home

Ingredients

A.k.a kernel shim components… :-^

Ingredients

Functions in ntoskrnl.exe

Start most of the time with Kse*:

- KsepEngineInitialize
- KseRegisterShim
- KseShimDatabaseOpen
- KsepResolveShimHooks
- KsepPoolAllocatePaged
- KsepGetShimsForDriver
- KsepApplyShimsToDriver
- etc.

No documentation but some symbols :)

Ingredients

Functions in ntoskrnl.exe

KSE engine in memory

Stores shim engine information like:

- Current engine status
- Shimmed drivers list
- Shim providers list
- Etc.

Ingredients

Functions in ntoskrnl.exe

KSE engine in memory

A bunch of shim providers

- Drivers storing the functions where the execution flow will be redirected to

Ingredients

Functions in ntoskrnl.exe

KSE engine in memory

Database (SDB) on the file system

- Stores registered shims on the OS
  -> C:\Windows\apppatch\drvmain.sdb
- Binary file
- Same format as in userland
  (but with new tags…)
- The SDB is not signed!

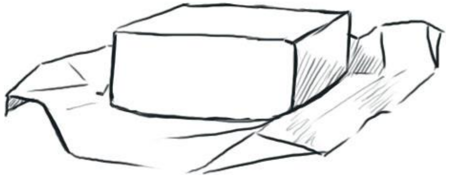
A bunch of shim providers

Ingredients

Functions in ntoskrnl.exe

KSE engine in memory

Database (SDB) on the file system

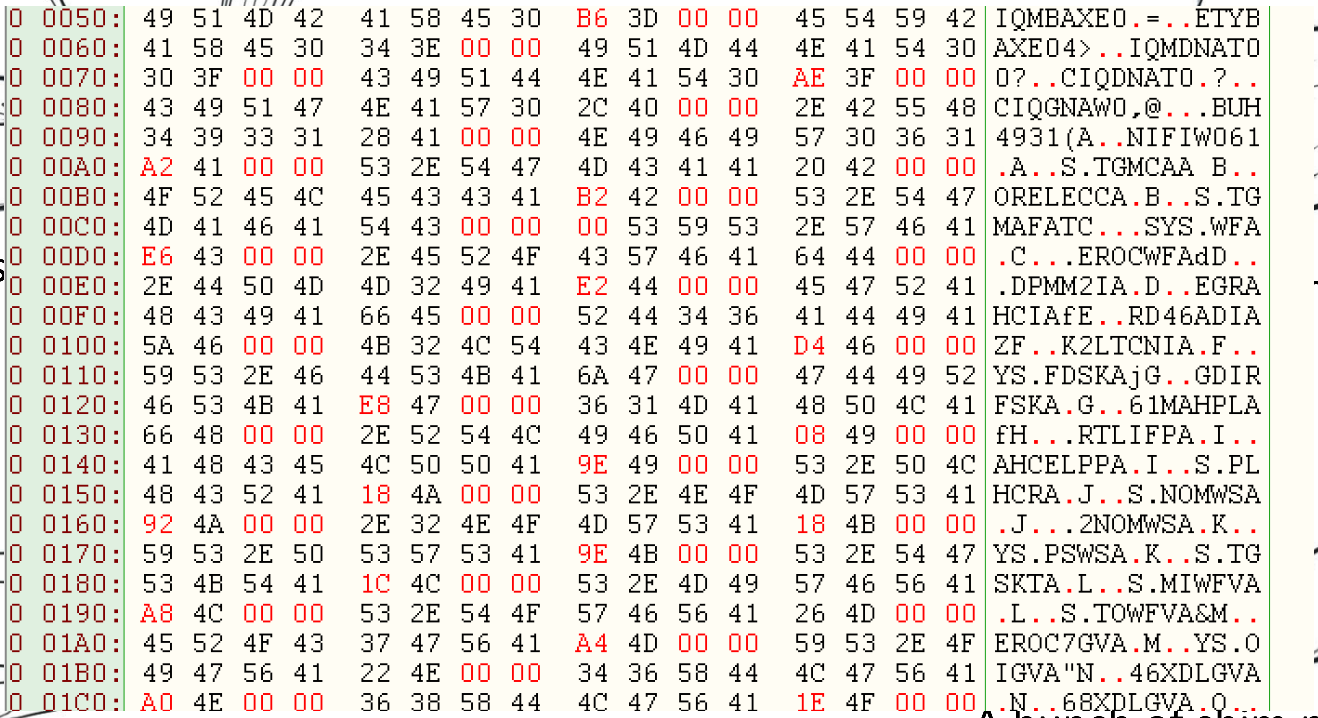


Registry

- Not mandatory
- Override the SDB

A bunch of shim providers

Ingredients



```
0 0050: 49 51 4D 42  41 58 45 30  B6 3D 00 00  45 54 59 42 IQMBAXE0.=..ETYB
0 0060: 41 58 45 30  34 3E 00 00  49 51 4D 44  4E 41 54 30 AXE04>..IQMDNAT0
0 0070: 30 3F 00 00  43 49 51 44  4E 41 54 30  AE 3F 00 00 0?..CIQDNAT0.?..
0 0080: 43 49 51 47  4E 41 57 30  2C 40 00 00  2E 42 55 48 CIQGNAW0,@...BUH
