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Studying the logging capability of Windows Telemetry component using Reverse Engineering

Tesis de Licenciatura en Ciencias de la Computación

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Buenos Aires, 2019

ABSTRACT (ENGLISH VERSION)

Windows, one of the most popular OS, has a component called Telemetry. It collects information from the system with the goal of analyzing and fixing software & hardware problems, improving the user experience, among others. The kind of information that can be obtained by this component is partially configurable in four different levels: security, basic, enhanced and full, being ”security” the level where less information is gathered and ”full” the opposite case.

How Telemetry stores/process/administrates the information extracted? It employs a widely used framework called Event Tracer for Windows (ETW) [4]. Embedded not only in userland application but also in the kernel modules, the ETW framework has the goal of providing a common interface to log events and therefore help to debug and log system operations, by instrumenting it.

In this work, we are going to analyze a part of the Windows kernel to better understand how Telemetry works from an internal perspective. This work will make windows analysts, IT admins or even windows users, more aware about the functionality of the Telemetry component helping to deal with privacy issues, bug fixing, knowledge of collected data, etc. Our analysis implies performing reverse engineering [5],[6] on the Telemetry component, which involves chal- lenging processes such as kernel debugging, dealing with undocumented kernel internal structures, reversing of bigger frameworks (i.e: ETW), binary libraries which lack symbols, etc. As part of the analysis we will also develop an in depth comparison between the differences among each level of Telemetry, stressing the contrast in the amount of events written, verbosity of information, etc. Finally, we will study how the communication between the Windows instance and the Microsoft backend servers is carried out.

ABSTRACT (SPANISH VERSION)

ACKNOWLEDGMENTS

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1. MOTIVATION

The analysis presented in this work was performed against the Telemetry component of the Windows OS, with the following goals:

- Understand how the process of generating logs was carried out.
- How, where and what logs were stored.
- Which applications are involved in gathering Telemetry information

2. INTRODUCTION

The analysis presented, was carried out in a particular version of the Windows OS. Specifically, Windows 10 64 bits Enterprise, 1607. Windows delivers a new version, usually, each Some words about ERNW and the project with the FBI

There are several reasons why this version was chosen:

- It was one of the mainstream version of Windows at the moment of starting the project.
- It was a long support version (EOS: April 2019).
- It was used by the German Police Office

Although this version may sound a bit old as of today, all the analysis is also applicable to newer versions such as Windows 10 64 bits Enterprise 1909.

2.1 Basic concepts

This section will describe basic concepts needed to fully understand the carried out process to perform the analysis.

2.1.1 Reverse Engineering

Software engineering can be defined as the process of designing, building and testing computer software. The processor of a computer, works with 1's and 0's, therefore developing any kind of sofware will mean Key concepts about what RE means, from a general perspective, how it should tackled which tools are usually there. 64 bits, calling convention ..

Static and dinaymyc analysis!

2.1.2 Debugging

Explaniation of the concept of debugging, what is the different with doing static RE. Some words specifically for KERNEL debugging.

2.2 Tools

2.2.1 IDA pro

Introduction to IDA pro. Explaniation of what it is and how it works.talk about hxrays

2.2.2 WinDBG

Introduction to WINDBG. Explaniation of what it is and how it works.

2.2.3 YARA

2.2.4 XPERF?

2.3 Windows components

2.3.0.1 Event Tracing for Windows

Complete explainiation of how it works due to its importance for the rest of the analysis. Different components: session, providers, consumers ,etc . Talk about the guid of the providers

2.3.0.2 Telemetry

Full description of the different features / characteristic which are involved in this analysis. Explaniation of how the worflow of the data is followed. talk about the name of the session,the levels of configuration, when it can be configured.. etc.

3. PREVIOUS WORK

Some lines about previous works in this topic. Most of them focused on just analysis from traffic / documentation.

4. ANALYSIS

The main objective was always the analysis of Telemetry. The best and most accurate option to study this component would have been to analyze it source code. Unluckily this isn’t possible as the Windows kernel is not open source. However, it was still possible to reverse engineer the Windows kernel to understand how Telemetry works. Several files (dynamic libraries, executables, drivers) had to be reversed and analyzed. Nonetheless, there was one file that had the main focus: **ntoskrnl.exe**. This binary holds the actual implementation of the Windows Kernel.

Following sections will depict different challenges and achievements faced during the analysis of this and the other binaries.

4.1 Understanding how Telemetry makes use of ETW

When Windows OS boots, multiple sessions are created inside ETW. Among them there is one related to Telemetry: DiagTrack. As explained in 2.3.0.1, every session has ”providers”: those entities that actually provide information to the session. In order to understand how Telemetry works with ETW, it was important to learn about DiagTrack’s session providers. To help us the following questions wanted to be answered:

1. Who are they?
2. Where are they?
3. What information are they logging?

Windows allowed to query the list of providers registered to a particular session by executing the following powershell command:

```
Get-EtwTraceProvider | where {$_.SessionName -match
"<SESSION_NAME>"}
```

Fig. 4.1: Powershell command to list ETW providers registered against a particular session.

For each provider registered to the queried session, the following information is outputted:

- GUID
- TO_CHECK
- TO_CHECK

With this list the question **Who are they?** seems to be answered. However, two questions are still missing to answer.

At this point and idea came up: To answer **Where are they running?** and **What are they logging?** it could be useful to hook into the exact moment when any of those providers are going to write to the DiagTrack’s session. In other words, it could be useful to set a breakpoint in the function that performs the write to the DiagTrack’s session. Once the breakpoint is hit, the following information could be extracted:

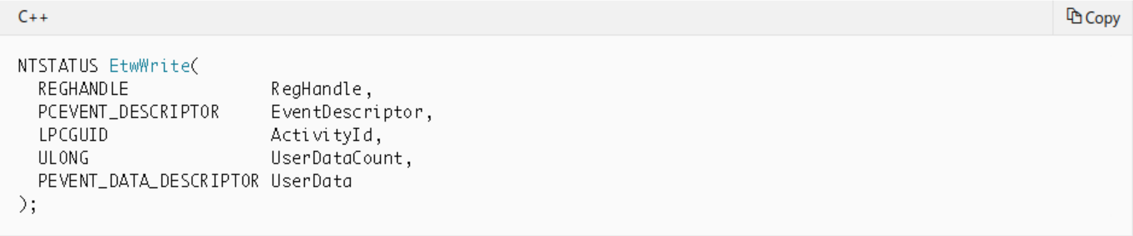
1. The piece of code that triggered the write (by inspecting the function's call stack). In other words, identify who is writing.
2. The actual content of the log being written.

That was when debugging (2.1.2) came into play. Analyzing the symbols exposed by the ntoskrnl binary, the function **EtwWrite** was found. This function seemed to be one in charge of carrying out the writes of providers inside sessions. Nonetheless, it wasn't worth to set a breakpoint at this function as every provider of the system (not necessarily related to DiagTrack) could use it. It was necessary to find a way of only detecting the writes performed by DiagTrack's providers.

Let's recall the powershell command (4.1). This command will return you information for each registered provider. Part of that information was the GUID.

The objective was to filter writes only from providers that were registered against the DiagTrack Session. To do so the idea was to set a conditional breakpoint inside function **EtwWrite** and try to check if the GUID provided was of interest.

