

The Art of Unpacking

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Abstract: Unpacking is an art—it is a mental challenge and is one of the most exciting mind games in the reverse engineering field. In some cases, the reverser needs to know the internals of the operating system in order to identify or solve very difficult anti-reversing tricks employed by packers/protectors, patience and cleverness are also major factors in a successful unpack. This challenge involves researchers creating the packers and on the other side, the researchers that are determined to bypass these protections.

The main purpose of this paper is to present anti-reversing techniques employed by executable packers/protectors and also discusses techniques and publicly available tools that can be used to bypass or disable these protections. This information will allow researchers, especially, malcode analysts to identify these techniques when utilized by packed malicious code, and then be able to decide the next move when these anti-reversing techniques impede successful analysis. As a secondary purpose, the information presented can also be used by researchers that are planning to add some level of protection in their software by slowing down reversers from analyzing their protected code, but of course, nothing will stop a skilled, informed, and determined reverser.

Keywords: reverse engineering, packers, protectors, anti-debugging, anti-reversing

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1. INTRODUCTION

In the reverse engineering field, packers are one of the most interesting puzzles to solve. In the process of solving these puzzles, the reverser gains more knowledge about a lot of things such operating system internals, reversing tricks, tools and techniques.

Packers (the term used in this paper for both compressors and protectors) are created to protect an executable from analysis. They are used legitimately by commercial applications to prevent information disclosure, tampering and piracy. Unfortunately, malcodes also use packers for the same reasons but for a malicious purpose.

Due to a large number of packed malcode, researchers and malcode analysts started to develop the skills to unpack samples for analysis. However, as time goes by, new anti-reversing techniques are constantly added into packers to prevent reversers from analyzing the protected executable and preventing a successful unpack. And the cycle goes on - new anti-reversing techniques are developed while reversers on the other side of the fence develop the skills, techniques, and tools to defeat them.

The main focus of this paper is to present anti-reversing techniques employed by packers, tools and techniques on how to bypass/disable these protections are also discussed. Conversely, some packers can easily be bypassed by process dumping and thus, dealing with anti-reversing techniques seems unnecessary. However, there are instances where the protector code needed to be traced and analyzed, such as:

- Parts of the protector code needed to be bypassed in order for a process dumping and import table rebuilding tool to properly work
- In-depth analysis of a protector code in order to integrate unpacking support into an AV product

Additionally, understanding anti-reversing techniques is also valuable in cases where they are directly applied to a malcode in order prevent tracing and analysis of their malicious routines.

This paper is by no means contain a complete list of anti-reversing techniques as it only covers the commonly used and interesting techniques found in packers. The reader is advised to refer to the last section which contains links and books information to learn more about other anti-reversing and reversing techniques.

The author hopes that the reader found this material useful and able to apply the tips, tricks and techniques presented. Happy Unpacking!

2. TECHNIQUES: DEBUGGER DETECTION

This section lists the techniques used by packers to determine if the process is being debugged, or if a debugger is running in the system. These debugger detection techniques range from the very simple (and obvious) checks to the one that deals with native APIs and kernel objects.

2.1. PEB.BeingDebugged Flag: IsDebuggerPresent()

The most basic debugger detection technique involves checking the BeingDebugged flag in the Process Environment Block (PEB)¹. The kernel32!IsDebuggerPresent() API checks the value of this flag to identify if the process is being debugged by a user-mode debugger.

The code below shows the actual implementation of the IsDebuggerPresent() API. It accesses the Thread Environment Block (TEB)² in order to get the address of PEB, and then checks the BeingDebugged flag at offset 0x02 of the PEB.

```

: mov     eax, large fs:18h
: mov     eax, [eax+30h]
: movzx  eax, byte ptr [eax+2]
: retn

```

Instead of calling IsDebuggerPresent(), some packers manually checks the PEB for the BeingDebugged flag, this is in case a reverser sets a breakpoint or patch the said API.

Example

Below is an example code for identifying if a debugger is present using the IsDebuggerPresent() API and the PEB.BeingDebugged flag:

```

; call kernel32!IsDebuggerPresent()
call    [IsDebuggerPresent]
test    eax,eax
jnz     .debugger_found

; check PEB.BeingDebugged directly
mov     eax,dword [fs:0x30]    ;EAX = TEB.ProcessEnvironmentBlock
movzx   eax,byte [eax+0x02]    ;AL = PEB.BeingDebugged
test    eax,eax
jnz     .debugger_found

```

Since these checks are very obvious, packers obfuscate them by using garbage codes or anti-disassembly techniques discussed in later sections.

Solution

This technique can be easily bypassed by manually patching the PEB.BeingDebugged flag with the byte value of 0x00. To view the PEB in OllyDbg, in the data window, press Ctrl+G (Goto Expression), type fs:[30].

Additionally, the Ollyscript³ command "dbh" patches the said byte:

```

: dbh

```

Finally, the Olly Advanced³ plugin has an option to set the BeingDebugged field to 0.

¹ Data type of the PEB structure is _PEB which can be viewed in WinDbg using the dt command

² Data type of the TEB structure is _TEB

³ See the TOOLS section for more information about these tools

2.2. PEB.NtGlobalFlag, Heap.HeapFlags, Heap.ForceFlags

PEB.NtGlobalFlag. The PEB has another field called NtGlobalFlag (offset 0x68) which packers also use to detect if a program had been loaded by a debugger. Normally, when a process is not being debugged, the NtGlobalFlag field contains the value 0x0, however, if the process is being debugged, the said field will usually contain the value 0x70 which signifies the following flags are set:

- FLG_HEAP_ENABLE_TAIL_CHECK (0x10)
- FLG_HEAP_ENABLE_FREE_CHECK (0x20)
- FLG_HEAP_VALIDATE_PARAMETERS (0x40)

These flag are set inside the ntdll!LdrpInitializeExecutionOptions(). Note that the default value of PEB.NtGlobalFlag can be overridden using the gflags.exe tool or by creating an entry in the following registry key:

```
HKLM\Software\Microsoft\Windows NT\CurrentVersion\Image File Execution
Options
```

Heap Flags. Due to the flags set in NtGlobalFlag, heaps that are created will have several flags turned on, and that this behavior can be observed inside ntdll!RtlCreateHeap(). Typically, the first heap created for the process will have its Flags and ForceFlags fields⁴ set to 0x02 (HEAP_GROWABLE) and 0x0 respectively. However, when a process is being debugged, these flags are usually set to 0x50000062 (depending on the NtGlobalFlag) and 0x40000060 (which is Flags AND 0x6001007D). By default, the following additional heap flags are set when a heap is created on a debugged process:

- HEAP_TAIL_CHECKING_ENABLED (0x20)
- HEAP_FREE_CHECKING_ENABLED (0x40)

Example

The example code below checks if PEB.NtGlobalFlag is not equal to 0, and if additional flags are set in the first heap created for the process (PEB.ProcessHeap):

```
;ebx = PEB
mov     ebx,[fs:0x30]

;Check if PEB.NtGlobalFlag != 0
cmp     dword [ebx+0x68],0
jne     .debugger_found

;eax = PEB.ProcessHeap
mov     eax,[ebx+0x18]

;Check PEB.ProcessHeap.Flags
cmp     dword [eax+0x0c],2
jne     .debugger_found

;Check PEB.ProcessHeap.ForceFlags
cmp     dword [eax+0x10],0
jne     .debugger_found
```

Solution

The solution is to patch PEB.NtGlobalFlag and PEB.HeapProcess flags to their corresponding values as if the process is not being debugged. The following is an example ollyscript to patch the said flags:

```
var     peb
var     patch_addr
```

⁴ Data type for the heap structure is _HEAP

```

var    process_heap

//retrieve PEB via a hardcoded TEB address (first thread: 0x7ffde000)
mov    peb,[7ffde000+30]

//patch PEB.NtGlobalFlag
lea    patch_addr,[peb+68]
mov    [patch_addr],0

//patch PEB.ProcessHeap.Flags/ForceFlags
mov    process_heap,[peb+18]
lea    patch_addr,[process_heap+0c]
mov    [patch_addr],2
lea    patch_addr,[process_heap+10]
mov    [patch_addr],0

```

Also, the Olly Advanced plugin has an option to set PEB.NtGlobalFlags and the PEB.ProcessHeap flags.

2.3. DebugPort: CheckRemoteDebuggerPresent() / NtQueryInformationProcess()

Kernel32!CheckRemoteDebuggerPresent() is another API which can be used to determine if a debugger is attached to the process. This API internally invokes ntdll!NtQueryInformationProcess() with the ProcessInformationClass parameter set to ProcessDebugPort (7). Furthermore, inside the kernel, NtQueryInformationProcess() queries the DebugPort field of the EPROCESS⁵ kernel structure. A non-zero value in the DebugPort field indicates that the process is being debugged by user-mode debugger, if that is the case, ProcessInformation will be set with the value 0xFFFFFFFF, otherwise, ProcessInformation will be set with the value 0x0.