0 0090: 34 39 33 31  28 41 00 00  4E 49 46 49  57 30 36 31 4931(A..NIFIW061
0 00A0: A2 41 00 00  53 2E 54 47  4D 43 41 41  20 42 00 00 .A..S.TGMCAA B..
0 00B0: 4F 52 45 4C  45 43 43 41  B2 42 00 00  53 2E 54 47 ORELECCA.B..S.TG
0 00C0: 4D 41 46 41  54 43 00 00  00 53 59 53  2E 57 46 41 MAFATC...SYS.WFA
0 00D0: E6 43 00 00  2E 45 52 4F  43 57 46 41  64 44 00 00 .C...EROCWFAdD..
0 00E0: 2E 44 50 4D  4D 32 49 41  E2 44 00 00  45 47 52 41 .DPMM2IA.D..EGRA
0 00F0: 48 43 49 41  66 45 00 00  52 44 34 36  41 44 49 41 HCIAfE..RD46ADIA
0 0100: 5A 46 00 00  4B 32 4C 54  43 4E 49 41  D4 46 00 00 ZF..K2LTCNIA.F..
0 0110: 59 53 2E 46  44 53 4B 41  6A 47 00 00  47 44 49 52 YS.FDSKAjG..GDIR
0 0120: 46 53 4B 41  E8 47 00 00  36 31 4D 41  48 50 4C 41 FSKA.G..61MAHPLA
0 0130: 66 48 00 00  2E 52 54 4C  49 46 50 41  08 49 00 00 fH...RTLIFPA.I..
0 0140: 41 48 43 45  4C 50 50 41  9E 49 00 00  53 2E 50 4C AHCELPPA.I..S.PL
0 0150: 48 43 52 41  18 4A 00 00  53 2E 4E 4F  4D 57 53 41 HCRA.J..S.NOMWSA
0 0160: 92 4A 00 00  2E 32 4E 4F  4D 57 53 41  18 4B 00 00 .J...2NOMWSA.K..
0 0170: 59 53 2E 50  53 57 53 41  9E 4B 00 00  53 2E 54 47 YS.PSWSA.K..S.TG
0 0180: 53 4B 54 41  1C 4C 00 00  53 2E 4D 49  57 46 56 41 SKTA.L..S.MIWFVA
0 0190: A8 4C 00 00  53 2E 54 4F  57 46 56 41  26 4D 00 00 .L..S.TOWFVA&M..
0 01A0: 45 52 4F 43  37 47 56 41  A4 4D 00 00  59 53 2E 4F EROC7GVA.M..YS.O
0 01B0: 49 47 56 41  22 4E 00 00  34 36 58 44  4C 47 56 41 IGVA"N..46XDLGVA
0 01C0: A0 4E 00 00  36 38 58 44  4C 47 56 41  1E 4F 00 00 .N..68XDLGVA.O..
```

