# MoVP 3.1 Detecting Malware Hooks in the Windows GUI Subsystem



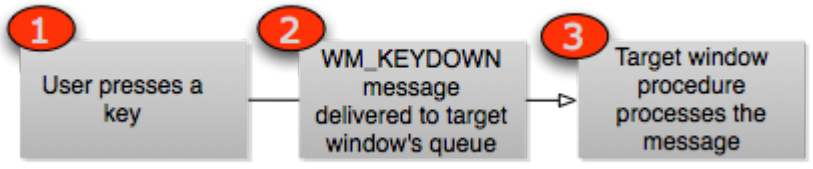
**Month of Volatility Plugins**

Applications can place hooks into the Windows GUI subsystem to customize the user experience, receive notification when certain actions take place, or to record everything the user does - for example to create a CBT training video. As you probably expected, this type of access and control is often exploited by malware for capturing keystrokes, injecting malicious DLLs into trusted processes, and other nefarious actions.

In this post, we'll discuss the undocumented Windows kernel data structures used to manage the two most popular classes of hooks - message hooks and event hooks. We'll also show how you can detect the installed hooks using new plugins for the Volatility memory forensics framework. This is significant because hooks are installed *very* frequently by malware, yet there are no forensic tools to detect and analyze these hooks. In fact, there aren't even many tools that run on live systems, except the old anti-rootkit IceSword (doesn't support all Windows versions) and the open source MsgHookLister (does not detect event hooks). Many sandboxes produce alerts when hooks are set, but they typically rely on pre-installed API hooks to determine when the involved functions are called.

## Message Hooks

When a user presses a key, the system generates a WM_KEYDOWN message and delivers it to the target window's queue. Typically the target window is the foreground window (i.e. the one the user is currently interacting with). When the message hits the queue, the owning thread wakes up and processes the message - which could mean appending it to a line being typed, taking some special action if the key is a "hot key" or even just ignoring it. The diagram below shows a very simplified diagram of a non-hooked messaging system:

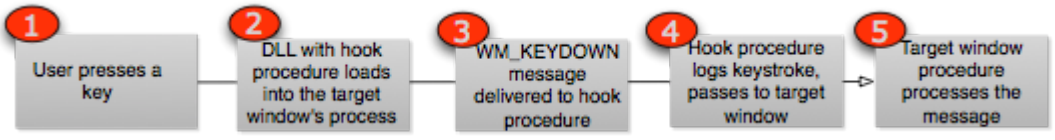



Message hooks can intercept these window messages before they reach the target window procedure. For example, by using SetWindowsHookEx with the WH_KEYBOARD filter, malware can essentially "spy" on the WM_KEYDOWN messages (and other keyboard operations), log them, and either pass them on to the intended application or prevent them from ever reaching the right place. This is one of the oldest and most effective ways to log keystrokes on Windows based systems.

Message hooks can also serve as a generic way of injecting a malicious DLL into a GUI process. Aside from the WH_* filter, the other parameters to SetWindowsHookEx include:

- an address to a hook procedure that will handle the message before the target window. This procedure is a function of type HOOKPROC that receives the message, processes it, and optionally passes it to the next hook in the chain (or the target window if there are no other hooks) with CallNextHookEx.
- a handle to the DLL that contains the hook procedure. This DLL is loaded into the address space of the thread that owns the target window.
- a thread ID (i.e. scope) for the hook. This can be a specific thread or 0 to affect all threads in the current desktop.

The diagram below shows how the messaging system works when hooks are installed. When a message is generated, the DLL containing the hook procedure is mapped into the address space of the specified thread(s), if it isn't already loaded. The message is passed to the hook procedure, which handles it as desired, and then finally, if allowed, the message reaches the target window procedure for normal processing.




Data Structures

The main data structure for message hooks is tagHOOK. The one below is from a Windows 7 x64 system.