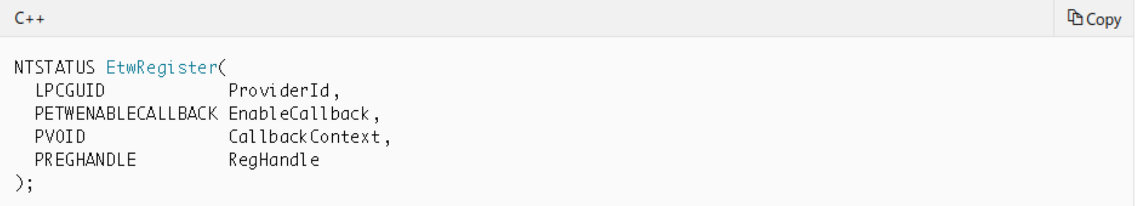
Unfortunately, this strategy had one minor issue. The function (**EtwWrite**) had five parameters and none of them would show directly the GUID:



```cpp
NTSTATUS EtwWrite(
  REGHANDLE              RegHandle,
  PCEVENT_DESCRIPTOR     EventDescriptor,
  LPCGUID                ActivityId,
  ULONG                  UserDataCount,
  PEVENT_DATA_DESCRIPTOR UserData
);
```

Fig. 4.2: Documentation for EtwWrite function [1].

The first parameter is the registration handler. This object is returned once the provider executed the registration (**EtwRegister)** successfully. However, taking a look to **EtwRegister** it is possible to observe that it receives the GUID as parameter:



```cpp
NTSTATUS EtwRegister(
  LPCGUID            ProviderId,
  PETWENABLECALLBACK EnableCallback,
  PVOID              CallbackContext,
  PREGHANDLE         RegHandle
);
```

Fig. 4.3: Documentation for EtwRegister function [2].

This finding basically meant that having only one breakpoint in **EtwWrite** wasn't going to be enough as information from **EtwRegister** was also needed.

In other words, to understand if the write was being done by a provider registered against the DiagTrack session it was necessary to:

1. Extract the whole list of providers registered against the DiagTrack session.
2. Intercept all the **EtwRegister** executions and check if the GUID being used was inside the list.

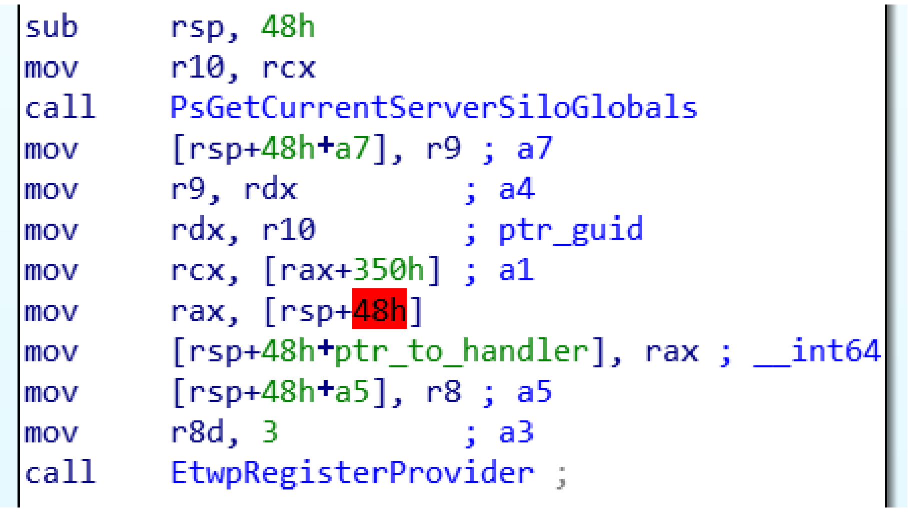
3. If it was, save the handler.
4. Intercept all the **EtwWrite** executions and check if the handler being used is one of the stored handlers.
5. If it was, the provider that is writing, is attached to the DiagTrack session.

Even though this strategy seemed to be theoretically promising, it was necessary to understand how to actually carry out each of these steps. Further sections will depict this process.

4.1.1 Reversing registration process

As mentioned in section 2.3.0.1, whenever a provider wants to register itself against a particular session it has to call the function **EtwRegister**. Because of this, the first step was to analyze the behavior of this function using **IDA**(2.2.1).

As can be seen in figure 4.4, the only interesting action being performed by **EtwRegister** was a call to another function named **EtwpRegisterProvider**.



```
sub     rsp, 48h
mov     r10, rcx
call    PsGetCurrentServerSiloGlobals
mov     [rsp+48h+a7], r9 ; a7
mov     r9, rdx         ; a4
mov     rdx, r10        ; ptr_guid
mov     rcx, [rax+350h] ; a1
mov     rax, [rsp+48h]
mov     [rsp+48h+ptr_to_handler], rax ; __int64
mov     [rsp+48h+a5], r8 ; a5
mov     r8d, 3          ; a3
call    EtwpRegisterProvider ;
```

Fig. 4.4: Dissasembly of ETWRegister function

A quick analysis of the latter function showed that it was the function holding the actual implementation of the registration process. However, due to the lack of documentation, it was necessary to understand in a more in-depth way what was actually happening inside it.

Following chapters will present a detailed description of reversing (partially, only the interesting parts for this research) **EtwpRegisterProvider**. To make it easier, it will be divided in different parts:

- 1. Understanding the layout of the function
- 2. Check if a GUID for this provider already exists.
- 3. If not, create a new one
- 4. Return the handler.

```
// 1. Understanding the layout of the function
signed __int64 __fastcall EtwpRegisterProvider(__int64 a1, _QWORD *a2, int a3,
    void (__fastcall *a4)(ULONG_PTR, __int64, __int128 *,__int64), __int64 a5,
    __int64 a6, __int64 *a7){

[..]

// 2. Check if a GUID for this provider already exists.
ptr_guid_entry = (char *)EtwpFindGuidEntryByGuid(etw_silo, ptr_guid, 0);

// 3. If not, create a new one
if ( ptr_guid_entry || (ptr_guid_entry = EtwpAddGuidEntry(ptr_etw_silo_cpy2,
    ptr_guid_cpy, 0)) != 0i64 )
{
  v15 = __readgsqword(0x188u);
  --*(_WORD *)(v15 + 484)

  [..]

  // 4. Return the handler.
  v35 = EtwpAddKmRegEntry((ULONG_PTR)ptr_guid_entry, v10, (__int64)v9, a5,
      (__int64)&ptr_handler);
  v20 = v35;

  [..]

}
return v20;
```

Fig. 4.5: EtwpRegisterProvider snippet .

4.1.1.1 1. Understanding the layout of the function

EtwpRegisterProvider received seven parameters:

```
signed __int64 __fastcall EtwpRegisterProvider(__int64 a1, _QWORD *a2,
       int a3, void (__fastcall *a4)(ULONG_PTR, __int64, __int128 *,
       __int64), __int64 a5, __int64 a6, __int64 *a7)
```

Usually when performing reverse engineering it is not necessary to understand every tiny detail but only the key points that are important to meet the proposed goals. This wasn't the exception.

