



# SOFTWARE EXPLOITATION

USING HBGARY'S RECON TECHNOLOGY

Software is the single most important business technology today. As a foundation, software supports trillions of dollars of information processing and storage globally. Yet, the very things that make software powerful are also harbingers of risk and vulnerability. Complexity, connectivity, and extensibility make software hard to control and measure. Once fielded, software evolves in ways that cannot be predicted. It is the very nature of software to give rise to emergent properties, behaviors, and bugs that were never intended as part of the design. Harsh reality has eroded the credibility of development process and quality assurance. To be comprehensive, security assessments have been forced to include red-teaming and 3rd-party penetration testing. HBGary has prepared this whitepaper to illustrate how low-level software behavior can be analyzed without source code. The technology presented has been developed in part with funding from the U.S. Department of Defense and represents a truly next-generation capability for software reverse engineering.

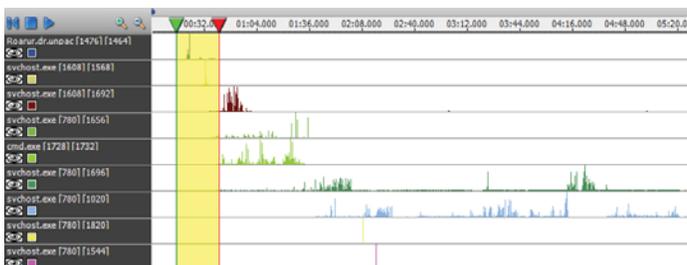
## SUMMARY

Software exploitation remains a dominant security problem for the Enterprise. Data security breaches have enormous costs. There are billions of lines of code represented within the average Enterprise, most of it third party. Software assurance practices, while getting better, are still not able to fully address code exploitation. Multiple sources, including Gartner, the National Institute of Standards and Technology, and the U.S. Air Force, all indicate a sharp rise in data security breaches facilitated by software exploits that target applications within the Enterprise<sup>1</sup>. A significant amount of software is written in languages that are prone to buffer overflows and parsing bugs. Outsourced development has high incidents of exploitable conditions, indicating a lack of security acceptance testing. Most importantly, a significant number of exploitable bugs are simple to fix, indicating a general lack of secure coding practices within the industry<sup>2</sup>. This whitepaper introduces HBGary's REcon technology and runtime tracing methods that can be used to identify several major categories of exploitable bug in closed source, COTS, and 3rd party software components.

REcon was developed to assist computer scientists in the task of automated blackbox reverse engineering of Windows™ software. HBGary developed REcon with the assistance of the U.S. Air Force in 2008–2009. It has now been incorporated directly into Responder™, a commercial reverse engineering platform. REcon and Responder work together to drastically reduce the time and skill level required to reverse engineer software behavior.

## RECON OVERVIEW

REcon is first and foremost a software tracing system. REcon can automatically trace every process and every thread, both usermode and kernelmode, system-wide and in real-time. REcon captures control and dataflow at a single-step resolution. Data sampling captures the contents of registers, the stack, and target buffers of dereferenceable pointers. Symbols are resolved for all known API calls, and when combined with argument sampling, drastically reduces the time required to gain program understanding. REcon also contains a suite of special features for automatically tracking processes that create or modify other processes on the system.



REcon records software behavior in multiple tracks, similar in concept to audio/video editing software.

### Useful ways to use REcon

Use REcon to trace specific system level activity, such as filesystem or registry activity, to learn how a program installs itself. This is useful for malware remediation.

Use REcon to trace network activity to reconstruct protocols. This is useful for NIDS signature development.

Use REcon when a network protocol is encrypted and you want to rapidly recover the clear-text without having to reverse engineer any algorithms. This is a major timesaver.

Use REcon when trying to locate vulnerabilities in a heavily multithreaded application. This can be cumbersome with traditional interactive debugging.

Use REcon to follow execution flow across multiple DLL's.

Use REcon to trace a process that launches a secondary process, or injects a DLL into a secondary process.

Use REcon to rapidly locate code that is processing external, user-supplied input. This can be used with fuzzing.

Use REcon to trace code that is using anti-debugging, packing, and other methods to make traditional debugging difficult. REcon has a tendency to bypass such methods.