Kernel32!CheckRemoteDebuggerPresent() accepts 2 parameters, the first parameter is the process handle and the second parameter is a pointer to a boolean variable that will contain a TRUE value if the process is being debugged.

```

BOOL CheckRemoteDebuggerPresent(
    HANDLE hProcess,
    PBOOL pbDebuggerPresent
)

```

Ntdll!NtQueryInformationProcess() on the other hand, have 5 parameters. For the purpose of detecting a debugger, the ProcessInformationClass is set to ProcessDebugPort (7):

```

NTSTATUS NTAPI NtQueryInformationProcess(
    HANDLE ProcessHandle,
    PROCESSINFOCLASS ProcessInformationClass,
    PVOID ProcessInformation,
    ULONG ProcessInformationLength,
    PULONG ReturnLength
)

```

Example

The example below shows a typical call to CheckRemoteDebuggerPresent() and NtQueryInformationProcess() to detect if the current process is being debugged:

```

; using kernel32!CheckRemoteDebuggerPresent()
lea    eax,[.bDebuggerPresent]
push   eax                ;pbDebuggerPresent
push   0xffffffff        ;hProcess
call   [CheckRemoteDebuggerPresent]
cmp    dword [.bDebuggerPresent],0

```

⁵ Data type of the EPROCESS structure is _EPROCESS

```

jne     .debugger_found

; using ntdll!NtQueryInformationProcess(ProcessDebugPort)
lea     eax,[.dwReturnLen]
push   eax           ;ReturnLength
push   4             ;ProcessInformationLength
lea     eax,[.dwDebugPort]
push   eax           ;ProcessInformation
push   ProcessDebugPort ;ProcessInformationClass (7)
push   0xffffffff    ;ProcessHandle
call   [NtQueryInformationProcess]
cmp    dword [.dwDebugPort],0
jne     .debugger_found

```

Solution

One solution involves setting a breakpoint where `NtQueryInformationProcess()` returns, then when the breakpoint is hit, `ProcessInformation` is patched with a `DWORD` value 0. An example ollyscript to perform this automatically is shown below:

```

var     bp_NtQueryInformationProcess

// set a breakpoint handler
eob     bp_handler_NtQueryInformationProcess

// set a breakpoint where NtQueryInformationProcess returns
gpa     "NtQueryInformationProcess", "ntdll.dll"
find    $RESULT, #C21400# //retn 14
mov     bp_NtQueryInformationProcess,$RESULT
bphws   bp_NtQueryInformationProcess,"x"
run

bp_handler_NtQueryInformationProcess:
//ProcessInformationClass == ProcessDebugPort?
cmp     [esp+8], 7
jne     bp_handler_NtQueryInformationProcess_continue

//patch ProcessInformation to 0
mov     patch_addr, [esp+c]
mov     [patch_addr], 0

//clear breakpoint
bphwc   bp_NtQueryInformationProcess

bp_handler_NtQueryInformationProcess_continue:
run

```

The Olly Advanced plugin has an option to patch `NtQueryInformationProcess()`. The patch involves injecting a code that will manipulate the return value of `NtQueryInformationProcess()`.

2.4. Debugger Interrupts

This technique uses the fact that when the instructions `INT3` and `INT1` are stepped thru inside a debugger, by default, the exception handler will not be invoked since debuggers typically handle these debugger interrupts. Thus, a packer can set flags inside the exception handler, and if these flags are not set after the `INT` instruction, it means that the process is being debugged. Additionally, `kernel32!DebugBreak()` internally invokes an `INT3` and some packers use the said API instead.

Example

This example sets the value of `EAX` to `0xFFFFFFFF` (via the `CONTEXT`⁶ record) while inside exception handler to signify that the exception handler had been called:

⁶ A context record contains the state of a thread; its data type is `_CONTEXT`. The context record passed to the exception handler is the current state of the thread that thrown the exception

```

;set exception handler
push    .exception_handler
push    dword [fs:0]
mov     [fs:0], esp

;reset flag (EAX) invoke int3
xor     eax,eax
int3

;restore exception handler
pop     dword [fs:0]
add     esp,4

;check if the flag had been set
test    eax,eax
je      .debugger_found

:::

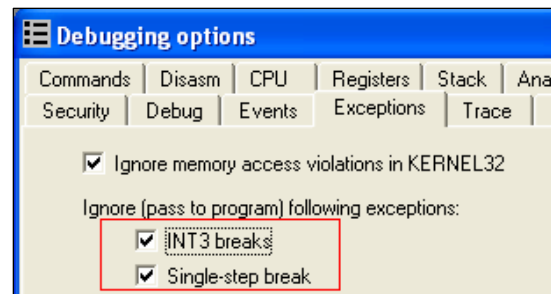
.exception_handler:
;EAX = ContextRecord
mov     eax,[esp+0xc]
;set flag (ContextRecord.EAX)
mov     dword [eax+0xb0],0xffffffff
;set ContextRecord.EIP
inc     dword [eax+0xb8]
xor     eax,eax
retn

```

Solution

In OllyDbg, while stepping thru or execution had stopped due to a debugger interrupt, identify the exception handler address (via View -> SEH Chain) and then set a breakpoint on the exception handler. Then, press Shift+F9 to pass the debugger interrupts/exception to the exception handler. The breakpoint will eventually be hit and the exception handler can be traced.

Another solution is to allow debugger interrupts to be automatically passed to the exception handler. This can be set in OllyDbg via Options -> Debugging Options -> Exceptions -> "Ignore following exceptions" and then check the "INT 3 breaks" and "Single-step break" check boxes.



2.5. Timing Checks

When a process is being debugged, several CPU cycles are spent by the debugger event handling code, a reverser stepping thru the instructions, etc. Packers takes advantage of this by determining the time spent between several instructions, if the time spent took longer compared to a normal run, it probably means that the process is being executed under a debugger.

Example

Below is a simple example of a timing check. It uses the RDTSC (Read Time-Stamp Counter) instruction before and after several instructions, and then computes the delta. The delta value of 0x200 depends on how much code is executed the two RDTSC instructions.

```

rdtsc
mov     ecx,eax
mov     ebx,edx

;... more instructions
nop

```



```

push    eax
pop     eax
nop
;... more instructions

;compute delta between RDTSC instructions
rdtsc

;Check high order bits
cmp     edx,ebx
ja      .debugger_found
;Check low order bits
sub     eax,ecx
cmp     eax,0x200
ja      .debugger_found

```

Variations of timing checks includes using the API `kernel32!GetTickCount()`, or manually checking the value of the `TickCountLow` and `TickCountMultiplier` fields of the `SharedUserData`⁷ data structure which is always located at the address `0x7FFE0000`.

These timing techniques, specially using RDTSC can be difficult to identify if garbage codes and other obfuscation techniques attempts to hide them.

Solution

One solution would be to identify where the timing checks are and then avoiding stepping thru code in between these timing checks. The reverser can just set a breakpoint just before the delta comparison and then perform a Run instead of a Step until the breakpoint is hit. Additionally, a breakpoint can be set in `GetTickCount()` to determine where it had been called or to modify its return value.

Olly Advanced has another solution - It installs a kernel mode driver that does the following:

1. Sets that Time Stamp Disable Bit (TSD) in control register CR4⁸. When the said bit is set and if the RDTSC instruction is executed in a privilege level other than 0, a General Protection (GP) exception will be triggered.
2. The Interrupt Descriptor Table (IDT) is set up so that the GP exception is hooked and execution of RTDSC is filtered. If the GP is because of an RDTSC instruction, just increment the returned timestamp from the previous call by 1.

It should be noted that the discussed driver may cause instability to the system, thus, experimenting with this feature should always be done on a non-production machine or in a virtual machine.

2.6. SeDebugPrivilege

By default, a process has the `SeDebugPrivilege` privilege in their access token disabled. However, when the process is loaded by a debugger such as `OlllyDbg` and `WinDbg`, the `SeDebugPrivilege` privilege is enabled. This is the case since these debuggers attempt to adjust their token to enable the said privilege and when the debugged process is loaded, the `SeDebugPrivilege` privilege is inherited.

Some packers indirectly use `SeDebugPrivilege` to identify if the process is being debugged by attempting to open the `CSRSS.EXE` process. If a process is able to open the `CSRSS.EXE` process; it means that the process has the `SeDebugPrivilege` privilege enabled in the access token, and thus, suggesting that the process is being debugged. This check works because the security descriptor of the `CSRSS.EXE` process only allows `SYSTEM` to access the said process,

⁷ Data type of `SharedUserData` is `_KUSER_SHARED_DATA`

⁸ See "Control Registers" in *IA-32 Intel® Architecture Software Developer's Manual Volume 3A: System Programming Guide, Part 1*

but if a process has the SeDebugPrivilege privilege; it can access another process regardless of the security descriptor⁹. Note that this privilege is only granted to members of the Administrators group by default.

Example

An example check is shown below:

```
;query for the PID of CSRSS.EXE
call  [CsrGetProcessId]

;try to open the CSRSS.EXE process
push  eax
push  FALSE
push  PROCESS_QUERY_INFORMATION
call  [OpenProcess]

;if OpenProcess() was successful,
; process is probably being debugged
test  eax,eax
jnz   debugger_found
```

This check uses the API `ntdll!CsrGetProcessId()` to retrieve the PID of CSRSS.EXE, but packers may obtain the PID of CSRSS.EXE manually via process enumeration. If `OpenProcess()` succeeds, it means that SeDebugPrivilege is enabled which also means that the process is possibly being debugged.

Solution

One solution is to set a breakpoint where `ntdll!NtOpenProcess()` returns, once the breakpoint is hit, set the value of EAX to `0xC0000022` (`STATUS_ACCESS_DENIED`) if the passed PID is that of CSRSS.EXE.

2.7. Parent Process

Typically, a process has `explorer.exe` as its parent process (eg: executable is double-clicked); a parent process other than `explorer.exe` suggests that an application is spawned by a different application and thus suggests that it is possibly being debugged.

One way to implement this check is as follows:

1. Retrieve the current process' PID via the TEB (`TEB.ClientId`) or using `GetCurrentProcessId()`
2. List all processes using `Process32First/Next()` and take note of `explorer.exe`'s PID (via `PROCESSENTRY32.szExeFile`) and the PID of the parent process of the current process via `PROCESSENTRY32.th32ParentProcessID`
3. If the PID of the parent process is not the PID of `explorer.exe`, the target is possibly being debugged.

However, note that this debugger check will trigger a false positive if the executable is being executed via the command prompt or the default shell is different.

Solution

A solution provided by Oilly Advanced is to set `Process32Next()` to always fail, this way, the packer's process enumeration code will fail and possibly skip the PID checks due to process enumeration failure. This is done by patching the entry of `kernel32!Process32NextW()` with a code that sets the value of EAX to 0 and then perform a return:

⁹ See `OpenProcess()` API in MSDN: <http://msdn2.microsoft.com/en-us/library/ms684320.aspx>

7C863B5F	33C0	XOR EAX,EAX	kernel32!Process32NextW
7C863B61	C2 0800	RETN 8	
7C863B64	83EC 0C	SUB ESP,0C	

2.8. DebugObject: NtQueryObject()

Instead of identifying if the process is being debugged, other techniques involve checking if a debugger is running in the system.