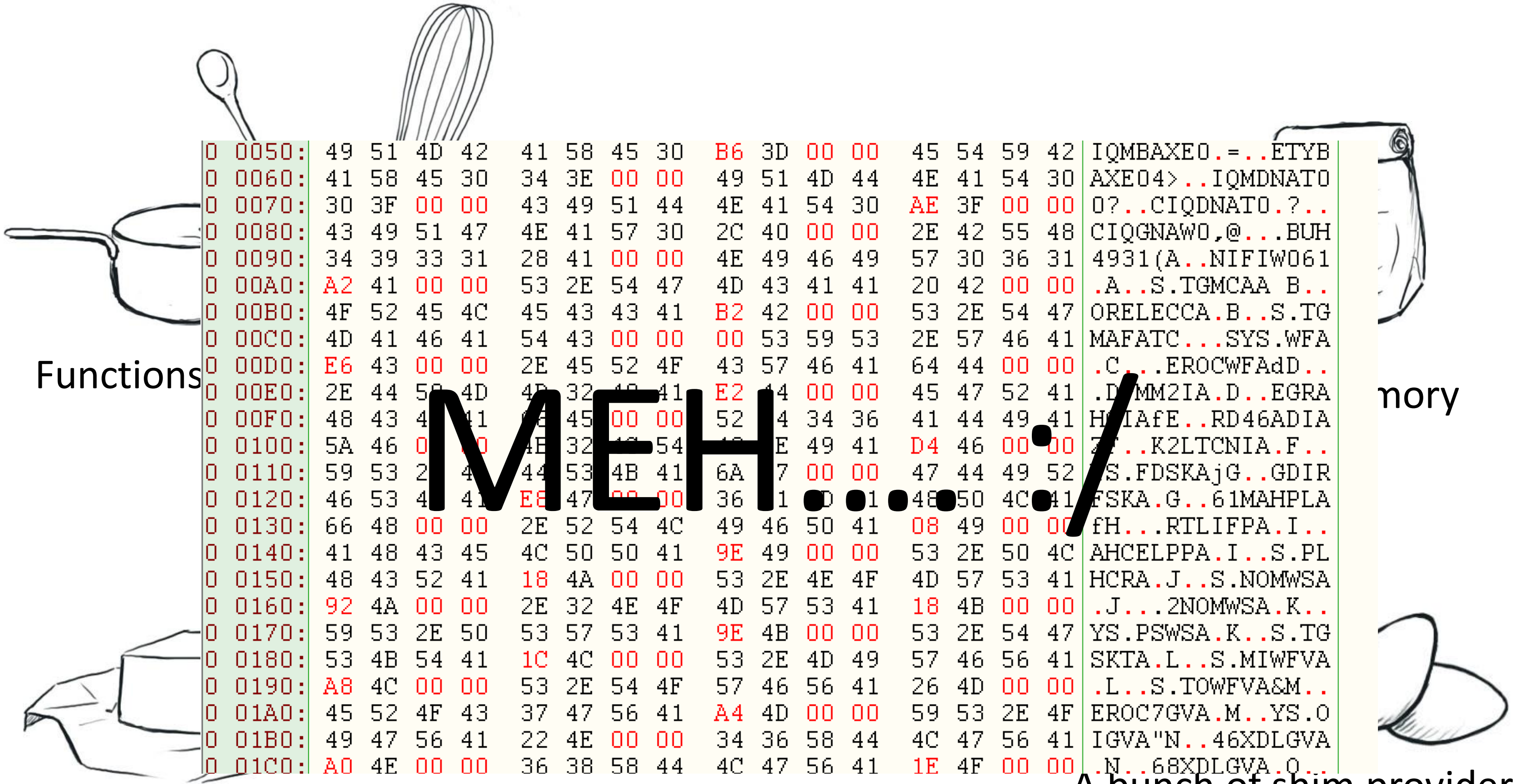
Functions

mory

Registry

A bunch of shim providers

Ingredients



```
0 0050: 49 51 4D 42  41 58 45 30  B6 3D 00 00  45 54 59 42 IQMBAXE0.=..ETYB
0 0060: 41 58 45 30  34 3E 00 00  49 51 4D 44  4E 41 54 30 AXE04>..IQMDNAT0
0 0070: 30 3F 00 00  43 49 51 44  4E 41 54 30  AE 3F 00 00 0?..CIQDNAT0.?..
0 0080: 43 49 51 47  4E 41 57 30  2C 40 00 00  2E 42 55 48 CIQGNAW0,@...BUH
0 0090: 34 39 33 31  28 41 00 00  4E 49 46 49  57 30 36 31 4931(A..NIFIW061
0 00A0: A2 41 00 00  53 2E 54 47  4D 43 41 41  20 42 00 00 .A..S.TGMCAA B..
0 00B0: 4F 52 45 4C  45 43 43 41  B2 42 00 00  53 2E 54 47 ORELECCA.B..S.TG
0 00C0: 4D 41 46 41  54 43 00 00  00 53 59 53  2E 57 46 41 MAFATC...SYS.WFA
0 00D0: E6 43 00 00  2E 45 52 4F  43 57 46 41  64 44 00 00 .C...EROCWFAdD..
0 00E0: 2E 44 [illegible] 4D  4D 32 49 41  E2 44 00 00  45 47 52 41 .D[illegible]MM2IA.D..EGRA
0 00F0: 48 43 49 41  66 45 00 00  52 44 34 36  41 44 49 41 HCIAfE..RD46ADIA
0 0100: 5A 46 00 00  4B 32 4C 54  43 4E 49 41  D4 46 00 00 ZF..K2LTCNIA.F..
0 0110: 59 53 2E 46  44 53 4B 41  6A 47 00 00  47 44 49 52 YS.FDSKAjG..GDIR
0 0120: 46 53 4B 41  E8 47 00 00  36 31 4D 41  48 50 4C 41 FSKA.G..61MAHPLA
0 0130: 66 48 00 00  2E 52 54 4C  49 46 50 41  08 49 00 00 fH...RTLIFPA.I..
0 0140: 41 48 43 45  4C 50 50 41  9E 49 00 00  53 2E 50 4C AHCELPPA.I..S.PL
0 0150: 48 43 52 41  18 4A 00 00  53 2E 4E 4F  4D 57 53 41 HCRA.J..S.NOMWSA
0 0160: 92 4A 00 00  2E 32 4E 4F  4D 57 53 41  18 4B 00 00 .J...2NOMWSA.K..
0 0170: 59 53 2E 50  53 57 53 41  9E 4B 00 00  53 2E 54 47 YS.PSWSA.K..S.TG
0 0180: 53 4B 54 41  1C 4C 00 00  53 2E 4D 49  57 46 56 41 SKTA.L..S.MIWFVA
0 0190: A8 4C 00 00  53 2E 54 4F  57 46 56 41  26 4D 00 00 .L..S.TOWFVA&M..
0 01A0: 45 52 4F 43  37 47 56 41  A4 4D 00 00  59 53 2E 4F EROC7GVA.M..YS.O
0 01B0: 49 47 56 41  22 4E 00 00  34 36 58 44  4C 47 56 41 IGVA"N..46XDLGVA
0 01C0: A0 4E 00 00  36 38 58 44  4C 47 56 41  1E 4F 00 00 .N..68XDLGVA.O..
```