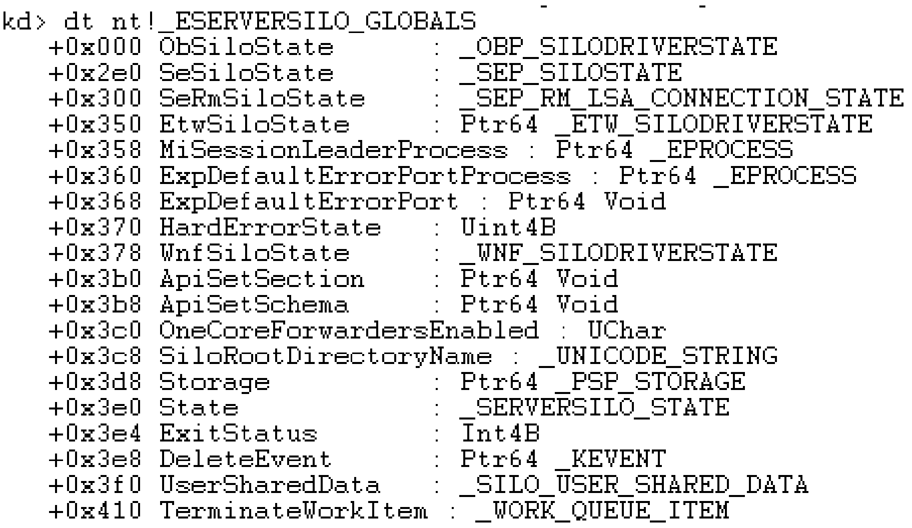
The main focus here was not to understand how the registration process fully worked but just to get an idea of it plus get to know the relation between GUID and registration handler.

After analyzing **EtwpRegisterProvider** it was possible to conclude that:

1. **a1**: Is the pointer to a structure.
2. **a2**: Is the pointer to the GUID structure.

3. **a7**: Is the address where the pointer to the registration handler will be placed (can be think as ”function output”).

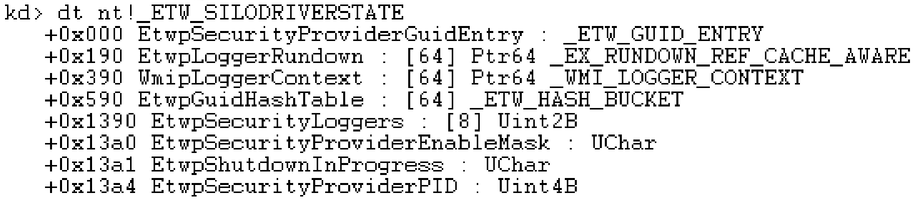
What is this **a1** structure? The figure 4.4 shows that before calling **EtwpRegisterProvider**, the function **PsGetCurrentServerSiloGlobals** is invoked. This latter one returns a pointer to a structure S of type **_ESERVERSILO_GLOBALS**.



```
kd> dt nt!_ESERVERSILO_GLOBALS
   +0x000 ObSiloState      : _OBP_SILODRIVERSTATE
   +0x2e0 SeSiloState      : _SEP_SILOSTATE
   +0x300 SeRmSiloState    : _SEP_RM_LSA_CONNECTION_STATE
   +0x350 EtwSiloState     : Ptr64 _ETW_SILODRIVERSTATE
   +0x358 MiSessionLeaderProcess : Ptr64 _EPROCESS
   +0x360 ExpDefaultErrorPortProcess : Ptr64 _EPROCESS
   +0x368 ExpDefaultErrorPort : Ptr64 Void
   +0x370 HardErrorState   : Uint4B
   +0x378 WnfSiloState     : _WNF_SILODRIVERSTATE
   +0x3b0 ApiSetSection    : Ptr64 Void
   +0x3b8 ApiSetSchema     : Ptr64 Void
   +0x3c0 OneCoreForwardersEnabled : UChar
   +0x3c8 SiloRootDirectoryName : _UNICODE_STRING
   +0x3d8 Storage          : Ptr64 _PSP_STORAGE
   +0x3e0 State            : _SERVERSILO_STATE
   +0x3e4 ExitStatus       : Int4B
   +0x3e8 DeleteEvent      : Ptr64 _KEVENT
   +0x3f0 UserSharedData   : _SILO_USER_SHARED_DATA
   +0x410 TerminateWorkItem : _WORK_QUEUE_ITEM
```

Fig. 4.6: _ESERVERSILO_GLOBALS structure layout (S).

However, the first parameter provided to **EtwpRegisterProvider** is not the pointer to S but is the pointer to another structure S_2 of type **_ETW_SILODRIVERSTATE**. which is part of S, more precisely, it is situated at offset 0x350.



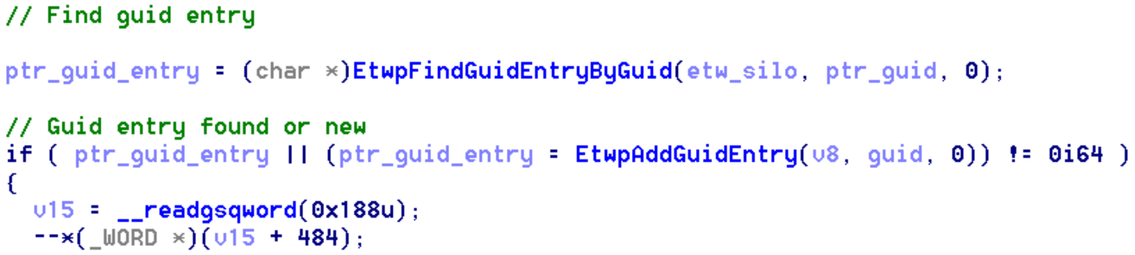
```
kd> dt nt!_ETW_SILODRIVERSTATE
   +0x000 EtwpSecurityProviderGuidEntry : _ETW_GUID_ENTRY
   +0x190 EtwpLoggerRundown : [64] Ptr64 _EX_RUNDOWN_REF_CACHE_AWARE
   +0x390 WmipLoggerContext : [64] Ptr64 _WMI_LOGGER_CONTEXT
   +0x590 EtwpGuidHashTable : [64] _ETW_HASH_BUCKET
   +0x1390 EtwpSecurityLoggers : [8] Uint2B
   +0x13a0 EtwpSecurityProviderEnableMask : UChar
   +0x13a1 EtwpShutdownInProgress : UChar
   +0x13a4 EtwpSecurityProviderPID : Uint4B
```

Fig. 4.7: _ETW_SILODRIVERSTATE structure layout (S_2).

With this information it was possible to conclude that **a1** will point to a global structure holding configurations, settings and information in general directly related with the **ETW** framework. **a2** and **a7** will hold pointers to a GUID and to a place were a registration handler will be stored afterwards.

With the information gathered from this analysis was enough to move forward.

Once inside the *EtwpRegisterProvider* function, after performing some sanity checks, it tries to get the guid entry related to the GUID provided. If it doesn’t exist, it will create one.



```
// Find guid entry

ptr_guid_entry = (char *)EtwpFindGuidEntryByGuid(etw_silo, ptr_guid, 0);

// Guid entry found or new
if ( ptr_guid_entry || (ptr_guid_entry = EtwpAddGuidEntry(v8, guid, 0)) != 0i64 )
{
  v15 = __readgsqword(0x188u);
  --*(_WORD *)(v15 + 484);
```

Fig. 4.8: First lines of EtwpRegisterProvider

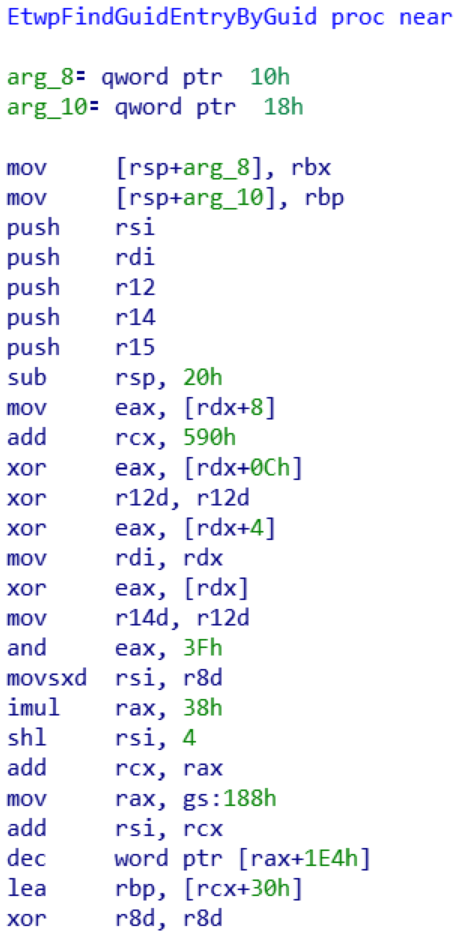
4.1.1.2 2. Check if GUID for this provider already exists

In this part, the focus will be on understanding how the process of recovering the already existing "GUID entry" works.