One interesting method discussed in reversing forums is by checking the number of kernel objects of type `DebugObject`¹⁰. This works because every time an application is being debugged, in the kernel, an object of type `DebugObject` is created for the debugging session.

The number of `DebugObject` can be obtained by querying information about all object types using `ntdll!NtQueryObject()`. `NtQueryObject` accepts 5 parameters, and for the purpose of querying all objects types, the `ObjectHandle` parameter is set to `NULL` and `ObjectInformationClass` is to `ObjectAllTypeInfoInformation (3)`:

```
NTSTATUS NTAPI NtQueryObject(
    HANDLE ObjectHandle,
    OBJECT_INFORMATION_CLASS ObjectInformationClass,
    PVOID ObjectInformation,
    ULONG Length,
    PULONG ResultLength
)
```

The said API returns an `OBJECT_ALL_INFORMATION` structure, in which the `NumberOfObjectsTypes` field is the count of total object types in the `ObjectTypeInformation` array:

```
typedef struct _OBJECT_ALL_INFORMATION {
    ULONG NumberOfObjectsTypes;
    OBJECT_TYPE_INFORMATION ObjectTypeInformation[1];
}
```

The detection routine will then iterate thru the `ObjectTypeInformation` array which has the following structure:

```
typedef struct _OBJECT_TYPE_INFORMATION {
    [00] UNICODE_STRING TypeName;
    [08] ULONG TotalNumberOfHandles;
    [0C] ULONG TotalNumberOfObjects;
    ... more fields ...
}
```

The `TypeName` field is then compared to the `UNICODE` string `"DebugObject"`, and then the `TotalNumberOfObjects` or the `TotalNumberOfHandles` field is checked for a non-zero value.

Solution

Similar to the `NtQueryInformationProcess()` solution, a breakpoint can be set where `NtQueryObject()` returns. Then, the returned `OBJECT_ALL_INFORMATION` structure can be patched. Specifically, the `NumberOfObjectsTypes` field can be set to 0 to prevent packers from iterating thru the `ObjectTypeInformation` array. A similar `ollyscript` from the `NtQueryInformationProcess()` solution can be created to perform this via a script.

Similarly, the Olly advanced plugin injects code in the `NtQueryObject()` API which will zero out the entire returned buffer if the query is of type `ObjectAllTypeInfoInformation`.

¹⁰ More information about `DebugObject` can be found on the Windows Native Debugging Internals articles by Alex Ionescu on http://www.openrce.org/articles/full_view/25 and http://www.openrce.org/articles/full_view/26

2.9. Debugger Window

The existence of debugger windows are identifying marks that a debugger is running in the system. Since debuggers create windows with specific class names (OLLYDBG for OllyDbg, WinDbgFrameClass for WinDbg), these debugger windows are easily identified using `user32!FindWindow()` or `user32!FindWindowEx()`.

Example

The example code below uses `FindWindow()` to identify if OllyDbg or WinDbg is running in the system via the windows they create:

```

push     NULL
push     .szWindowClassOllyDbg
call    [FindWindowA]
test    eax,eax
jnz     .debugger_found

push     NULL
push     .szWindowClassWinDbg
call    [FindWindowA]
test    eax,eax
jnz     .debugger_found

.szWindowClassOllyDbg  db "OLLYDBG",0
.szWindowClassWinDbg  db "WinDbgFrameClass",0

```

Solution

One solution is to set a breakpoint in the entry of `FindWindow()/FindWindowEx()`. When the breakpoint is hit, change the contents of the `lpClassName` string parameter so that the API will fail. Other solution involves just setting the return value to `NULL`.

2.10. Debugger Process

Another way to identify if a debugger is running in the system is to list all process and check if the process name is that of a debugger (e.g. OLLYDBG.EXE, windbg.exe, etc.) The implementation is straight forward and just involves using `Process32First/Next()` and then checking if the image name is that of a debugger.

Some packers also go as far as reading a process' memory using `kernel32!ReadProcessMemory()` and then search for debugger-related strings (e.g. "OLLYDBG") in case the reverser renames the debugger's executable. Once a debugger is found, the packer may display an error message, silently exit or terminate the debugger.

Solution

Similar to the solution for the parent process check, the solution involves patching `kernel32!Process32NextW()` to always fail to prevent the packer from enumerating the processes.

2.11. Device Drivers

A classic technique for detecting if a kernel mode debugger is active in the system is to try accessing their device drivers. The technique is fairly simple and just involves calling `kernel32!CreateFile()` against well-known device names used by kernel mode debuggers such as SoftICE.

Example

A simple check would be:

```

push     NULL
push     0

```

```

push    OPEN_EXISTING
push    NULL
push    FILE_SHARE_READ
push    GENERIC_READ
push    .szDeviceNameNtice
call    [CreateFileA]
cmp     eax,INVALID_HANDLE_VALUE
jne     .debugger_found

.szDeviceNameNtice db "\\.\NTICE",0

```

Some versions of SoftICE also append numbers in the device name causing this check to always fail. A workaround described in reversing forums involve brute forcing the appended numbers until the correct device name is found. Newer packers also use the device driver detection technique to detect system monitors such as Regmon and Filemon.

Solution

A simple solution would be to set a breakpoint inside kernel32!CreateFileFileW(), and when the breakpoint is hit, either manipulate the FileName parameter or change its return value to INVALID_HANDLE_VALUE (0xFFFFFFFF).

2.12. OllyDbg: Guard Pages

This check is specific to OllyDbg, since it is related to OllyDbg's on-access/write memory breakpoint feature.

Aside from hardware and software breakpoints, OllyDbg allows an on-access/write memory breakpoint; this type of breakpoint is implemented using guard pages¹¹. Simply stated, guard pages provide an application a way to be notified if a memory is being accessed.

Guard pages are set using the PAGE_GUARD page protection modifier, if the address is being accessed is part of a guard page, STATUS_GUARD_PAGE_VIOLATION (0x80000001) will be raised. Packers use the behavior that if the process is being debugged under OllyDbg and a guard page is being accessed, no exception will be thrown, instead, the access will be treated as a memory breakpoint.

Example

In the example code below, the code allocates a memory, store code in the allocated memory, and then enable the PAGE_GUARD attribute. It then initializes its marker (EAX) to 0, and trigger the STATUS_GUARD_PAGE_VIOLATION by executing code in the page guarded allocated memory. If the code is being debugged in OllyDbg, the marker will be unchanged since the exception handler will not be called.

```

; set up exception handler
push    .exception_handler
push    dword [fs:0]
mov     [fs:0], esp

; allocate memory
push    PAGE_READWRITE
push    MEM_COMMIT
push    0x1000
push    NULL
call    [VirtualAlloc]
test   eax,eax
jz     .failed
mov    [.pAllocatedMem],eax

; store a RETN on the allocated memory
mov    byte [eax],0xC3

```

¹¹ See <http://msdn2.microsoft.com/en-us/library/aa366549.aspx> for explanation of guard pages

```

; then set the PAGE_GUARD attribute of the allocated memory
lea    eax,[.dwOldProtect]
push   eax
push   PAGE_EXECUTE_READ | PAGE_GUARD
push   0x1000
push   dword [.pAllocatedMem]
call   [VirtualProtect]

; set marker (EAX) as 0
xor    eax,eax
; trigger a STATUS_GUARD_PAGE_VIOLATION exception
call   [.pAllocatedMem]
; check if marker had not been changed (exception handler not called)
test   eax,eax
je     .debugger_found
:::

.exception_handler
;EAX = CONTEXT record
mov    eax,[esp+0xc]
;set marker (CONTEXT.EAX) to 0xffffffff
; to signal that the exception handler was called
mov    dword [eax+0xb0],0xffffffff
xor    eax,eax
retn

```

Solution

Since guard pages triggers an exception, the reverser can deliberately trigger an exception so that the exception handler will be called. In the example shown, a reverser can replace the RETN instruction with an "INT3" then a "RETN" instruction, once INT3 is executed, force the debugger to call the exception handler via Shift+F9. Then, after the exception handler is called, EAX will be set to the proper value, and then the RETN instruction will be executed.

If the exception handler checks if the exception was indeed a STATUS_GUARD_PAGE_VIOLATION, a reverser can set a breakpoint in the exception handler and then modify the passed ExceptionRecord parameter, specifically, ExceptionRecord.ExceptionCode is set to STATUS_GUARD_PAGE_VIOLATION manually.

3. TECHNIQUES: BREAKPOINT AND PATCHING DETECTION

This section lists the most common ways on how packers identified software breakpoints, hardware breakpoints and patching.

3.1. Software Breakpoint Detection

Software breakpoints are breakpoints which are set by modifying the code at the target address replacing it with a byte value 0xCC (INT3 / Breakpoint Interrupt). Packers identify software breakpoints by scanning for the byte 0xCC in the protector code and/or an API function.

Example

A check can be as simple as the following:

```

cld
mov    edi,Protected_Code_Start
mov    ecx,Protected_Code_End - Protected_Code_Start
mov    al,0xcc
repne scasb
jz     .breakpoint_found

```

Some packers apply some operation on the compared byte value so the check is not obvious, such as:

```

: if(byte XOR 0x55 == 0x99) then breakpoint found
:
: Where: 0x99 == 0xCC XOR 0x55
:

```

Solution

If software breakpoints are being identified, the reverser can use hardware breakpoints instead. If a breakpoint is needed to be set inside an API code, but the packer attempts to search for breakpoints inside an API code, the reverser can set a breakpoint on the UNICODE version of the API which will be eventually called by the ANSI versions (eg: LoadLibraryExW instead of LoadLibraryA), or the corresponding native API (ntdll!LdrLoadDll) instead.