>>> **dt("tagHOOK")**

'tagHOOK' (96 bytes)

0x0 : head ['_THRDESKHEAD']

0x28 : phkNext ['pointer64', ['tagHOOK']]

0x30 : iHook ['long']

0x38 : offPfn ['unsigned long long']

0x40 : flags ['Flags', {'bitmap': {'HF_INCHECKWHF': 8, 'HF_HOOKFAULTED': 4, 'HF_WX86KNOWNDLL': 6, 'HF_HUNG': 3, 'HF_FREED': 9, 'HF_ANSI': 1, 'HF_GLOBAL': 0, 'HF_DESTROYED': 7}}]

0x44 : ihmod ['long']

0x48 : ptiHooked ['pointer64', ['tagTHREADINFO']]

0x50 : rpdesk ['pointer64', ['tagDESKTOP']]

0x58 : fLastHookHung ['BitField', {'end_bit': 8, 'start_bit': 7, 'native_type': 'long'}]

0x58 : nTimeout ['BitField', {'end_bit': 7, 'start_bit': 0, 'native_type': 'unsigned long'}]

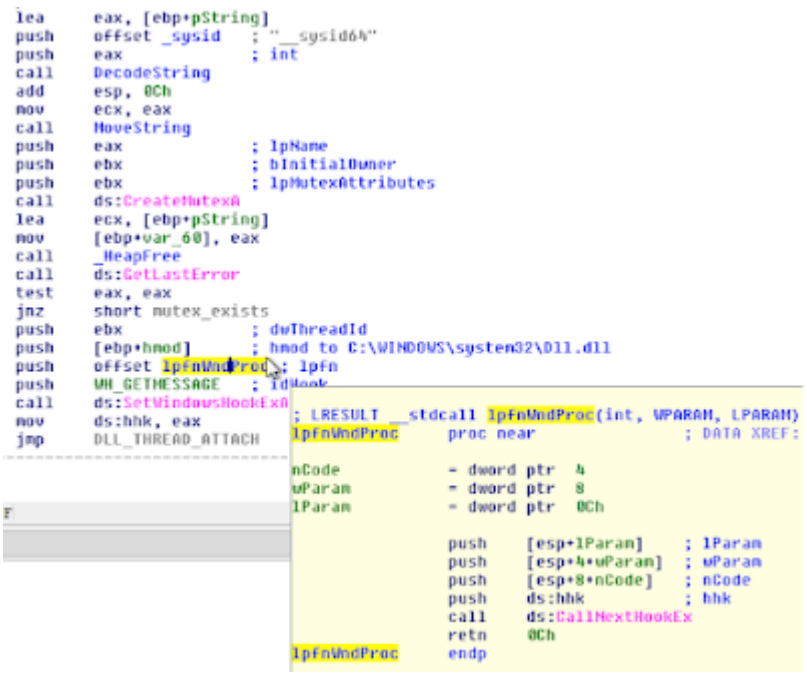
Key Points

- head is the common header for USER objects and can help identify the owning process or thread. More information on these headers will be published in a future MoVP post.
- phkNext is a pointer to the next hook in the chain. When a hook procedure calls CallNextHookEx, the system locates the next hook using this member.
- offPfn is an RVA (relative virtual address) to the hook procedure. The procedure can be in the same module as the code calling SetWindowsHookEx (for local, thread-specific hooks only) in which case ihmod will be -1. Otherwise, for global hooks, the procedure is in a DLL and ihmod is an index into win32k!_aatomSysLoaded (an array of atoms). To determine the name of the DLL, you must translate the ihmod into an atom and then obtain the atom name.
- ptiHooked can be used to identify the hooked thread.
- rpdesk can be used to identify the desktop in which the hook is set. Hooks cannot cross desktop boundaries.

The MessageHooks Plugin

The messagehooks plugin enumerates global hooks by finding all desktops and analyzing tagDESKTOP.pDeskInfo.aphkStart - an array of tagHOOK structures whose positions in the array indicate which type of message is to be filtered (such as WH_KEYBOARD or WH_MOUSE). The tagDESKTOP.pDeskInfo.fsHooks value can be used as a bitmap to tell you which positions in the array are actively being used. Likewise, for each thread attached to a desktop, the plugin scans for thread-specific hooks by looking at tagTHREADINFO.aphkStart and tagTHREADINFO.fsHooks.

The disassembly below shows malware installing a WM_GETMESSAGE hook. This is an example of malware using SetWindowsHookEx as simply a means to load DLLs in other processes (not to actually monitor/intercept messages sent to/from other windows). You can tell because the lpfnWndProc is empty - it just passes control to the next hook in the chain using CallNextHookEx. Also note the dwThreadId parameter (ebx) is going to be 0, which means the hook is global and will affect all GUI threads in the desktop.