MEH…:/

Functions

mory

Registry

A bunch of shim providers

But parsers exist ffs!

- Same format as in userland
- Some tools available:
  - Sdb2xml.exe
  - Sdb-explorer.exe
  - Ect.

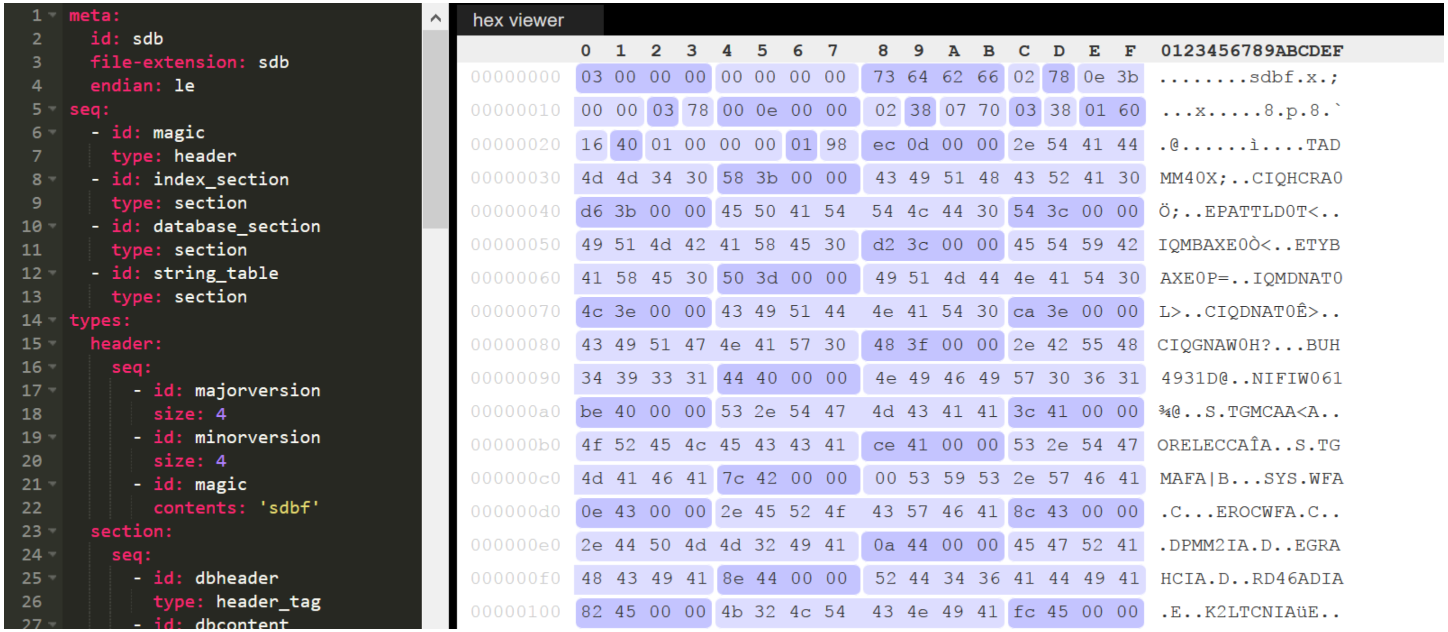
But parsers exist ffs!