3.2. Hardware Breakpoint Detection

Another type of breakpoint is a hardware breakpoint. Hardware breakpoints are set by setting the debug registers¹², these registers are named Dr0 to Dr7. Dr0-Dr3 contains the address of up to four breakpoints, Dr6 contains flags to identify what breakpoint had been triggered, while Dr7 contains flags to control the four hardware breakpoints such as enabling/disabling breakpoints or breaking on read/write.

Detecting hardware breakpoints requires a bit of code to perform since debug registers are not accessible in Ring 3. Thus, packers utilize the CONTEXT structure which contains the values of the debug registers. The CONTEXT structure is accessed via the ContextRecord parameter passed to an exception handler.

Example

Here is an example code to query the debug registers:

```

; set up exception handler
push  .exception_handler
push  dword [fs:0]
mov   [fs:0], esp

; eax will be 0xffffffff if hardware breakpoints are identified
xor   eax,eax

; throw an exception
mov   dword [eax],0

; restore exception handler
pop   dword [fs:0]
add   esp,4

; test if EAX was updated (breakpoint identified)
test  eax,eax
jnz   .breakpoint_found

:::

.exception_handler
;EAX = CONTEXT record
mov   eax,[esp+0xc]

;check if Debug Registers Context.Dr0-Dr3 is not zero
cmp   dword [eax+0x04],0
jne   .hardware_bp_found
cmp   dword [eax+0x08],0
jne   .hardware_bp_found
cmp   dword [eax+0x0c],0

```

¹² See "Debug Registers" in IA-32 Intel® Architecture Software Developer's Manual Volume 3B: System Programming Guide, Part 2

```

jne     .hardware_bp_found
cmp     dword [eax+0x10],0
jne     .hardware_bp_found
jmp     .exception_ret

.hardware_bp_found
;set Context.EAX to signal breakpoint found
mov     dword [eax+0xb0],0xffffffff

.exception_ret
;set Context.EIP upon return
add     dword [eax+0xb8],6
xor     eax,eax
retn

```

Some packers also use the debug registers as part of decryption keys. Either these registers are initialized to a specific value or left to have the value 0. Thus, if these debug registers are modified, decryption will fail and will cause unexpected termination due to invalid instructions if the code being decrypted is part of the unpacking stub or the protected executable.

Solution

The reverser can try using software breakpoints if software breakpoints are not being checked. Also, the on-access/write memory breakpoint feature of OllyDbg can be used. Setting software breakpoints inside UNICODE version of the APIs or the native APIs can be another solution if the reverser would need to set API breakpoints.

3.3. Patching Detection via Code Checksum Calculation

Patching detection tries to identify if a part of the packer code had been modified which suggests that anti-debugging routines may have been disabled, and as a second purpose can identify if software breakpoints are set. Patching detection is implemented via code checksum, and the checksum calculation can range from simple to intricate checksum/hash algorithms.

Example

Below is a fairly simple example for checksum calculation:

```

mov     esi,Protected_Code_Start
mov     ecx,Protected_Code_End - Protected_Code_Start
xor     eax,eax

.checksum_loop
movzx   ebx,byte [esi]
add     eax,ebx
rol     eax,1
inc     esi
loop   .checksum_loop

cmp     eax,dword [.dwCorrectChecksum]
jne     .patch_found

```

Solution

If software breakpoints are being identified by a code checksum routine, hardware breakpoints can be used instead. If code patching is being identified by the checksum routine, a reverser can identify where the checksum routine is by setting an on-access breakpoint on the patched address, and once the checksum routine is found, modify the checksum value to the expected value or just change the appropriate flags after a failed comparison.

4. TECHNIQUES: ANTI-ANALYSIS

Anti-analysis techniques aim to slow down reversers from analyzing and understanding the protector code and/or the packed executable. Techniques such as encryption/compression, garbage code, permutation, and anti-disassembly are discussed. These are the techniques

which require a reverser to have traits such as patience and cleverness in order to solve since they aim to confuse, bore and waste the time of a reverser.

4.1. Encryption and Compression

Encryption and compression are the most basic forms of anti-analysis. They are initial defenses to prevent a reverser from just loading the protected executable in a disassembler and then start analysis without any difficulty.

Encryption. Packers usually encrypt both the protector code and the protected executable. The encryption algorithm greatly varies between packers, which range from very simple XOR loops to very complex loops that perform several computations. With polymorphic packers, the encryption algorithm also varies between generated samples and the decryption code is permuted to look very different on each generated samples, and may prevent a packer identifier tool from correctly identifying the packer.

Decryption routines are easily recognizable as loops which perform a fetch, compute, and store data operation. Below is an example of a simple decryption routine that performs several XOR operations on an encrypted DWORD value.

```

: 0040A07C LODS DWORD PTR DS:[ESI]
: 0040A07D XOR EAX,EBX
: 0040A07F SUB EAX,12338CC3
: 0040A084 ROL EAX,10
: 0040A087 XOR EAX,799F82D0
: 0040A08C STOS DWORD PTR ES:[EDI]
: 0040A08D INC EBX
: 0040A08E LOOPD SHORT 0040A07C ;decryption loop

```

Here is another example of a decryption routine of a polymorphic packer:

```

: 00476056 MOV BH,BYTE PTR DS:[EAX]
: 00476058 INC ESI
: 00476059 ADD BH,0BD
: 0047605C XOR BH,CL
: 0047605E INC ESI
: 0047605F DEC EDX
: 00476060 MOV BYTE PTR DS:[EAX],BH
: 00476062 CLC
: 00476063 SHL EDI,CL
: :: More garbage code
: 00476079 INC EDX
: 0047607A DEC EDX
: 0047607B DEC EAX
: 0047607C JMP SHORT 0047607E
: 0047607E DEC ECX
: 0047607F JNZ 00476056 ;decryption loop

```

And below is another decryption routine generated by the same polymorphic packer:

```

: 0040C045 MOV CH,BYTE PTR DS:[EDI]
: 0040C047 ADD EDX,EBX
: 0040C049 XOR CH,AL
: 0040C04B XOR CH,0D9
: 0040C04E CLC
: 0040C04F MOV BYTE PTR DS:[EDI],CH
: 0040C051 XCHG AH,AH
: 0040C053 BTR EDX,EDX
: 0040C056 MOVSX EBX,CL
: :: More garbage code
: 0040C067 SAR EDX,CL
: 0040C06C NOP
: 0040C06D DEC EDI
: 0040C06E DEC EAX
: 0040C06F JMP SHORT 0040C071

```

```
0040C071  JNZ 0040C045      ;decryption loop
```

In the last two examples, the highlighted lines are the main decryption instructions, while the remaining instructions are garbage codes to confuse the reverser. Notice how the registers are being swapped and how the decryption method changes between the two examples.

Compression. The main purpose of compression is to reduce the size of the executable code and its data, but because this results for the original executable including its readable strings becoming compressed data, it has the side effect of obfuscation. Some examples of compression engine used by packers are - NRV (Not Really Vanished) compression and LZMA (Lempel-Ziv-Markov chain-Algorithm) for UPX, aPLib for FSG, LZMA for Upack and LZO for yoda's Protector. Some of these compression engines are free for non-commercial use but requires a license/registration for commercial use.

Solution

Decryption and decompression loops are easy to bypass, the reverser just needs to know when the decryption/decompression loop terminates and then set a breakpoint on the instruction after the loop. Remember, some packers may have breakpoint detection code inside these decryption loops.

4.2. Garbage Code and Code Permutation

Garbage Code. Inserting garbage code in the unpacking routine is another effective way to confuse a reverser. It aims to hide the real purpose of the code, be it a decryption routine or anti-reversing routines such as debugger detection. Garbage code adds effectiveness to the debugger/breakpoint/patching detection techniques described in this paper by hiding them in a mass of unrelated "do nothing" and confusing instructions. Furthermore, effective garbage codes are those that look like legitimate/working code.

Example

Below is an example decryption routine with several garbage code inserted between the relevant instructions:

```
0044A21A  JMP SHORT sample.0044A21F
0044A21C  XOR DWORD PTR SS:[EBP],6E4858D
0044A223  INT 23
0044A225  MOV ESI,DWORD PTR SS:[ESP]
0044A228  MOV EBX,2C322FF0
0044A22D  LEA EAX,DWORD PTR SS:[EBP+6EE5B321]
0044A233  LEA ECX,DWORD PTR DS:[ESI+543D583E]
0044A239  ADD EBP,742C0F15
0044A23F  ADD DWORD PTR DS:[ESI],3CB3AA25
0044A245  XOR EDI,7DAC77F3
0044A24B  CMP EAX,ECX
0044A24D  MOV EAX,5ACAC514
0044A252  JMP SHORT sample.0044A257
0044A254  XOR DWORD PTR SS:[EBP],AAE47425
0044A25B  PUSH ES
0044A25C  ADD EBP,5BAC5C22
0044A262  ADC ECX,3D71198C
0044A268  SUB ESI,-4
0044A26B  ADC ECX,3795A210
0044A271  DEC EDI
0044A272  MOV EAX,2F57113F
0044A277  PUSH ECX
0044A278  POP ECX
0044A279  LEA EAX,DWORD PTR SS:[EBP+3402713D]
0044A27F  DEC EDI
0044A280  XOR DWORD PTR DS:[ESI],33B568E3
0044A286  LEA EBX,DWORD PTR DS:[EDI+57DEFEE2]
0044A28C  DEC EDI
0044A28D  SUB EBX,7ECDAE21
0044A293  MOV EDI,185C5C6C
0044A298  MOV EAX,4713E635
```

```

: 0044A29D MOV EAX,4
: 0044A2A2 ADD ESI,EAX
: 0044A2A4 MOV ECX,1010272F
: 0044A2A9 MOV ECX,7A49B614
: 0044A2AE CMP EAX,ECX
: 0044A2B0 NOT DWORD PTR DS:[ESI]

```

The only relevant decryption instructions in the example were:

```

: 0044A225 MOV ESI,DWORD PTR SS:[ESP]
: 0044A23F ADD DWORD PTR DS:[ESI],3CB3AA25
: 0044A268 SUB ESI,-4
: 0044A280 XOR DWORD PTR DS:[ESI],33B568E3
: 0044A29D MOV EAX,4
: 0044A2A2 ADD ESI,EAX
: 0044A2B0 NOT DWORD PTR DS:[ESI]

```

Code Permutation. Code permutation is another technique used by more advanced packers. With code permutation, simple instructions are translated into a more complex series of instructions. This requires the packer to understand the instructions and generate new series of instructions that performs the equivalent operation.