Running the messagehooks plugin on a memory dump infected with this malware will show results such as the following:

$ **python vol.py -f laqma.vmem messagehooks --output=block**

Volatile Systems Volatility Framework 2.1_alpha

Offset(V) : 0xbc693988

Session : 0

Desktop : WinSta0\Default

Thread : <any>

Filter : WH_GETMESSAGE

Flags : HF_ANSI, HF_GLOBAL

Procedure : 0x1fd9

ihmod : 1

Module : C:\WINDOWS\system32\Dll.dll

Offset(V) : 0xbc693988

Session : 0

Desktop : WinSta0\Default

Thread : 1584 (explorer.exe 1624)

Filter : WH_GETMESSAGE

Flags : HF_ANSI, HF_GLOBAL

Procedure : 0x1fd9

ihmod : 1

Module : C:\WINDOWS\system32\Dll.dll

Offset(V) : 0xbc693988

Session : 0

Desktop : WinSta0\Default

Thread : 252 (VMwareUser.exe 1768)

Filter : WH_GETMESSAGE

Flags : HF_ANSI, HF_GLOBAL

Procedure : 0x1fd9

ihmod : 1

Module : C:\WINDOWS\system32\Dll.dll

[snip]

As you can see, all of the hooks are global, because the flags include HF_GLOBAL. That means they're the direct result of calling SetWindowsHookEx with the dwThreadId parameter set to 0. Although *all* global hooks are not malicious, out of the malware samples I've seen that hook window messages, they typically do use global hooks.

The difference between the three hooks shown is that the first one is global and was gathered from the tagDESKTOP structure. You can tell because the target thread is "<any>". This is essentially just telling you that any GUI threads that run in the WinSta0\Default desktop *will* be subject to monitoring by the malware. The next two are associated with specific threads (as a result of the global hook) and have caused Dll.dll to be injected into explorer.exe and VMwareUser.exe.

We already know from the disassembly that the lpfnWndProc is empty - this hook just exists to inject a DLL into other processes. However, don't overlook the fact that the messagehooks plugin shows you the address (as an RVA) of the hook procedure in the DLL. In the examples shown the hook procedure can be found at 0x1fd9 from the base of Dll.dll in the affected processes. Thus if you didn't preemptively know the purpose of a hook, you can easily use volshell and switch into the target process' contexts and disassemble the function.

Below, we first locate the base address (0xac0000) of the injected DLL inside explorer.exe. Next we disassemble the code at offset 0x1fd9:

$ **python vol.py -f laqma.vmem dlllist -p 1624 | grep Dll.dll**
Volatile Systems Volatility Framework 2.2_alpha
**0x00ac0000** 0x8000 C:\Documents and Settings\Mal Ware\Desktop\Dll.dll

$ **python vol.py -f laqma.vmem volshell**
Volatile Systems Volatility Framework 2.2_alpha
Current context: process System, pid=4, ppid=0 DTB=0x31a000
Welcome to volshell! Current memory image is:
file:///Users/Michael/Desktop/laqma.vmem
To get help, type 'hh()'
>>> **cc(pid = 1624)**
Current context: process explorer.exe, pid=1624, ppid=1592 DTB=0x80001c0
>>> **dis(0x00ac0000 + 0x00001fd9)**
0xac1fd9 ff74240c PUSH DWORD [ESP+0xc]
0xac1fdd ff74240c PUSH DWORD [ESP+0xc]
0xac1fe1 ff74240c PUSH DWORD [ESP+0xc]
0xac1fe5 ff350060ac00 PUSH DWORD [0xac6000]
0xac1feb ff157c40ac00 CALL DWORD [0xac407c] ; CallNextHookEx
0xac1ff1 c20c00 RET 0xc

Event Hooks

Event hooks can be used by applications to receive notification when certain events occur. Similar to message hooks, the SetWinEventHook API function can also be used to generically load a DLL into any processes that fire events, such as explorer.exe. For example, Explorer uses events when sounds are played (EVENT_SYSTEM_SOUND), when a scroll operation begins (EVENT_SYSTEM_SCROLLSTART), or when an item in a menu bar such as the Start menu is selected (EVENT_SYSTEM_MENUSTART). If malware doesn't care about the type of event (just that it can load a DLL into the remote process), it will use EVENT_MIN and EVENT_MAX, which apply to all events. This is a quick and effective way to execute code in the context of a remote process.

Data Structures

The data structure for event hooks is tagEVENTHOOK. Microsoft does not document this internal structure (even in the public Windows 7 PDBs), so its fields and offsets are reverse engineered from win32k.sys binaries.