- Decompiled SDB:

```
 <?xml version="1.0" encoding="UTF-16"?>
<DATABASE NAME="Microsoft Driver Compatibility Database" ID="{F9AB2228-3312-4A73-B6F9-
936D70E112EF}">
[…]
<DRIVER NAME="WSRRCI" VENDOR="Wisair">
    <KDRIVER NAME="wsr_rci.sys" ID="{1E61CDCD-D929-4094-B3BD-1772F7459CBE}"
RUNTIME_PLATFORM="X86">
      <KSHIM NAME="usbshim" COMMAND_LINE="null" />
    </KDRIVER>
  </DRIVER>
[…]
<LIBRARY>
    <KSHIM NAME="autofail" ID="{407D63CE-419D-4550-B54A-4F1C1B5BDD9F}" ONDEMAND="YES"
FILE="autofail" />
[…]
    <KSHIM NAME="usbshim" ID="{FD8FD62E-4D94-4FC7-8A68-BFF7865A706B}" FILE="usbd" />
  </LIBRARY>
```

But not that much for editing…

- Geoff Chappell’s article in PoC||GTFO 13:9
- Or… We can write our own!
  - Kaitai struct to the rescue \o/



```yaml
meta:
  id: sdb
  file-extension: sdb
  endian: le
seq:
  - id: magic
    type: header
  - id: index_section
    type: section
  - id: database_section
    type: section
  - id: string_table
    type: section
types:
  header:
    seq:
      - id: majorversion
        size: 4
      - id: minorversion
        size: 4
      - id: magic
        contents: 'sdbf'
  section:
    seq:
      - id: dbheader
        type: header_tag
      - id: dbcontent
```

```
           0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F  0123456789ABCDEF
00000000  03 00 00 00 00 00 00 00  73 64 62 66 02 78 0e 3b  ........sdbf.x.;
00000010  00 00 03 78 00 0e 00 00  02 38 07 70 03 38 01 60  ...x.....8.p.8.`
00000020  16 40 01 00 00 00 01 98  ec 0d 00 00 2e 54 41 44  .@......ì....TAD
00000030  4d 4d 34 30 58 3b 00 00  43 49 51 48 43 52 41 30  MM40X;..CIQHCRA0
00000040  d6 3b 00 00 45 50 41 54  54 4c 44 30 54 3c 00 00  Ö;..EPATTLD0T<..
00000050  49 51 4d 42 41 58 45 30  d2 3c 00 00 45 54 59 42  IQMBAXE0Ò<..ETYB
00000060  41 58 45 30 50 3d 00 00  49 51 4d 44 4e 41 54 30  AXE0P=..IQMDNAT0
00000070  4c 3e 00 00 43 49 51 44  4e 41 54 30 ca 3e 00 00  L>..CIQDNAT0Ê>..
00000080  43 49 51 47 4e 41 57 30  48 3f 00 00 2e 42 55 48  CIQGNAW0H?...BUH
00000090  34 39 33 31 44 40 00 00  4e 49 46 49 57 30 36 31  4931D@..NIFIW061
000000a0  be 40 00 00 53 2e 54 47  4d 43 41 41 3c 41 00 00  ¾@..S.TGMCAA<A..
000000b0  4f 52 45 4c 45 43 43 41  ce 41 00 00 53 2e 54 47  ORELECCAÎA..S.TG
000000c0  4d 41 46 41 7c 42 00 00  00 53 59 53 2e 57 46 41  MAFA|B...SYS.WFA
000000d0  0e 43 00 00 2e 45 52 4f  43 57 46 41 8c 43 00 00  .C...EROCWFA.C..
000000e0  2e 44 50 4d 4d 32 49 41  0a 44 00 00 45 47 52 41  .DPMM2IA.D..EGRA
000000f0  48 43 49 41 8e 44 00 00  52 44 34 36 41 44 49 41  HCIA.D..RD46ADIA
00000100  82 45 00 00 4b 32 4c 54  43 4e 49 41 fc 45 00 00  .E..K2LTCNIAüE..
```

- Need just a bit of work to have the builder

Recipe

How to write a shim in few^W^W^W a lot of slides…

1- Create a provider

- Create a driver & implement the hook functions
- Define the shim and hooks
  - Register them in the KSE engine with:

```
NTSTATUS KseRegisterShimEx(
                            KSE_SHIM *pShim,
                            PVOID ignored,
                            ULONG flags,
                            DRIVER_OBJECT *pDrv_Obj);
```

-> exported by ntoskrnl.exe but not declared in any headers!