A simple permutation example would be the following instructions:

```

: mov     eax,ebx
: test   eax,eax

```

Being translated into the following equivalent instructions:

```

: push   ebx
: pop    eax
: or     eax,eax

```

Combined with garbage code, permuted code is an effective technique to slow down a reverser from understanding a protected code.

Example

To illustrate, below is an example of a debugger detection routine which had been permuted and garbage codes inserted in between the permuted instructions:

```

: 004018A3 MOV EBX,A104B3FA
: 004018A8 MOV ECX,A104B412
: 004018AD PUSH 004018C1
: 004018B2 RETN
: 004018B3 SHR EDX,5
: 004018B6 ADD ESI,EDX
: 004018B8 JMP SHORT 004018BA
: 004018BA XOR EDX,EDX
: 004018BC MOV EAX,DWORD PTR DS:[ESI]
: 004018BE STC
: 004018BF JB SHORT 004018DE
: 004018C1 SUB ECX,EBX
: 004018C3 MOV EDX,9A01AB1F
: 004018C8 MOV ESI,DWORD PTR FS:[ECX]
: 004018CB LEA ECX,DWORD PTR DS:[EDX+FFFF7FF7]
: 004018D1 MOV EDX,600
: 004018D6 TEST ECX,2B73
: 004018DC JMP SHORT 004018B3
: 004018DE MOV ESI,EAX
: 004018E0 MOV EAX,A35ABDE4
: 004018E5 MOV ECX,FAD1203A
: 004018EA MOV EBX,51AD5EF2
: 004018EF DIV EBX
: 004018F1 ADD BX,44A5
: 004018F6 ADD ESI,EAX

```

```

: 004018F8 MOVZX EDI,BYTE PTR DS:[ESI]
: 004018FB OR EDI,EDI
: 004018FD JNZ SHORT 00401906

```

The example shown is simple debugger detection routine:

```

: 00401081 MOV EAX,DWORD PTR FS:[18]
: 00401087 MOV EAX,DWORD PTR DS:[EAX+30]
: 0040108A MOVZX EAX,BYTE PTR DS:[EAX+2]
: 0040108E TEST EAX,EAX
: 00401090 JNZ SHORT 00401099

```

Solution

Garbage codes and permuted instructions are ways to bore and waste the reverser's time. Thus, it is important to know if the hidden instructions between these obscuring techniques are worth understanding (eg: just performing decryption, packer initialization etc).

One way to avoid tracing thru the obscured instructions is to try setting breakpoints on APIs which packers mostly used (eg: VirtualAlloc, VirtualProtect, LoadLibrary, GetProcAddress, etc.) and treat these APIs as "*trace markers*" in a packer trace. If something went wrong (such as the debugger or breakpoints being detected) in between these trace markers, then it is the time to do a detailed trace of the code. Additionally, setting on-access/write breakpoints allows a reverser to pinpoint what instructions are trying to modify/access interesting parts of the protected process instead of tracing thru a mass of code that eventually (and hopefully) lead to the exact routine.

Finally, running OllyDbg in VMWare and routinely taking snapshots of the debugging session allows the reverser to go back on a specific trace state. And if something went wrong, the tracing session can be reverted back to a specific trace state.

4.3. Anti-Disassembly

Another way to confuse the reverser is to obfuscate the disassembly. Anti-disassembly is an effective way to complicate the process of understanding the binary via static analysis, and if combined with garbage code and permutation, makes it even more effective.

One example of an anti-disassembly technique is to insert a garbage byte and then add a conditional branch which will transfer execution to the garbage byte; however, the condition for the conditional branch will always be FALSE. Thus, the garbage byte will never be executed but will trick disassemblers to start disassembling the garbage byte address, which eventually will lead to an incorrect disassembly output.

Example

Here is an example of the simple PEB.BeingDebugged flag check with some anti-disassembly code added. The highlighted lines are the main instructions, while the remaining are the anti-disassembly codes. It uses the garbage byte 0xff and adds fake conditional jump into the garbage byte for disassemblers to follow:

```

;Anti-disassembly sequence #1
push    .jmp_real_01
stc
jnc     .jmp_fake_01
retn
.jmp_fake_01:
db      0xff
.jmp_real_01:
;-----
mov     eax,dword [fs:0x18]
;Anti-disassembly sequence #2
push    .jmp_real_02

```

```

    clc
    jc     .jmp_fake_02
    retn
.jmp_fake_02:
    db     0xff
.jmp_real_02:
;-----
    mov    eax,dword [eax+0x30]
    movzx  eax,byte [eax+0x02]
    test   eax,eax
    jnz    .debugger_found

```

Below is the disassembly output in WinDbg:

```

0040194a 6854194000    push    0x401954
0040194f f9           stc
00401950 7301         jnb     image00400000+0x1953 (00401953)
00401952 c3           ret
00401953 ff64a118     jmp     dword ptr [ecx+0x18]
00401957 0000         add     [eax],al
00401959 006864         add     [eax+0x64],ch
0040195c 194000         sbb     [eax],eax
0040195f f8           clc
00401960 7201         jb     image00400000+0x1963 (00401963)
00401962 c3           ret
00401963 ff8b40300fb6 dec     dword ptr [ebx+0xb60f3040]
00401969 40           inc     eax
0040196a 0285c0750731 add     al,[ebp+0x310775c0]

```

And the disassembly output in OllyDbg:

```

0040194A 68 54194000    PUSH 00401954
0040194F F9           STC
00401950 73 01         JNB SHORT 00401953
00401952 C3           RETN
00401953 FF64A1 18     JMP DWORD PTR DS:[ECX+18]
00401957 0000         ADD BYTE PTR DS:[EAX],AL
00401959 0068 64     ADD BYTE PTR DS:[EAX+64],CH
0040195C 1940 00     SBB DWORD PTR DS:[EAX],EAX
0040195F F8           CLC
00401960 72 01         JB SHORT 00401963
00401962 C3           RETN
00401963 FF8B 40300FB6 DEC DWORD PTR DS:[EBX+B60F3040]
00401969 40           INC EAX
0040196A 0285 C0750731 ADD AL,BYTE PTR SS:[EBP+310775C0]

```

And finally, the disassembly output in IDAPro:

```

0040194A          push    (offset loc_401953+1)
0040194F          stc
00401950          jnb     short loc_401953
00401952          retn
00401953 ; -----
00401953          ;
00401953 loc_401953:          ; CODE XREF: sub_401946+A
00401953          ; DATA XREF: sub_401946+4
00401953          jmp     dword ptr [ecx+18h]
00401953 sub_401946 endp
00401953 ; -----
00401957          db     0
00401958          db     0
00401959          db     0
0040195A          db     68h ; h
0040195B          dd     offset unk_401964
0040195F          db     0F8h ; °
00401960          db     72h ; r

```

```

: 00401961          db      1
: 00401962          db      0C3h ; +
: 00401963          db      0FFh
: 00401964 unk_401964 db      8Bh ; i          ; DATA XREF: text:0040195B
: 00401965          db      40h ; @
: 00401966          db      30h ; 0
: 00401967          db      0Fh
: 00401968          db      0B6h ; |
: 00401969          db      40h ; @
: 0040196A          db      2
: 0040196B          db      85h ; à
: 0040196C          db      0C0h ; +
: 0040196D          db      75h ; u

```

Notice how all three disassemblers/debuggers had fallen into the anti-disassembly trick, which is very annoying and confusing to a reverser analyzing the disassembly. There are several other ways to confuse disassemblers, and the illustration was just one example. Additionally, these anti-disassembly codes can be coded in a macro so that the assembly source is cleaner.

The reader is advised to refer to an excellent reversing book by Eldad Eliam¹³ which contains detailed information about anti-disassembly techniques and other reversing topics.

5. TECHNIQUES : DEBUGGER ATTACKS

This section enumerates techniques that packers use to actively attack the debugger in such a way that execution will suddenly stop if the process is being debugged, breakpoints are disabled, etc. Similar to the previously described techniques, these techniques can be made more effective if they are hidden using anti-analysis techniques.

5.1. Misdirection and Stopping Execution via Exceptions

Tracing thru the code in a linear manner allows a reverser to easily understand and grasp the purpose of the code. Thus, some packers employ several techniques so that tracing the code is not linear and time consuming.

One commonly used technique is to throw several exceptions in the process of unpacking. By throwing caught exceptions, the reverser will need to understand where EIP will be pointing to upon exception, and where the EIP will be pointing after the exception handler had executed.

Additionally, exceptions are a way for packers to repeatedly stop execution of the unpacking code. Because when exceptions are thrown and the process is under a debugger, the debugger temporarily stops execution of the unpacking code.

Packers commonly use the Structured Exception Handling (SEH)¹⁴ as a mechanism for exception handling. However, newer packers also started to use Vectored Exceptions¹⁵.

Example

Below is an example code that performs misdirection by throwing an overflow exception (via INTO) when the overflow flag is set by the ROL instruction after several loops. But since an overflow exception is a trap exception, EIP will just point to the JMP instruction. If the reverser is using OllyDbg, and the reverser did not pass the exception to the process (via Shift+F7/F8/F9) and just continually performs a step, the reverser will be tracing an endless loop.