The action of recovering is performed by a particular function called **EtwpFindGuidEntryByGuid**:

```
ptr_guid_entry = (char *)EtwpFindGuidEntryByGuid(etw_silo, ptr_guid, 0);
```

As can be inferred from the previous line, two important parameters are provided: the **ETWSILODRIVERSTATE**(a1) structure S and the pointer to the GUID *ptr_guid*.



```
EtwpFindGuidEntryByGuid proc near

arg_8= qword ptr  10h
arg_10= qword ptr  18h

mov     [rsp+arg_8], rbx
mov     [rsp+arg_10], rbp
push    rsi
push    rdi
push    r12
push    r14
push    r15
sub     rsp, 20h
mov     eax, [rdx+8]
add     rcx, 590h
xor     eax, [rdx+0Ch]
xor     r12d, r12d
xor     eax, [rdx+4]
mov     rdi, rdx
xor     eax, [rdx]
mov     r14d, r12d
and     eax, 3Fh
movsxd  rsi, r8d
imul    rax, 38h
shl     rsi, 4
add     rcx, rax
mov     rax, gs:188h
add     rsi, rcx
dec     word ptr [rax+1E4h]
lea     rbp, [rcx+30h]
xor     r8d, r8d
```

Fig. 4.9: First basic block of EtwpFindGuidEntryByGuid.

Figure 4.9 depicts how the function gets the guid entry related to the provider (if it exists): rcx holds the pointer to S and rdx holds *ptr_guid*. Let's analyze this function deeper.

The first highlight is the *add* function which stores in rcx the pointer to the structure stored at the offset $0x590$ of S. Going back to the structure layout of S (figure 4.7), it can be appreciated that at the offset $0x590$, the structure $EtwpGuidHashTable$ of type *_ETW_HASH_BUCKET*[64] is present. Figure 4.11 depicts its layout.

Just before the *add* function, eax is filled with the content of the address $rdx + 8$. rdx held the *ptr_guid*, meaning that eax will have the third group of 4 bytes inside of the guid structure. Why the third? Because the offset was 8. Why 4 bytes? Because the register eax (32 bits) was used.

In the following lines, the value of eax is being constantly modified by xoring it successively with the different group of 4 bytes that compose the guid structure[3]. After performing these successive xor operations, a boolean and is applied against eax (result of xoring) using a mask of $0x3f$. This mask will set all eax bits to 0 with the exception of the

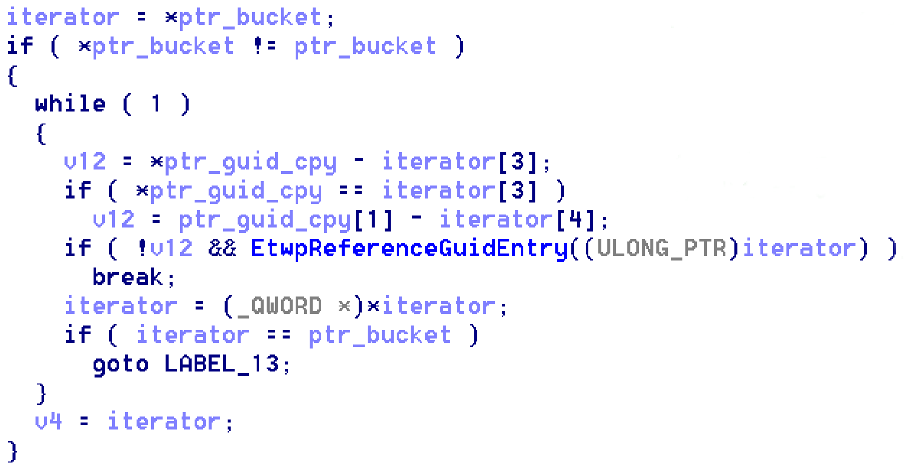
[3] Sometimes the structures weren't documented at all. Sometimes they were, but was not possible to find it until some kind of clue pointing to it was found. So far the layout of the structure pointed by *ptr_guid* was unknown, however from this function it was possible to conclude that the structure had a size of 16 bytes.

last 6 that will remain having its actual value. The reason to do this is because $2^6 = 64$. In other words, this mask is making the xoring result fit into the range of a valid bucket index. Afterwards, multiplies the result against $0x38$ (size of *_ETW_HASH_BUCKET* structure). Finally, the value of $rax(eax)$ is added to rcx which had the pointer to the *EtwpGuidHashTable* structure.

Writing the aforementioned function in a pseudo-code style (*ptr* is a short version of "pointer"):

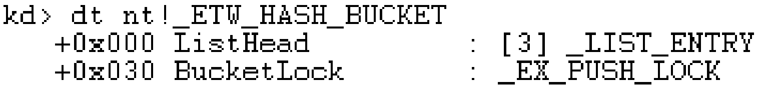
```
xor_guid_parts = ptr_guid[0] ^ ptr_guid[1] ^ ptr_guid[2] ^ ptr_guid[3]
ptr_hash_table = ptr_S + 0x590
ptr_bucket = ptr_hash_table + 0x38 * ((xor_guid_parts) & 0x3F)
```

Therefore, *ptr_bucket* is basically a pointer to a particular bucket inside the *EtwpGuidHashTable* calculated based on the GUID of the provider[4]. Once this value is obtained, a "look up" inside the structure is carried out in the following way:



```
iterator = *ptr_bucket;
if ( *ptr_bucket != ptr_bucket )
{
  while ( 1 )
  {
    v12 = *ptr_guid_cpy - iterator[3];
    if ( *ptr_guid_cpy == iterator[3] )
      v12 = ptr_guid_cpy[1] - iterator[4];
    if ( !v12 && EtwpReferenceGuidEntry((ULONG_PTR)iterator) )
      break;
    iterator = (_QWORD *)*iterator;
    if ( iterator == ptr_bucket )
      goto LABEL_13;
  }
  v4 = iterator;
}
```

Fig. 4.10: Part of EtwpFindGuidEntryByGuid function extracted using IDA Hex-Rays plugin.



```
kd> dt nt!_ETW_HASH_BUCKET
   +0x000 ListHead          : [3] _LIST_ENTRY
   +0x030 BucketLock        : _EX_PUSH_LOCK
```

Fig. 4.11: _ETW_HASH_BUCKET structure layout.

At first an iterator is built. This iterator will point initially to the Flink of the first list entry[5] of the bucket (figure 4.11). The right-after "if" will capture the special case were the list is empty. In that particular case, the whole cycle will be skipped and the **LABEL_13** (routine to exit, which isn't displayed in the figure) will be executed. It's worth to mention that this routine executes a return statement with the value of the variable $v4$ (which is initially defined as 0).