1- Create a provider

- Shim objects

```
typedef struct _KSE_SHIM {
        _In_ SIZE_T         Size;
        _In_ PGUID          ShimGuid;
        _In_ PWCHAR         ShimName;
        _Out_ PVOID         KseCallbackRoutines;
        _In_ PVOID          ShimmedDriverTargetedNotification;
        _In_ PVOID          ShimmedDriverUntargetedNotification;
        _In_ PVOID          HookCollectionsArray; // array of _KSE_HOOK_COLLECTION
} KSE_SHIM, *PKSE_SHIM;
```

1- Create a provider

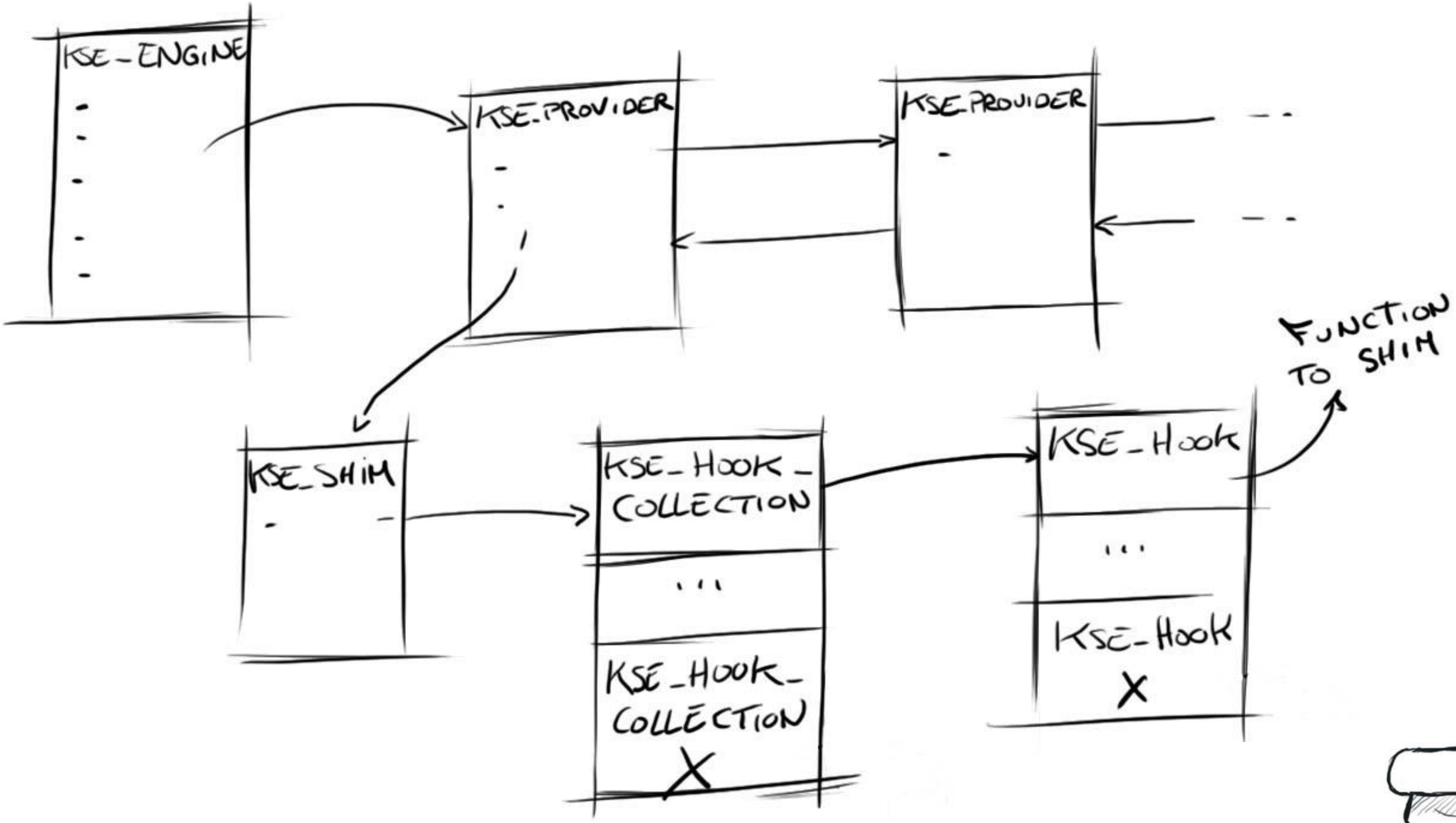
- Collection of similar hooks

```
typedef struct _KSE_HOOK_COLLECTION {
        ULONG64  Type;       // 0: NT Export, 1: HAL Export, 2: Driver Export, 3: Callback, 4: Last
        PWCHAR   ExportDriverName;   // If Type == 2
        PVOID    HookArray;          // array of _KSE_HOOK
} KSE_HOOK_COLLECTION, *PKSE_HOOK_COLLECTION;


KSE_HOOK_COLLECTION pCollecArray[2];
pCollecArray[0].Type = 3;                    // Driver callback
pCollecArray[0].ExportDriverName = NULL;
pCollecArray[0].HookArray = pHookArray;

pCollecArray[1].Type = 4;                    // Last entry in array
pCollecArray[1].ExportDriverName = NULL;
pCollecArray[1].HookArray = NULL;
```