¹³ See Reversing: Secrets of Reverse Engineering in the reference section

¹⁴ See <http://www.microsoft.com/msj/0197/exception/exception.aspx> for in-depth information about SEH

¹⁵ See <http://msdn.microsoft.com/msdnmag/issues/01/09/hood/> for an in-depth information about Vectored Exceptions

```

; set up exception handler
push    .exception_handler
push    dword [fs:0]
mov     [fs:0], esp

; throw an exception
mov     ecx,1
.loop:
rol     ecx,1
into
jmp     .loop

; restore exception handler
pop     dword [fs:0]
add     esp,4
:::

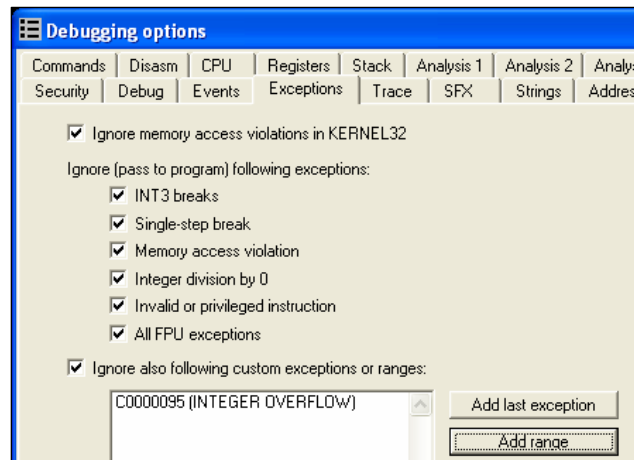
.exception_handler
;EAX = CONTEXT record
mov     eax,[esp+0xc]
;set Context.EIP upon return
add     dword [eax+0xb8],2
xor     eax,eax
retn

```

Packers commonly throw access violations (0xC0000005), breakpoint (0x80000003) and single step (0x80000004) exceptions.

Solution

For packers which uses caught exceptions for no other reason than transferring execution to different parts of the code, OllyDbg can be configured so that exceptions handlers are automatically called. This feature can be configured via Options -> Debugging Options -> Exceptions. On the right side is a screen shot of the configuration dialog for handling exceptions. A reverser can also add custom exceptions if the exception is not one of those that can be selected via a checkbox.



For packers which performs important operations inside an exception handler.

The reverser can set a breakpoint in the exception handler in which the address can be viewed in OllyDbg using View->SEH Chain. Then, pressing Shift+F7/F8/F9 to transfer control to the exception handler.

5.2. Blocking Input

To prevent a reverser from controlling the debugger, a packer can use the user32!BlockInput() API to block keyboard and mouse input while the main unpacking routine is being executed. Hidden within garbage codes and anti-disassembly techniques, this can be effective if not identified by the reverser. If executed, the system will appear to be unresponsive, leaving the reverser baffled.

A typical example would be a reverser setting a breakpoint inside GetProcAddress(), then running the unpacking code until the breakpoint is hit. However, in the process of skipping several garbage codes, the packer had called BlockInput(). And once the GetProcAddress() breakpoint is hit, the reverser suddenly cannot control the debugger leaving him perplexed on what just happened.

Example

BlockInput() takes 1 boolean parameter fBlockIt. If true, keyboard and mouse events are blocked, if false, keyboard and mouse events are unblocked:

```

; Block input
push  TRUE
call  [BlockInput]

; ...Unpacking code...

; Unblock input
push  FALSE
call  [BlockInput]

```

Solution

Fortunately, the simple solution to patch BlockInput() to just perform a RETN. Here's the ollyscript to patch the entry of user32!BlockInput():

```

gpa  "BlockInput", "user32.dll"
mov  [$RESULT], #C20400# //retn 4

```

The Olly Advanced plugin also has the option to patch BlockInput(). Additionally, pressing CTRL+ALT+DELETE will allow the user to unblock input manually.

5.3. ThreadHideFromDebugger

This technique uses the API ntdll!NtSetInformationThread() which is usually used for setting a thread's priority. However, the said API can also be used to prevent debugging events to be sent to the debugger.

The parameters to NtSetInformationThread() are shown below. To perform this technique, ThreadHideFromDebugger (0x11) is passed as the ThreadInformationClass parameter, ThreadHandle is usually set to the current thread handle (0xffffffff):

```

NTSTATUS NTAPI NtSetInformationThread(
    HANDLE ThreadHandle,
    THREAD_INFORMATION_CLASS ThreadInformationClass,
    PVOID ThreadInformation,
    ULONG ThreadInformationLength
);

```

Internally, ThreadHideFromDebugger will set the HideThreadFromDebugger field of the ETHREAD¹⁶ kernel structure. Once set, the internal kernel function _DbgkpSendApiMessage(), whose main purpose is to send events to the debugger is never invoked.

Example

A typical example of a call to the NtSetInformationThread() would be:

```

push  0 ;InformationLength
push  NULL ;ThreadInformation
push  ThreadHideFromDebugger ;0x11
push  0xffffffff ;GetCurrentThread()
call  [NtSetInformationThread]

```

Solution

A breakpoint can be set in ntdll!NtSetInformationThread(), and once hit, the reverser can manipulate the EIP to prevent the API call from reaching the kernel. This can also be done automatically via an ollyscript. Additionally, the Olly Advanced plugin has the option to patch

¹⁶ Data type of the ETHREAD structure is _ETHREAD

this API so that if the ThreadInformationClass parameter is set to HideThreadFromDebugger, it will just perform a return instead of calling the kernel code.

5.4. Disabling Breakpoints

Another way to attack the debugger is by disabling breakpoints. To disable hardware breakpoints, a packer will modify the debug registers via the CONTEXT structure.

Example

In this example, the debug registers are cleared via the CONTEXT record passed to the exception handler:

```

; set up exception handler
push    .exception_handler
push    dword [fs:0]
mov     [fs:0], esp

; throw an exception
xor     eax,eax
mov     dword [eax],0

; restore exception handler
pop     dword [fs:0]
add     esp,4
:::

.exception_handler
;EAX = CONTEXT record
mov     eax,[esp+0xc]

;Clear Debug Registers: Context.Dr0-Dr3,Dr6,Dr7
mov     dword [eax+0x04],0
mov     dword [eax+0x08],0
mov     dword [eax+0x0c],0
mov     dword [eax+0x10],0
mov     dword [eax+0x14],0
mov     dword [eax+0x18],0

;set Context.EIP upon return
add     dword [eax+0xb8],6
xor     eax,eax
retn

```

On the other hand, with software breakpoints, the packer can just search for INT3s (0xCC) and replace them with an arbitrary/random opcode; by doing this, the breakpoint will be disabled and the original instruction is corrupted.

Solution

Clearly, if hardware breakpoints are being detected, software breakpoints can be used, vice versa. If both are being detected, try using the on-memory access/write breakpoints feature of OllyDbg.

5.5. Unhandled Exception Filter

The MSDN documentation states that if an exception reaches unhandled exception filter (kernel32!UnhandledExceptionFilter), and that the application is not being debugged, the unhandled exception filter will call the top level exception filter specified as parameter in the kernel32!SetUnhandledExceptionFilter() API. Packers take advantage of this by setting up an exception filter and then throwing an exception, the exception will just be received by the debugger as a second chance exception if it is being debugged, otherwise, control is transferred into the exception filter and execution can continue.

Example

Below is an example in which an top level exception filter is set using `SetUnhandledExceptionFilter()`, and then an access violation is thrown. If the process is being debugged, the debugger will just receive a second chance exception; otherwise, the exception filter will setup `CONTEXT.EIP` and continue the execution.

```

;set the exception filter
push  .exception_filter
call  [SetUnhandledExceptionFilter]
mov   [.original_filter],eax

;throw an exception
xor   eax,eax
mov   dword [eax],0

;restore exception filter
push  dword [.original_filter]
call  [SetUnhandledExceptionFilter]

:::

.exception_filter:
;EAX = ExceptionInfo.ContextRecord
mov   eax,[esp+4]
mov   eax,[eax+4]

;set return EIP upon return
add   dword [eax+0xb8],6

;return EXCEPTION_CONTINUE_EXECUTION
mov   eax,0xffffffff
retn

```

Some packers also manually set up the exception filter by setting `kernel32!_BasepCurrentTopLevelFilter` directly instead of calling `SetUnhandledExceptionFilter()`, this is in case the reverser sets a breakpoint on the said API.

Solution

Interestingly, the code inside `kernel32!UnhandledExceptionFilter()` uses `ntdll!NtQueryInformationProcess (ProcessDebugPort)` to determine if the process is being debugged, which it will then use to decide whether to call the registered exception filter or not. Thus, the solution is the same solution as the `DebugPort` debugger detection technique.

5.6. OllyDbg: `OutputDebugString()` Format String Bug

This debugger attack is specific to OllyDbg. OllyDbg is known to be vulnerable to a format string bug which can cause it to crash or execute arbitrary code, the bug is triggered by an improper string parameter passed to `kernel32!OutputDebugString()`. This bug exists in the current version of OllyDbg (1.10) and still not patched.

Example

This simple example causes OllyDbg to throw an access violation or unexpectedly terminate:

```

push  .szFormatString
call  [OutputDebugStringA]
:::
.szFormatString db  "%s%s",0

```

Solution

The solution involves patching the entry of `kernel32!OutputDebugStringA()` so it will just perform a `RETN`.

6. TECHNIQUES : ADVANCED AND OTHER TECHNIQUES

This section enumerates advanced and other techniques that do not fall in the previous anti-reversing categories.

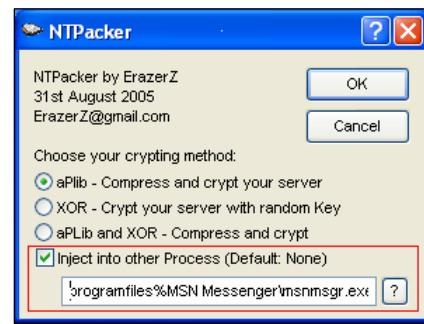
6.1. Process Injection

Process injection has become a feature of some packers. With this feature, the unpacking stub spawns a selected host process (e.g.: itself, explorer.exe, iexplorer.exe, etc.) and then inject the unpacked executable into the host process.