[4] There was also an additional value involved in the calculation of the bucket. However, in this particular context, the value wasn't taken into account as it was always 0.

[5] https://docs.microsoft.com/en-us/windows/desktop/api/ntdef/ns-ntdef-_list_entry

If the list is not empty, the first operation which is carried out is a subtraction between the first quadword of the GUID and a value of $iterator[3]$. Due to the variable $iterator$ is defined as a 8-bytes pointer, $iterator[3]$ will point to the offset $0x18$ of the structure stored inside the Flink. In the case that both values are equal, the second comparison (between the second quadword of the GUID and the $iteartor[4]$) is carried out.

At this point some things can be concluded:

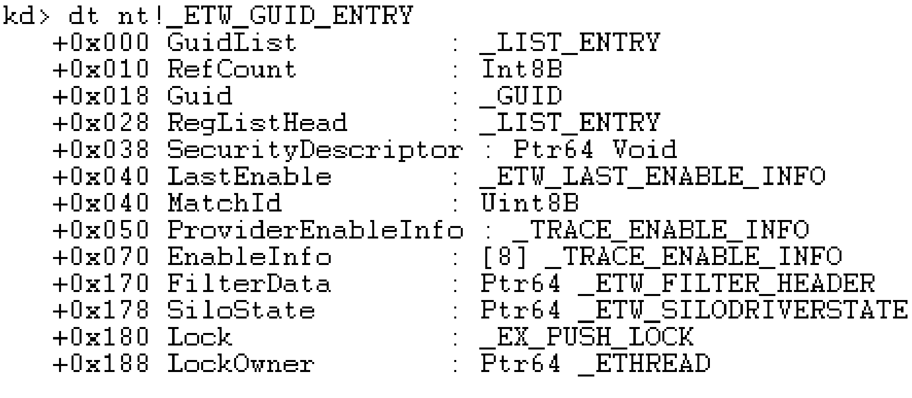
- The cycle is iterating a double-linked-list which holds a particular structure T.
- T has the GUID of the provider stored at offset $0x18$
- Again, seems that the GUID is 16 bytes long.
- From the function name it can concluded that T is a structure that represents the GUID entry.

Moving forward with the code analysis, if some of the comparisons failed, the iterator changes its values to the next one in the list. Before continuing, it ensures that the cycle is not finished by checking if the actual value of the iterator is the same one used as the starting point. If they are equal, the exit routine is executed meaning that the return value will be 0.

If both comparisons are equal (the GUID of the provider and the one stored in T are the same), a function called $EtwpReferenceGuidEntry$ with the current value of the iterator as parameter, is called. After this execution, the cycle is finished by the break statement. However, before executing the exit routine, the value of $v4$ is filled up with the value of the $iterator$, meaning that the return value will be pointer to the guid entry related to the GUID of the provider. The $EtwpReferenceGuidEntry$ function just made some security checks not relevant for this task.

Therefore, to summarize, it is possible to say that:
The function $EtwpFindGuidEntryByGuid$ looks for a particular structure (most probably called guid entry), which is stored inside a double-linked-list of a bucket inside the $EtwpGuidHashTable$ of the $\_ETW\_SILODRIVERSTATE$, based on doing some mathematical operations with the GUID of the provider.

After finishing with this analysis, the documentation of the guid entry structure was found:



```
kd> dt nt!_ETW_GUID_ENTRY
   +0x000 GuidList          : _LIST_ENTRY
   +0x010 RefCount          : Int8B
   +0x018 Guid              : _GUID
   +0x028 RegListHead       : _LIST_ENTRY
   +0x038 SecurityDescriptor : Ptr64 Void
   +0x040 LastEnable        : _ETW_LAST_ENABLE_INFO
   +0x040 MatchId           : Uint8B
   +0x050 ProviderEnableInfo : _TRACE_ENABLE_INFO
   +0x070 EnableInfo        : [8] _TRACE_ENABLE_INFO
   +0x170 FilterData        : Ptr64 _ETW_FILTER_HEADER
   +0x178 SiloState         : Ptr64 _ETW_SILODRIVERSTATE
   +0x180 Lock              : _EX_PUSH_LOCK
   +0x188 LockOwner         : Ptr64 _ETHREAD
```

Fig. 4.12: $\_ETW\_GUID\_ENTRY$ structure.

```
kd> dt nt!_GUID
   +0x000 Data1            : Uint4B
   +0x004 Data2            : Uint2B
   +0x006 Data3            : Uint2B
   +0x008 Data4            : [8] UChar
```

Fig. 4.13: _ETW_GUID structure.

Luckily, all the previous guesses made, were correct:

- The guid entry (now *_ETW_GUID_ENTRY*) had the GUID of at offset $0x18$ (figure 4.12)
- The GUID was a structure of 16 bytes long (figure 4.13)

4.1.1.3 3. If not found, create a new one

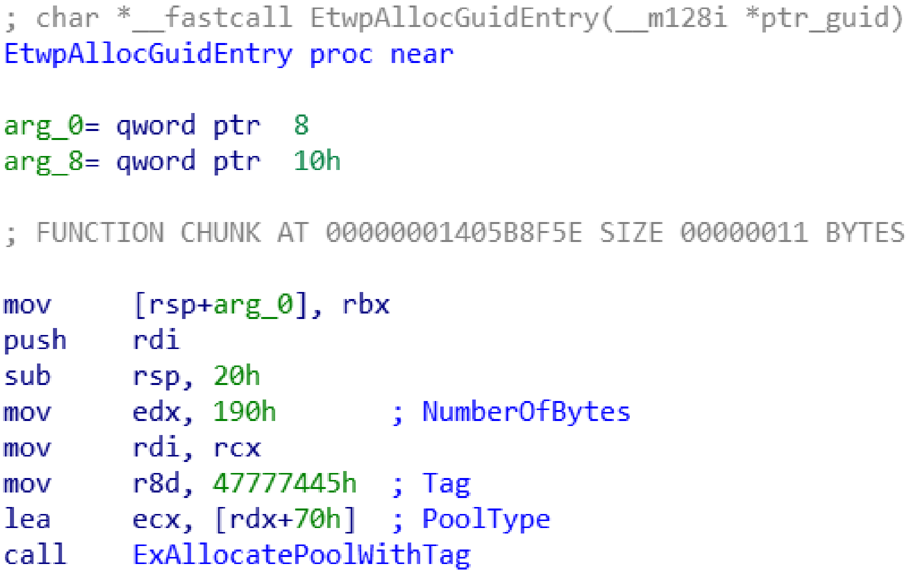
Previous section detailed how was the process to find an already existing guid entry based on the GUID of the provider. This one will explain the process of creating a new guid entry.

From figure 4.8 can be observed that the function in charge of this part is the function *EtwpAddGuidEntry*:

```
ptr_guid_entry = EtwpAddGuidEntry(ptr_etw_silo_cpy2, ptr_guid_cpy, 0)
```

As can be inferred from the previous line, two important parameters were provided: the pointer to the _ETW_SILODRIVERSTATE structure (for simplicity will be called *ptr_etw_silo* instead of *ptr_etw_silo_cpy*2) and the pointer to the GUID (for simplicity will be called *ptr_guid* instead of *ptr_guid_cpy*).