1- Create a provider

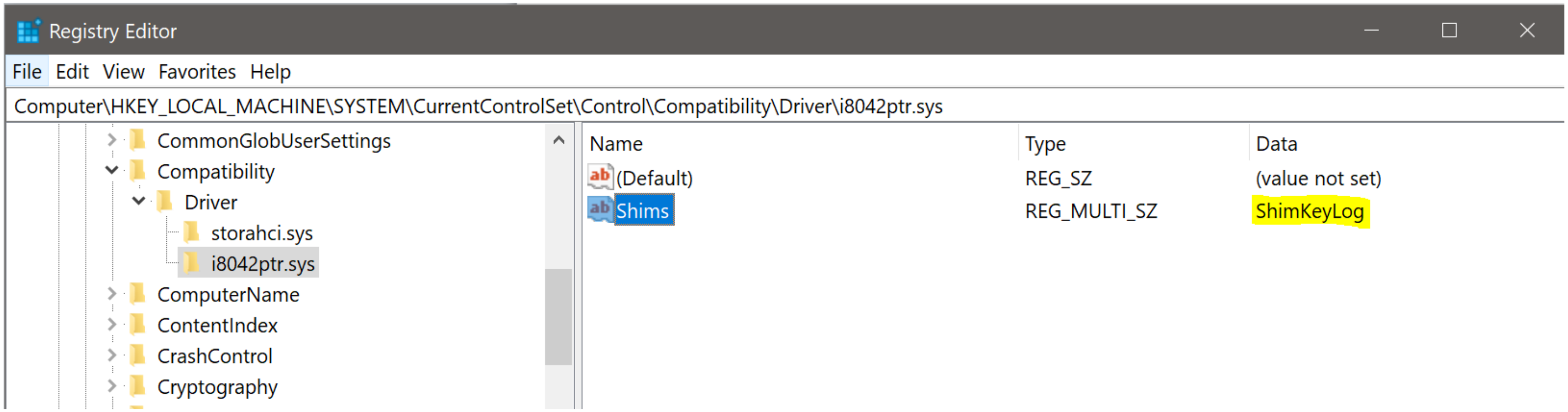
```
typedef struct _KSE_HOOK {
        _In_ ULONG64 Type;                          // 0: Function, 1: IRP Callback, 2: Last
        union {
                _In_ PCHAR FunctionName;            // If Type == 0
                _In_ ULONG64 CallbackId;            // If Type == 1
        };
        _In_ PVOID HookFunction;
        _Out_ PVOID OriginalFunction;
} KSE_HOOK, *PKSE_HOOK;

KSE_HOOK pHookArray[2];
pHookArray[0].Type = 1;                             // IRP Callback
pHookArray[0].CallbackId = 115;                     // IRP_MJ_DEVICE_CONTROL
pHookArray[0].HookFunction = (PVOID)ShimCallbackAddr;
pHookArray[0].OriginalFunction = NULL;

pHookArray[0].Type = 2;                             // Last entry in array
pHookArray[0].FunctionName = NULL;
pHookArray[0].HookFunction = NULL;
pHookArray[0].OriginalFunction = NULL;
```

In the KSE engine in memory…



2- Associate the shim with a driver

- With the Registry
  - Easy peasy…



Computer\HKEY_LOCAL_MACHINE\SYSTEM\CurrentControlSet\Control\Compatibility\Driver\i8042ptr.sys

```
CommonGlobUserSettings
Compatibility
  Driver
    storahci.sys
    i8042ptr.sys
ComputerName
ContentIndex
CrashControl
Cryptography
```

Name	Type	Data
(Default)	REG_SZ	(value not set)
Shims	REG_MULTI_SZ	ShimKeyLog

- With the SDB
  - C:\Windows\apppatch\drvmain.sdb
  - Harder to modify…

3- Associate the shim with the provider

- Hijack a shim already defined in the SDB
  - Register the provider (step 1) with the same name as in the SDB
    - autofail.sys… ;))
- Add a new entry in the SDB

3- Associate the shim with the provider

```
Strnametag = BinaryTag()
Strnametag.tag = 0x8801
Strnametag.data = unicodeStr('ShimKeyLog')
Strnametag.buffer_size = len(strnametag.data)

offset = sdb_str_section.getsize()+ strnametag .getsize()
sdb_str_section.append(strnametag)

Kshim_name = ParentBlock()
Kshim_name.tag = 0x6001
Kshim_name.reste =  offset

[…]

Kshim_tag = ParentBlock()
Kshim_tag.tag = 0x7025
Kshim_tag.reste = ListTag()
Kshim_tag.reste.content = [Kshim_name, Kshim_guid, Kshim_flag, Kshim_module]

sdb_db_section.append(Kshim_tag)
```

To sum up

1. Create a shim provider (driver)
   - Define the hooks and the shims structure
   - Register the shim provider in the KSE Engine
2. Define the modules that should use the shim
   - Either in the registry or in the shim database
3. Add the correlation between shim and shim provider in the sdb
   - Or hijack one already defined

For fun!