OLLYDBG.EXE	1	OllyDbg, 32-bit a...
notepad-ie.exe	1	
ieexplore.exe	1	

On the right side is a screen shot of a packer that supports process injection.

Malcodes use this packer feature to allow them to bypass some firewalls that checks if the process is in the list of allowed applications to perform external network connections.



One method that packers use to perform process injection is as follows:

1. Spawn the host process as a suspended child process. This is done using the CREATE_SUSPENDED process creation flag passed to kernel32!CreateProcess(). At this point an initialization thread is created and suspended, DLLs are still not loaded since the loader routine (ntdll!LrdInitializeThunk) is still not called. The context of the said thread is setup such as the register values contains information such as the PEB address, and entry point of the host process.
2. Using kernel32!GetThreadContext(), the context of the child process' initialization thread is retrieved
3. The PEB address of the child process is retrieved via CONTEXT.EBX
4. The image base of the child process is retrieved by reading PEB.ImageBase (PEB + 0x8)
5. The original host image in the child process is then unmapped using ntdll!NtUnmapViewOfSection() with the BaseAddress parameter pointing to the retrieved image base
6. The unpacking stub will then allocate memory inside the child process using kernel32!VirtualAllocEx() with dwSize parameter equal to the image size of the unpacked executable.
7. Using kernel32!WriteProcessMemory(), the PE header and each of the sections of the unpacked executable is written to the child process.

8. The PEB.ImageBase of the child process is then updated to match the image base of the unpacked executable.
9. The context of the child process' initialization thread is then updated via `kernel32!SetThreadContext()` in which `CONTEXT.EAX` is set to the entry point of the unpacked executable.
10. Execution of the child process is resumed via `kernel32!ResumeThread()`

In order to debug the spawned child process beginning from its entry point, the reverser can set a breakpoint in `WriteProcessMemory()` and when the section containing the entry point is about to be written to the child process, the entry point code is patched with a "jump to self" instruction (`0xEB 0xFE`). When the main thread of the child process is resumed, the child process will enter an endless loop in its entry point. Then, at that point, the reverser can attach a debugger in the child process, restore the modified instructions, and continue normal debugging.

6.2. Debugger Blocker

A feature that had been introduced by the Armadillo packer is called the Debugger Blocker. This prevents a reverser from attaching a debugger to a protected process. This protection is implemented through the use of debugging functions provided by Windows.

Specifically, the unpacking stub acts as a debugger (parent process) where it spawns and debugs/controls the child process which contains the unpacked executable.

explorer.exe	1680	11	Windows Explorer	Microsoft Corpor
VMwareUser.exe	1768	2	VMwareUser	VMware, Inc.
procexp.exe	1336	2	6.06 Sysinternals Pro...	Sysinternals
OLLYDBG.EXE	896	1	OllyDbg, 32-bit a...	
videodrv.exe	1752	3		
videodrv.exe	1800	2		

Since the protected process is already being debugged, attaching a debugger via `kernel32!DebugActiveProcess()` will fail since the corresponding native API, `ntdll!NtDebugActiveProcess()` will return `STATUS_PORT_ALREADY_SET`. Internally, the failure of `NtDebugActiveProcess()` is due to the `DebugPort` field of the `EPROCESS` kernel structure being already set.

In order to attach a debugger to the protected process, a solution posted on several reversing forums involves invoking `kernel32!DebugActiveProcessStop()` in the context of the parent process. This can be done by attaching a debugger on the parent process, and setting a breakpoint inside `kernel32!WaitForDebugEvent()`, once the breakpoint is hit, a code to invoke `DebugActiveProcessStop(ChildProcessPID)` is then injected and executed, once the call succeeds, a debugger can be attached to the protected process.

6.3. TLS Callbacks

Another technique used by packers is to execute code before the actual entry point is executed. This is achieved through the use of Thread Local Storage (TLS) callback functions. Packers may perform their debugger detection and decryption routines via these callback functions so that the reverser will not be able to trace these routines.

TLS callbacks can be identified using PE file parsing tools such as `pedump`. With `pedump`, the Data Directory entries will display if a TLS directory exists in the executable:

```
-----
Data Directory
EXPORT          rva: 00000000  size: 00000000
-----
```

```

-----
IMPORT      rva: 00061000  size: 000000E0
:::
TLS      rva: 000610E0  size: 00000018
:::
IAT        rva: 00000000  size: 00000000
DELAY_IMPORT  rva: 00000000  size: 00000000
COM_DESCRPTR  rva: 00000000  size: 00000000
unused     rva: 00000000  size: 00000000
-----

```

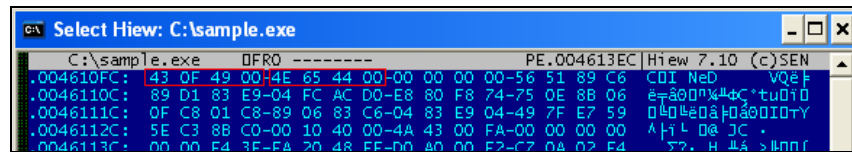
Then, the actual contents TLS directory is displayed. The AddressOfCallbacks field points to an array of callback functions and is null-terminated:

```

-----
TLS directory:
StartAddressOfRawData: 00000000
EndAddressOfRawData: 00000000
AddressOfIndex: 004610F8
AddressOfCallbacks: 004610FC
SizeOfZeroFill: 00000000
Characteristics: 00000000
-----

```

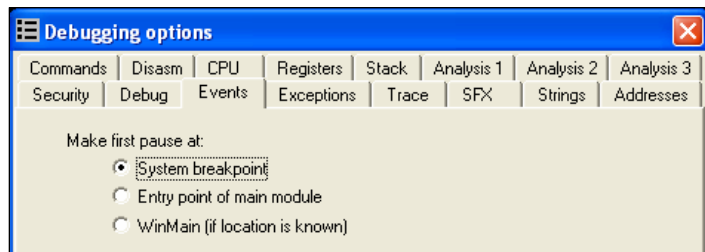
In this example, RVA 0x4610fc points to the callback function pointers (0x490f43 and 0x44654e):



By default, OllyDbg will load the sample then pause at the entry point. Since TLS callbacks are called before the actual entry point, OllyDbg should be configured so that that it will break on the actual loader and before the TLS callbacks are called.

Breaking on the actual loader code inside ntdll.dll can be set by selecting Options -> Debugging Options -> Events -> Make first pause at -> System breakpoint.

Once set, OllyDbg will break inside ntdll! _LdrpInitializeProcess() which is just before



ntdll!_LdrpRunInitializeRoutines() executes the TLS callbacks. Once set, breakpoints can be set on the callback routines and then traced.

More information about the PE file format including the binary/source for pedump can be found on the following links:

An In-Depth Look into the Win32 Portable Executable File Format by Matt Pietrek

<http://msdn.microsoft.com/msdnmag/issues/02/02/PE/default.aspx>

An In-Depth Look into the Win32 Portable Executable File Format, Part 2 by Matt Pietrek

<http://msdn.microsoft.com/msdnmag/issues/02/03/PE2/>

A latest version of the PE file format from Microsoft can be found on the following link:

Microsoft Portable Executable and Common Object File Format Specification

<http://www.microsoft.com/whdc/system/platform/firmware/PECOFF.mspx>

6.4. Stolen Bytes

Stolen bytes are basically portions of codes of the protected executable (usually few instructions of the entry point) which are removed by the packer and is copied and executed from an allocated memory. This protects the executable in a way that if the protected process is dumped from memory, instructions that had been stolen are not recovered.

Here is an example of an executable's original entry point:

```

004011CB MOV EAX,DWORD PTR FS:[0]
004011D1 PUSH EBP
004011D2 MOV EBP,ESP
004011D4 PUSH -1
004011D6 PUSH 0047401C
004011DB PUSH 0040109A
004011E0 PUSH EAX
004011E1 MOV DWORD PTR FS:[0],ESP
004011E8 SUB ESP,10
004011EB PUSH EBX
004011EC PUSH ESI
004011ED PUSH EDI

```

And below is the same sample with the first two instructions stolen by the Enigma Protector packer:

```

004011CB POP EBX
004011CC CMP EBX,EBX
004011CE DEC ESP
004011CF POP ES
004011D0 JECXZ SHORT 00401169
004011D2 MOV EBP,ESP
004011D4 PUSH -1
004011D6 PUSH 0047401C
004011DB PUSH 0040109A
004011E0 PUSH EAX
004011E1 MOV DWORD PTR FS:[0],ESP
004011E8 SUB ESP,10
004011EB PUSH EBX
004011EC PUSH ESI
004011ED PUSH EDI

```

This is the sample example in which the several instructions had been stolen by the ASProtect packer. It added a jump instruction to a routine which executes the stolen instructions. The stolen instructions are then intertwined with garbage code to make it harder to restore the stolen instructions.

```

004011CB JMP 00B70361
004011D0 JNO SHORT 00401198
004011D3 INC EBX
004011D4 ADC AL,0B3
004011D6 JL SHORT 00401196
004011D8 INT1
004011D9 LAHF
004011DA PUSHFD
004011DB MOV EBX,1D0F0294
004011E0 PUSH ES
004011E1 MOV EBX,A732F973
004011E6 ADC BYTE PTR DS:[EDX-E],CH
004011E9 MOV ECX,EBP
004011EB DAS
004011EC DAA
004011ED AND DWORD PTR DS:[EBX+58BA76D7],ECX

```

6.5. API Redirection

API redirection is a way to prevent a reverser from easily rebuilding the import table of the protected executable. Typically, the original import table is destroyed and calls to APIs are redirected into routines located into an allocated memory, these routines are then responsible for calling the actual API.