One of the first lines of *EtwpAddGuidEntry*, calls another function named *EtwpAllocGuidEntry*. As it can be quickly inferred from the name, it basically allocates certain amount of memory inside the heap to be used by the guid entry afterwards and returns the pointer to it. The allocation part happens in the first basic block of *EtwpAllocGuidEntry*:



```
; char *__fastcall EtwpAllocGuidEntry(__m128i *ptr_guid)
EtwpAllocGuidEntry proc near

arg_0= qword ptr  8
arg_8= qword ptr  10h

; FUNCTION CHUNK AT 00000001405B8F5E SIZE 00000011 BYTES

mov     [rsp+arg_0], rbx
push    rdi
sub     rsp, 20h
mov     edx, 190h       ; NumberOfBytes
mov     rdi, rcx
mov     r8d, 47777445h  ; Tag
lea     ecx, [rdx+70h]  ; PoolType
call    ExAllocatePoolWithTag
```

Fig. 4.14: EtwpAllocGuidEntry allocation.

As can be observed in figure 4.14 the Windows function *ExAllocatePoolWithTag*[6] is called with the following parameters:

- **PoolType**: 0x200 (**NonPagedPoolNx**). This value indicates that the system memory allocated will be nonpageable and not executable[7].
- **NumberOfBytes**: 0x190. This value is the size of the structure *_ETW_GUID_ENTRY* (figure 4.12).
- **Tag**: "0x47777445". According the documentation just a four character long to be used as the pool tag. Due to it is specified in reverse order: 0x45747747 → "EtwG".

Therefore, as it was thought, *EtwpAllocGuidEntry* allocs the necessary memory for holding the *_ETW_GUID_ENTRY* structure and returns a heap pointer to it.

The remaining code of *EtwpAddGuidEntry* is devoted to populate and adjust some parts of related structures. Some key points about it:

- A guid entry related to this GUID is looked up inside the guid entries double-linked list using the same technique as the one used in *EtwpFindGuidEntryByGuid*. If a structure is found, the pointer is freed.
- Only three parts of the *_ETW_GUID_ENTRY* structure are populated at this point:
  1. The pointer to the previous guid entry in the double-linked list (offset 0x0)
  2. The pointer to the following guid entry in the double-linked list (offset 0x8)
  3. The pointer to the SILO STATE (offset 0x178)

To summarize, once *EtwpAllocGuidEntry* is executed, the pointer to heap memory holding the *_ETW_GUID_ENTRY* structure is returned. The next step is insert this entry into *EtwpGuidHashTable*. To perform that action, first it looks for the correct place to insert it as depicted previously.

4.1.1.4 4. Return the handler

Going back to what the figure 4.3 states, the 4th parameter of *EtwRegister* it's something of type *PREGHANDLE*. Although it isn't very clear, this parameter is the output of the function (usually called "out" type of parameter). Furthermore, as it was mentioned previously the real registration logic is implemented by *EtwpRegisterProvider* therefore the output of *EtwRegister* is none other than the output of *EtwpRegisterProvider*.

Despite the fact the provider's GUID existed previously or not, at this point it exist a pointer to a *_ETW_GUID_ENTRY* structure holding its data and already inside the main structures of ETW. Once the code achieved this point, the next step is basically get the handler.

Just right after the pointer to the *_ETW_GUID_ENTRY* is found, the function *EtwpAddKmRegEntry* is called:

[6] Documentation: https://docs.microsoft.com/en-us/windows-hardware/drivers/ddi/content/wdm/nf-wdm-exallocatepoolwithtag

[7] Documentation: https://docs.microsoft.com/en-us/windows-hardware/drivers/ddi/content/wdm/ne-wdm-_pool_type

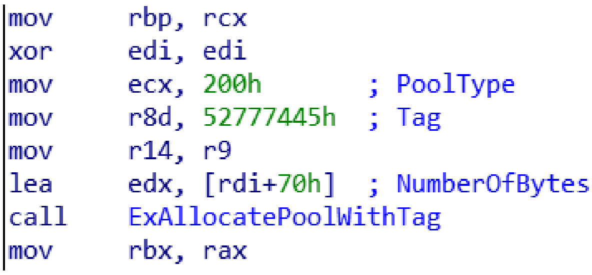
```
__int64 __usercall EtwpAddKmRegEntry(ULONG_PTR a1, int a2, __int64 a3,
__int64 a4, __int64 a5)
```

where :

1. **a1**: Is the pointer to *_ETW_GUID_ENTRY*, called *ptr_guid*.
2. **a5**: Is the memory address provided by *EtwWrite* (and afterwards by *EtwpRegisterProvider*) where the handler should be placed.

The remaining parameters are not interesting for the sake of our research.

Once inside *EtwpAddKmRegEntry*, the first important lines were:



```
mov     rbp, rcx
xor     edi, edi
mov     ecx, 200h       ; PoolType
mov     r8d, 52777445h  ; Tag
mov     r14, r9
lea     edx, [rdi+70h]  ; NumberOfBytes
call    ExAllocatePoolWithTag
mov     rbx, rax
```

Fig. 4.15: *EtwpAddKmRegEntry* allocation.

As can be inferred from 4.14, this is also an allocation in the heap:

- **PoolType**: 0x200 (**NonPagedPoolNx**).
- **NumberOfBytes**: 0x70. As depicted in the image, *rdi* is first set to 0.
- **Tag**: "0x52777445". According the documentation just a four character long to be used as the pool tag. Due to it is specified in reverse order: 0x45747752 → "EtwR".

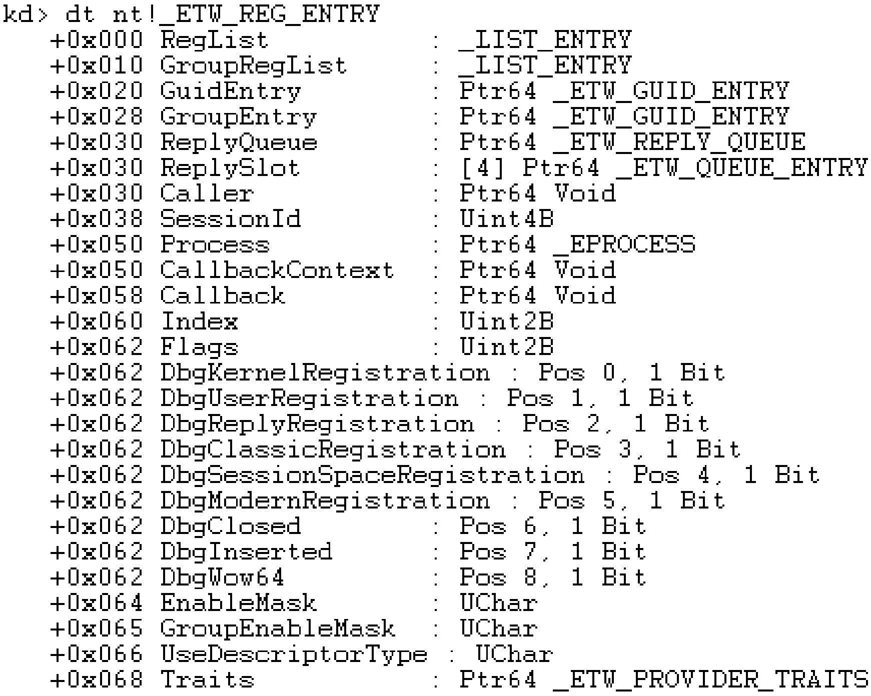
The analysis of the following lines of *EtwpAddKmRegEntry* showed how the aforementioned reserved space (structure) was being filled. While debugging this function the following line excelled from the rest:

```
mov     [rbx+20h], rbp
```

The reason to excelled was that, at that point, *rbp* held the pointer to the GUID entry. Meaning that this structure, potentially the registration handler structure, has the pointer to the GUID entry at offset 0x20. After finish filling the rest, the pointer to the structure is returned.