>>> **dt("tagEVENTHOOK")**
'tagEVENTHOOK' (None bytes)
0x18 : phkNext ['pointer', ['tagEVENTHOOK']]
0x20 : eventMin ['Enumeration', {'target': 'unsigned long', 'choices': {1: 'EVENT_MIN', 2: 'EVENT_SYSTEM_ALERT', [snip]
0x24 : eventMax ['Enumeration', {'target': 'unsigned long', 'choices': {1: 'EVENT_MIN', 2: 'EVENT_SYSTEM_ALERT', [snip]

```
0x28  : dwFlags                ['unsigned long']
0x2c  : idProcess              ['unsigned long']
0x30  : idThread               ['unsigned long']
0x40  : offPfn                 ['unsigned long long']
0x48  : ihmod                  ['long']
```

Key Points

- phkNext is the next hook in the chain
- eventMin is the lowest system event that the hook applies to
- eventMax is the highest system event that the hook applies to
- dwFlags tells you if the process generating the event will load the DLL containing the event hook procedure into its address space (WINEVENT_INCONTEXT). It also tells you if the thread installing the hook wishes to be except from the hook (WINEVENT_SKIPOWNPROCESS and WINEVENT_SKIPOWNTHREAD).
- idProcess is the pid of the target process, or 0 for all processes in the desktop
- idThread is the tid of the target thread, or 0 for all threads in the desktop
- offPfn is the RVA to the hook procedure in the DLL
- ihmod is the index into the win32k!_aatomSysLoaded array, which can be used to identify the full path to the DLL containing the hook procedure (see ihmod in the message hook section).

The EventHooks Plugin

The eventhooks plugin leverages Volatility's API for USER handles (to be presented in a future MoVP post) and it filters TYPE_WINEVENTHOOK types. Before showing the plugin output, here's a quick volshell demo script so you can see exactly how the API works. The goal is to print the thread IDs that installed the hooks and associate them with the hooked threads. The code first enumerates all unique sessions and finds each session's shared information structure. Then it walks the handle table looking for event hooks. Finally, it calls _HANDLEENTRY.reference_object() which basically casts the handle entry's phead pointer as a tagEVENTHOOK.

```
$ python vol.py -f win7x64.dd --profile=Win7SP1x64 volshell

Volatile Systems Volatility Framework 2.1_alpha

Current context: process System, pid=4, ppid=0 DTB=0x187000

Welcome to volshell! Current memory image is:

file:///Users/Michael/Desktop/win7x64.dd

>>> for session in gui_utils.session_spaces(self.addrspace):

...   shared_info = session.find_shared_info()

...   for handle in shared_info.handles():
```

```
... if str(handle.bType) == "TYPE_WINEVENTHOOK":
... event_hook = handle.reference_object()
... print "Hook for tid", event_hook.idThread, "installed by", handle.Thread.Cid.UniqueThread
...
```

Hook for tid 0 installed by 1516

Now let's view the full eventhooks output for this Windows 7 x64 system:

```
$ python vol.py -f  win7x64.dd --profile=Win7SP1x64 eventhooks
```

Volatile Systems Volatility Framework 2.1_alpha

Handle: 0x300cb, Object: 0xfffff900c01eda10, Session: 1

Type: TYPE_WINEVENTHOOK, Flags: 0, Thread: 1516, Process: 880

eventMin: 0x4 EVENT_SYSTEM_MENUSTART

eventMax: 0x7 EVENT_SYSTEM_MENUPOPUPEND

Flags: none, offPfn: 0xff567cc4, idProcess: 0, idThread: 0

ihmod: -1

There is one event hook installed, by a thread of the process 880 (explorer.exe). The types of events being filtered are menu operations and desktop switches. Since ihmod is -1 for the hook, you know the offPfn hook procedure is located in explorer.exe itself and not a loaded DLL. Thus, most likely this hook is not malicious. Why would we show a benign example? Because you need to be able to distinguish for yourself during your own investigations. If the hook was malicious, it would look very similar to the message hooks in the previous section - it would be global and the hook procedure would be inside a DLL.

## Conclusion

Message and Event hooks are similar to API hooks (such as trampoline, IAT, EAT hooks) in that they allow malware to redirect the normal flow of execution to attacker-designed functions. Yet they are also unique because they're legitimate components of the GUI subsystem just being used in a malicious manner. They don't rely on overwriting pointers or patching instructions in process or kernel memory, so typical API-hook detecting utilities won't catch them. The low-level internals and data structures are completely undocumented, which explains why there aren't many tools, much less forensic tools, that can analyze a system in the way that Volatility now can.

More information on the messagehooks and eventhooks plugin and its usages in forensic investigations will be presented at Open Memory Forensics Workshop (OMFW) 2012.

---