In this example, the code calls the API `kernel32!CopyFileA()`:

```

: 00404F05 LEA EDI,DWORD PTR SS:[EBP-20C]
: 00404F0B PUSH EDI
: 00404F0C PUSH DWORD PTR SS:[EBP-210]
: 00404F12 CALL <JMP.&KERNEL32.CopyFileA>

```

The call was to a stub that performs a JMP in which the address is referenced from the import table:

```

: 004056B8 JMP DWORD PTR DS:[<&KERNEL32.CopyFileA>]

```

However, when the ASProtect redirected the `kernel32!CopyFileA()` API, the stub was replaced by a CALL to a routine in an allocated memory which eventually leads to execution of stolen instructions from `kernel32!CopyFileA()`:

```

: 004056B8 CALL 00D90000

```

Below is an illustration on how the stolen instructions are placed. The first 7 instructions of the `kernel!CopyFileA()` code had been copied. Additionally, the code in which the call instruction at `0x7C83005E` points to had also been copied. Then, control is transferred back inside `kernel32.dll` in the middle of the `kernel32!CopyFileA()` routine via a RETN to `0x7C830063`:

Stolen instructions from kernel32!CopyFileA

```

00D80003 MOV EDI,EDI
00D80005 PUSH EBP
00D80006 MOV EBP,ESP
00D80008 PUSH ECX
00D80009 PUSH ECX
00D8000A PUSH ESI
00D8000B PUSH DWORD PTR SS:[EBP+8]
00D8000E JMP SHORT 00D80013
00D80011 INT 20
00D80013 PUSH 7C830063 ;return EIP
00D80018 MOV EDI,EDI
00D8001A PUSH EBP
00D8001B MOV EBP,ESP
00D8001D PUSH ECX
00D8001E PUSH ECX
00D8001F PUSH ESI
00D80020 MOV EAX,DWORD PTR FS:[18]
00D80026 PUSH DWORD PTR SS:[EBP+8]
00D80029 LEA ESI,DWORD PTR DS:[EAX+BF8]
00D8002F LEA EAX,DWORD PTR SS:[EBP-8]
00D80032 PUSH EAX
00D80033 PUSH 7C80E2BF
00D80038 RETN

```

Actual kernel32!CopyFileA code

```

7C830053 MOV EDI,EDI
7C830055 PUSH EBP
7C830056 MOV EBP,ESP
7C830058 PUSH ECX
7C830059 PUSH ECX
7C83005A PUSH ESI
7C83005B PUSH DWORD PTR SS:[EBP+8]
7C83005E CALL kernel32.7C80E2A4
7C830063 MOV ESI,EAX
7C830065 TEST ESI,ESI
7C830067 JE SHORT kernel32.7C8300A6

```

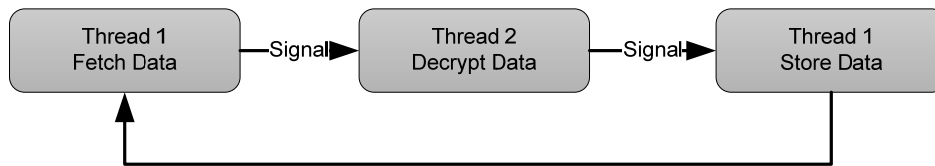
Some packers also go as far as loading the whole DLL image in an allocated memory and then redirecting API calls into these DLL image copies. This technique effectively makes it difficult to set breakpoints in the actual APIs.

6.6. Multi-Threaded Packers

With multi-threaded packers, another thread is usually spawned to perform some required operation such as decrypting the protected executable. With multi-thread packers, complexity is added and the difficulty of understanding the code increases since tracing the code gets complicated.

One example of a multi-threaded packer is PEcrypt, it uses a second thread to perform decryption of a data that had been fetched by the main thread, and these threads are synchronized using event objects.

PEcrypt operates and synchronizes its threads as follows:

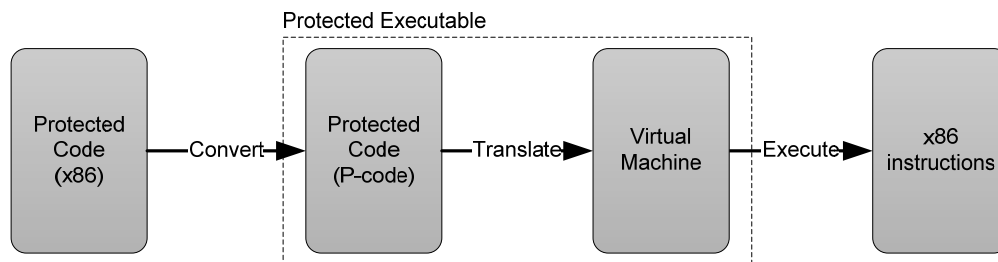


6.7. Virtual Machines

The concept of using virtual machines is simple: a reverser will eventually figure out how to bypass/solve anti-debugging and anti-reversing techniques and that eventually, the protected executable needs to be decrypted and executed in memory leaving it vulnerable to static analysis.

With the advent of virtual machines, protected parts of the code are translated into p-codes which are then translated into machine code for execution. Thus, the original machine instructions are replaced and the complexity of understanding what the code does exponentially increases.

Below is a fairly simple illustration of the concept:



Modern packers such as Oreans technologies' CodeVirtualizer and StarForce apply the concept of virtual machines to protect executables.

The solution for virtual machines, though not simple, is to analyze how the p-code is structured and translated by the virtual machine. And with the obtained information, a disassembler which will parse the p-code and translate them into machine code or understandable instructions can be developed.

An example of developing a p-code disassembler and detailed information about implementation of virtual machines can be found on the following link:

Defeating HyperUnpackMe2 With an IDA Processor Module, Rolf Rolles III

http://www.openrce.org/articles/full_view/28

7. TOOLS

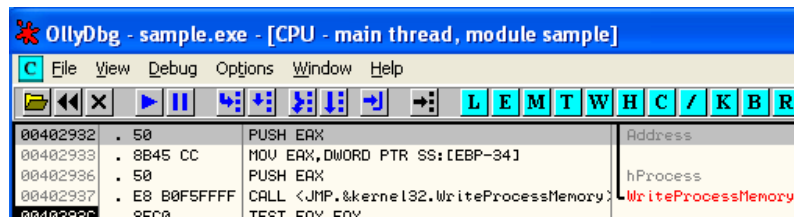
This section lists publicly available tools that reversers and malcode analysts can use to perform packer analysis and unpacking.

Disclaimer: These tools are 3rd party tools; the author of this paper is not liable if any of these tools causes system instability or other issues that may impact your system. It is always advisable to run these tools in a test or a malware analysis environment.

7.1. OllyDbg

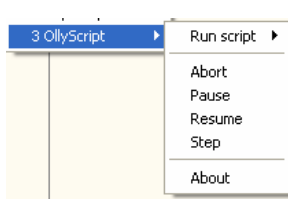
<http://www.ollydbg.de/>

A powerful ring 3 debugger; used by reversers and malcode analysts. Its plug-in capabilities allow other reversers to create add-ons to make reversing and unpacking much easier.



7.2. Ollyscript

<http://www.openrce.org/downloads/details/106/OllyScript>

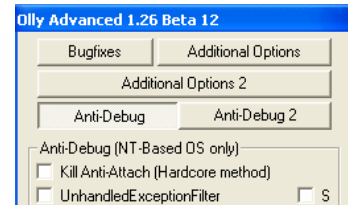


An OllyDbg plug-in which allows automation of setting/handling breakpoints, patching code/data, etc. thru the use of a scripting language similar to assembly language. It's most useful in performing repetitive tasks and automate unpacking.

7.3. Olly Advanced

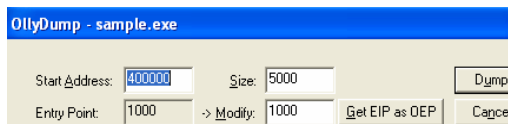
http://www.openrce.org/downloads/details/241/Olly_Advanced

If packers contain armoring code against reversers, this OllyDbg plug-in is the armor to the reverser's debugger. It has several options to bypass several anti-debugging techniques and hide OllyDbg from packers detecting the debugger, and much more.



7.4. OllyDump

<http://www.openrce.org/downloads/details/108/OllyDump>

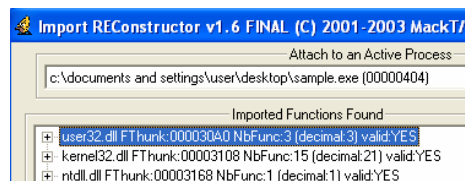


After a successful unpack, this OllyDbg plug-in can be used for process dumping and import table rebuilding.

7.5. ImpRec

<http://www.woodmann.com/crackz/Unpackers/Imprec16.zip>

Finally, this is another tool for process dumping and import table rebuilding; it is a stand-alone tool, it offers one of the most excellent import table rebuilding capability.



8. REFERENCES

Books: Reverse Engineering, Software Protection

- Reversing: Secrets of Reverse Engineering. E.Eilam. Wiley, 2005.
- Crackproof Your Software, P.Cerven.No Starch Press, 2002.

Books: Windows and Processor Internal

- Microsoft Windows Internal, 4th Edition. M. Russinovich, D. Solomon, Microsoft Press, 2005
- IA-32 Intel® Architecture Software Developer's Manual. Volume 1-3, Intel Corporation, 2006.

Links: Windows Internals

- ReactOS Project
<http://www.reactos.org/en/index.html>
Source Search: <http://www.reactos.org/generated/doxygen/>
- Wine Project
<http://www.winehq.org/>
Source Search: <http://source.winehq.org/source/>
- The Undocumented Functions
<http://undocumented.ntinternals.net>
- MSDN
<http://msdn2.microsoft.com/en-us/default.aspx>

Links: Reverse Engineering, Software Protection, Unpacking

- OpenRCE
<http://www.openrce.org>
- OpenRCE Anti Reverse Engineering Techniques Database
http://www.openrce.org/reference_library/anti_reversing
- RCE Forums
<http://www.woodmann.com/forum/index.php>
- EXETOOLS Forums
<http://forum.exetools.com>