Going back to 4.5, it can be appreciated that the output of *EtwpAddKmRegEntry* is the output of *EtwpRegisterProvider* too. Which confirmed that this was the registration handler structure.

After finishing with this analysis, the documentation of the registration handler structure was found:



```
kd> dt nt!_ETW_REG_ENTRY
   +0x000 RegList          : _LIST_ENTRY
   +0x010 GroupRegList     : _LIST_ENTRY
   +0x020 GuidEntry        : Ptr64 _ETW_GUID_ENTRY
   +0x028 GroupEntry       : Ptr64 _ETW_GUID_ENTRY
   +0x030 ReplyQueue       : Ptr64 _ETW_REPLY_QUEUE
   +0x030 ReplySlot        : [4] Ptr64 _ETW_QUEUE_ENTRY
   +0x030 Caller           : Ptr64 Void
   +0x038 SessionId        : Uint4B
   +0x050 Process          : Ptr64 _EPROCESS
   +0x050 CallbackContext  : Ptr64 Void
   +0x058 Callback         : Ptr64 Void
   +0x060 Index            : Uint2B
   +0x062 Flags            : Uint2B
   +0x062 DbgKernelRegistration : Pos 0, 1 Bit
   +0x062 DbgUserRegistration : Pos 1, 1 Bit
   +0x062 DbgReplyRegistration : Pos 2, 1 Bit
   +0x062 DbgClassicRegistration : Pos 3, 1 Bit
   +0x062 DbgSessionSpaceRegistration : Pos 4, 1 Bit
   +0x062 DbgModernRegistration : Pos 5, 1 Bit
   +0x062 DbgClosed        : Pos 6, 1 Bit
   +0x062 DbgInserted      : Pos 7, 1 Bit
   +0x062 DbgWow64         : Pos 8, 1 Bit
   +0x064 EnableMask       : UChar
   +0x065 GroupEnableMask  : UChar
   +0x066 UseDescriptorType : UChar
   +0x068 Traits           : Ptr64 _ETW_PROVIDER_TRAITS
```

Fig. 4.16: _ETW_REG_ENTRY structure .

4.2 First steps into catching writes from providers

In section 4.1 an idea on how to answer two important questions was presented: Hook in the exact moment when providers write to DiagTrack's session. However the idea would have been unfeasible without the analysis performed in section 4.1.1.

At this point it is possible to detect if a particular provider is writing by knowing just its GUID. However it was important to understand to which session this provider was writing. For an initial analysis a mix between automatic and manual analysis was performed. A breakpoint in the function **EtwWrite** was set using the following Windbg(2.2.2) script:

```
bp nt!EtwWrite ".printf \"Handler: %N\\n\",@rcx"
```

This script just printed the address of provider's registration handle that is making a write (@*rcx* holds the first parameter of the function according to Windows x64 calling convention). Once the handler's address was obtained it was possible to get the GUID as well. Comparing the GUID with the output of the powershell command **Get-EtwTraceProvider** (without filters) threw an interesting result: Most of the time a provider with E02A841C-75A3-4FA7-AFC8-AE09CF9B7F23 as GUID was the one writing. This provider wasn't related with DiagTrack at all.

The following step was to filter out this provider:

```
bp nt!EtwWrite ".if (@rcx != ffffda839f0c2c50){.printf \"Handler:
    %N\\n\",@rcx;gc;}.else{gc;} "
```

Unfortunately, providers which weren't related to DiagTrack neither flooded the output of the script. Clearly, this wasn't a good path.

With the goal of pursuing interesting results, the function was changed by another one called **EtwWriteTransfer**:.

```
bp nt!EtwWriteTransfer ".if (@rcx != ffffda839f0c2c50){.printf \"Handler:
    %N\\n\",@rcx;gc;}.else{gc;}"
```

This time, a new provider attached to DiagTrack with GUID E9EAF418-0C07-464C-AD14-A7F353349A00 appeared. In order to get some more information, the script was updated once more to get the Call Stack of the provider's process:

```
bp nt!EtwWriteTransfer ".if (@rcx == FFFFDA83A036F0D0){.printf \"Handler:
    %N\\n\",@rcx;kc;gc;}.else{gc;} "

 Call Site
00 nt!EtwWriteTransfer
01 nt!TlgWrite
02 nt!CmpInitHiveFromFile
03 nt!CmpCmdHiveOpen
04 nt!CmLoadAppKey
05 nt!CmLoadDifferencingKey
06 nt!NtLoadKeyEx
07 nt!KiSystemServiceCopyEnd
08 ntdll!NtLoadKeyEx
09 0x0
```

At this point, the only way so far to detect when providers related to DiagTrack were writing consisted in two steps:

1. Hook in the ETW write function call.
2. Check if the provider is attached to DiagTrack based on its GUID and the output of the powershell command.

However, even if it was a DiagTrack's related provider the one writing, it is not enough to ensure that it is currently writing to DiagTrack's session as providers could be attached to several sessions.

This quick result made two new questions to be raised

1. 1. Is **EtwWrite** the only write function used? (clearly no!)
2. 2. How can we sure that a provider is actually writing to DiagTrack's session

Further and deeper analysis was needed.

4.2.1 ETW functions to write

A quick analysis of the symbols and cross references of the **ntoskrnl.exe** binary showed that there were actually a "group of functions" that could be used to perform writes within the ETW framework:

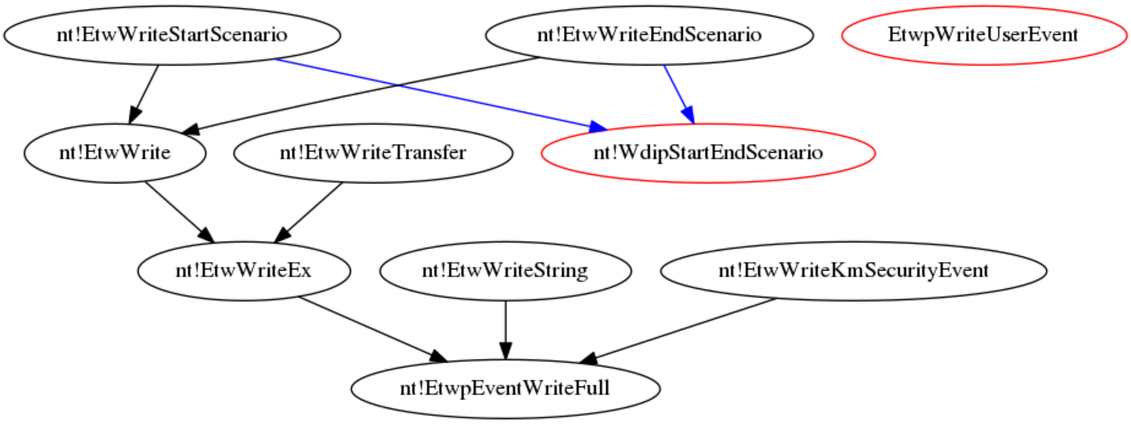


Fig. 4.17: Group of ETW Write functions.