Demo time \o/

Plz, demo god!

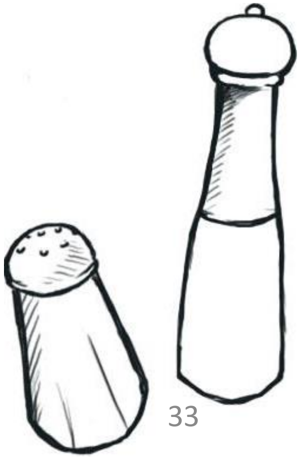
…

No actually I don’t trust you…

Not reaaally for profit

- Good points
  - Hard to detect if you don’t know where to look
  - Kind of legit actually
    - Not that much ugly hooking required
- Bad points
  - Need to sign the provider
    - Expensive… >.>’
    - Hard to load through a vulnerable driver
      - at boot time or by reloading the shimmed driver
  - Hard to use for really early started drivers

Question?

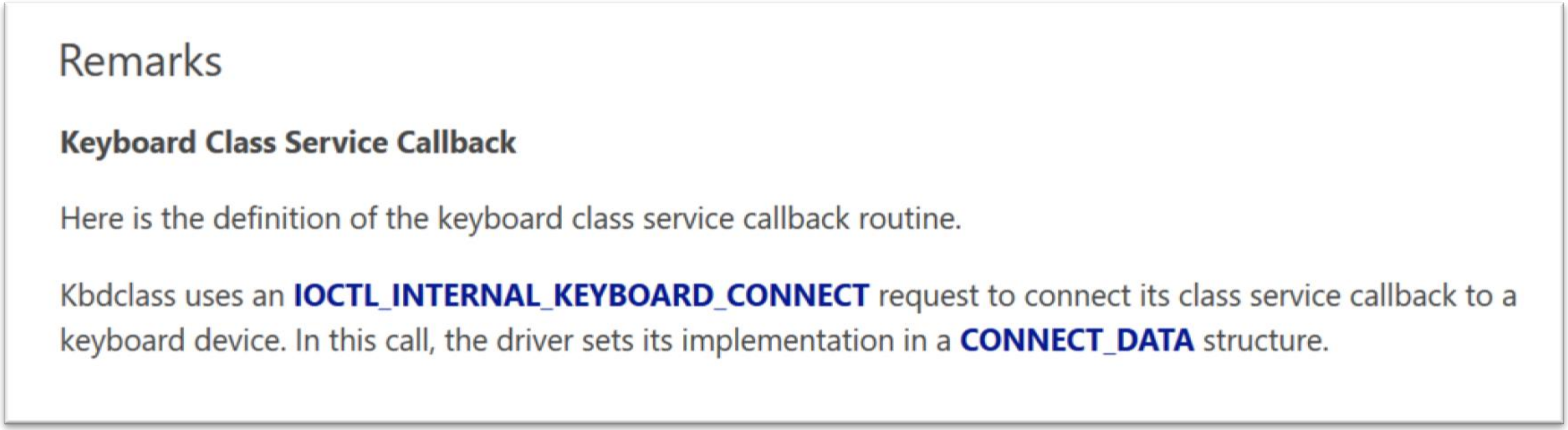


Just in case…

Keylogger

- Key pressed
- IRQ sent to CPU -> interrupt!
- Call the interrupt handler (ISR)
- Cannot do the job -> dispatch DPC
  - To execute a routine later
- Call the Deferred Routine from the keyboard driver
- Call a Class Service Callback routine
- --> retrieve the data from the hardware

MSDN with love…



Remarks

Keyboard Class Service Callback

Here is the definition of the keyboard class service callback routine.

Kbdclass uses an **IOCTL_INTERNAL_KEYBOARD_CONNECT** request to connect its class service callback to a keyboard device. In this call, the driver sets its implementation in a **CONNECT_DATA** structure.

- Device Input and Output Control
  - Control code used to communicate with the driver
  - Callback #15 called on driver side
    - IRP_MJ_DEVICE_CONTROL for the ones who wonder…
    - Driver performs the job assigned to the IOCTL