As can be appreciated in figure 4.17 all functions end up calling either **nt!EtwpEventWriteFull** or **nt!EtwpWriteUserEvent** or **nt!WdispStartEndScenario**. After extensive analysis logging all actions and which functions were executed it was possible to detect that the function **nt!WdispStartEndScenario** was never called under the context of interest of this research and therefore it was possible to discard it from further analysis.

4.2.2 Ensuring providers write to DiagTrack session

The previous idea of only analyzing writes from providers that were returned by the powershell command had, at least, three problems:

1. The output of the powershell command returns the providers that are registered in a particular session at a given time t. If a provider registers, writes and unregisters itself from the session in a given time t_2 with $t_2 \neq t$, that write won't be took into consideration.
2. Even if the provider is registered against DiagTrack's session, this doesn't ensure the provider is currently writing to it.
3. It relied too much on manual analysis.

With these problems in mind new ideas started to appear. In particular there was one that made the difference: What if it's possible to relate the handler that it's used at the moment of writing, with the session where the provider going to write, somehow. If that's possible, the first two problems would be solved. The third one could be solved as only one breakpoint at the writing function will be enough to make the full analysis. In order to find this relationship, an analysis of different structures related to ETW had to be performed.

Following section will detail the process of analyzing this structures together with its results.

4.2.2.1 Inspecting ETW structures

So far it happened a lot that ETW structures were the key to overcome different obstacles. The first structure analyzed was *_ETW_REG_ENTRY* (figure 4.16) as it would have been the most direct and easier way to relate session and provider. Unfortunately, none of its components was helpful.

The next structure analyzed was *_WMI_LOGGER_CONTEXT*. This structure seemed to be represent an ETW session. Due to the size of this structure only the necessary and representative offsets are depicted:

```
+0x000 LoggerId         : Uint4B
+0x004 BufferSize       : Uint4B
+0x008 MaximumEventSize : Uint4B
+0x00c LoggerMode       : Uint4B
+0x010 AcceptNewEvents : Int4B
[...]
+0x070 ProviderBinaryList : _LIST_ENTRY
+0x080 BatchedBufferList : Ptr64 _WMI_BUFFER_HEADER
+0x080 CurrentBuffer  : _EX_FAST_REF
+0x088 LoggerName       : _UNICODE_STRING
+0x098 LogFileName      : _UNICODE_STRING
+0x0a8 LogFilePattern : _UNICODE_STRING
+0x0b8 NewLogFileName : _UNICODE_STRING
[...]
+0x428 LastBufferSwitchTime : _LARGE_INTEGER
+0x430 BufferWriteDuration : _LARGE_INTEGER
+0x438 BufferCompressDuration : _LARGE_INTEGER
```

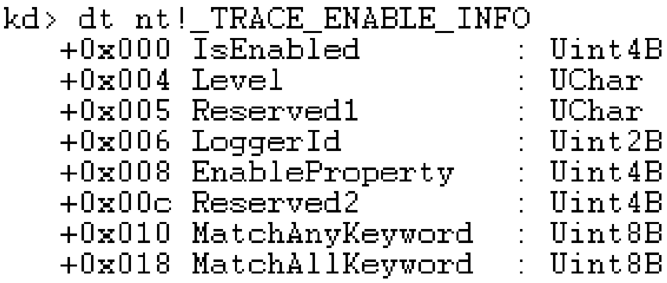
Fig. 4.18: _WMI_LOGGER_CONTEXT structure.

Each session created inside the ETW framework will be represented by one of this structures. At offset $0x70$ there is an attribute called **ProviderBinaryList**. After a quick analysis this attribute seemed to held all providers registered against the session in the format of a double linked list. In order to confirm that theory, the process of attaching new providers to an existing session was analyzed.

The function *nt!EtwpAddProviderToSession* seemed to be the one creating these links. However due to several reasons (lot of unknown new functions, hard to reverse and more) the analysis was cancelled. Besides the mentioned reasons there was one that was actually the one that made the preivous analysis to got cancelled: The finding of a new and promising structure.

4.2.2.2 New structure: Trace enable info

Among all structures related to the ETW there was one called *_TRACE_ENABLE_INFO*:



```
kd> dt nt!_TRACE_ENABLE_INFO
   +0x000 IsEnabled        : Uint4B
   +0x004 Level            : UChar
   +0x005 Reserved1        : UChar
   +0x006 LoggerId         : Uint2B
   +0x008 EnableProperty   : Uint4B
   +0x00c Reserved2        : Uint4B
   +0x010 MatchAnyKeyword  : Uint8B
   +0x018 MatchAllKeyword  : Uint8B
```

Fig. 4.19: Trace Enable Info structure.

This structure seemed to contain the relation between a session and the provider (bingo!). This structure was found by analysing *_ETW_GUID_ENTRY* and how it was used when executing writing functions. As can be seen in figure 4.12, at offset $0x50$ and $0x70$ there are structures of type *_TRACE_ENABLE_INFO*.

the first one... is.. the second one is an array...

nside the handler structure, we found one (seems to be special) of this guys and afterwards an array of 8 of them. Doing some empiric (TODO: Find this in the code) tests, I realize that if a provider is enabled for a session, then the ”special” one will have the activated field in 1, but nothing in the loggerid field. Seems that this ”special” is only for telling that the provider is enabled, but if you want more information about it you should go to each bucket of the array. Experience tell that if the ”special” has the field activated in 1, there must be at least one bucket in the array with information about a session. There, you'll find, in the loggerid field, so this is our link to the session!.

4.2.2.3 asdassds

1. We couldn't ensure that the data was being written was actually going to the DiagTrack session
.

4.3 When and how providers are registered

4.4 How writes are carried out

4.5 Relation between ETW session and ETW providers

4.6 Identifying the buffers

4.7 Provider GUID vs Group Provider GUID

4.8 Checking correctness of logged events

4.9 Automatization of event logging

4.10 Service isolation

4.11 Triggers

4.12 searching for new triggers

YARA

4.13 Difference among configuration levels of telemtry

4.14 Analysis of sent data over the channel to Microsfot backend services

5. RESULTS

6. CONCLUSIONS

GDPR?

7. APPENDIXES

7.1 Structures layout

- _ESERVERSILO_GLOBALS, figure 4.6
- _ETW_SILODRIVERSTATE, figure 4.7
- _ETW_HASH_BUCKET, figure 4.11
- _ETW_GUID_ENTRY, figure 4.12
- _GUID, figure 4.13

8. REFERENCES

BIBLIOGRAPHY

[1] Bolin Ding, Janardhan Kulkarni and Sergey Yekhanin. Collecting Telemetry Data Privately. In proceedings of Neural Information Processing Systems Conference (NIPS), 2017.

[2] Vasyl Pihur, Úlfar Erlingsson and Aleksandra Korolova. RAPPOR: Randomized Aggregatable Privacy-Preserving Ordinal Response. In CCS, pages 1054–1067, 2014

[3] Microsoft Corporation. Dynamic collection analysis and reporting of telemetry data. US 9,590,880 B2, 2017.

[4] Tarik Soulami. Inside Windows debugging. Chapter 12, 2012

[5] Hausi A. Miiller, Jens H. Jahnke, Kenny Wong ,Dennis B. Smith , Scott R. Tilley , Margaret-Anne Storey. Reverse Engineering: A Roadmap. In Proceedings of the Conference on The Future of Software Engineering, Pages 47-60, 2000.

[6] Bruce Dang, Alexandre Gazet, Sbastien Josse, Elias Bachaalany. Practical Reverse Engineering: x86, x64, ARM, Windows Kernel, Reversing Tools, and Obfuscation. 2014.