## A CASE FOR POST-EXECUTION DEBUGGING

Post-execution debugging is a paradigm shift from traditional interactive live debugging. While traditional interactive debugging is useful for development, it becomes cumbersome when used for tracing program behavior. Traditional debugging tools are designed for CONTROL of the execution, as opposed to OBSERVATION ONLY. Typically, the reverse engineer does not need to control the execution of a binary at this level, and instead only needs observe the behavior and data. REcon is focused entirely on OBSERVATION. The software is first recorded, and then analysis takes place. This makes REcon a *post-execution* debugger.

Imagine REcon as having a breakpoint on every basic block 100% of the time, without having to micromanage breakpoints.

REcon allows the analyst to see and query large volumes of relevant data at one time without having to get into the bits and bytes of single-stepping instructions and using breakpoints. Imagine REcon as having a breakpoint on every basic block 100% of the time, without having to micromanage breakpoints.

#### Modern Advantages of REcon

Traditional debuggers don't follow multiple processes. They cannot trace process->child process execution, nor can they follow a process injecting a DLL into another process. REcon, on the other hand, can trace everything on the system at once.

Tools that fuse traditional static analysis with runtime debugging have several problems. First, in order to obtain performance, they inject breakpoints at the beginning of basic blocks to gather coverage events. This can crash the target program if the static analysis cannot provide accurate basic block reconstruction. Secondly, this approach commonly requires the use of the windows debugging API's which can be effected by anti-debugging. Finally, a static disassembly is used to augment event data arriving from the debugger, again for performance reasons. REcon, on the other hand, does not require a disassembler or a static image, since every single instruction is captured in single-step mode as it executes. This all but eliminates the possibility of bad analysis.

Multi-platform debuggers (those that operate on unix, windows, and cellular phones in one system) are typically based on **gdb** for cross-platform support. Because **gdb** is designed to work on everything, it represents a 'lowest common denominator' - in other words its not exceptional on any single platform. REcon, on the other hand, is designed only for windows and is highly optimized for this single platform, far exceeding the performance of a multi-platform solution like **gdb**.

Many solutions in the past have consisted of a hodge-podge of scripts, integration between a disassembler and a separate debugger, and third party tools for graphing and such. This requires someone to have skill and patience to make all those connections work. REcon and Responder, on the other hand, were designed to work together from the beginning.

#### HOW RECON WORKS UNDER THE HOOD

REcon is nothing like existing, traditional debuggers. REcon has complete control over the operating environment, including the kernel, while at the same time maintaining performance levels so that software can be traced in real-time. REcon does not modify the target software in any way. No breakpoints are injected, no thread context is changed, and no debugger is attached. Tracing is performed completely external to the process operating environment. REcon operates at a very low level within the system, layering itself directly above the HAL (Hardware Abstraction Layer) and underneath the Windows kernel.

#### REQUIREMENTS

REcon is designed primarily to be used in conjunction with a virtual machine environment such as VMWare™ - although it can also run on native hardware that meets a narrow set of requirements. The REcon driver is intended to be loaded on a pre-configured, restorable single processor virtual installation of Windows XP Service Pack 2.



Process	Pid
smss.exe	364
csrss.exe	428
winlogon.exe	452
services.exe	696
lsass.exe	700
vmacthlp.exe	856
svchost.exe	872
svchost.exe	944
svchost.exe	1028
svchost.exe	1004

## QUICK START

This section will help you get up and running with REcon and walk you through performing a trace and viewing the results. Copy the **RECON.EXE** executable to the target virtual machine (drag and drop will work with VMWare™ if **VMWare Tools** is installed). Double click to execute **RECON.EXE**. A user interface should become visible. Once a REcon trace has been configured and started, the REcon driver automatically begins recording trace data into a binary journal format located at **C:\REcon.fbj**. Finally, once the analyst has recorded enough data, the trace is stopped and the resultant **C:\REcon.fbj** file can be moved to a separate system for offline analysis with HBGary Responder Pro.

#### USER INTERFACE

To begin tracing, click the **START** button (figure 1, A). You can either launch a program using the **LAUNCH NEW** button (figure 1, B), or you can select an existing process from the task list (figure 1, C) and select **TRACE SELECTED** (figure 1, D).

FEATURE	DESCRIPTION
LAUNCH NEW (figure 1, location C.)	This will query you for a program to execute. The program will be launched and traced.
TRACE SELECTED (figure 1, location B.)	You can select an existing process for tracing. Please be aware that only new execution behavior will be traced, so whatever executed on program startup will not be represented in the capture.
STOPPING (figure 1, location A.)	When you press STOP (figure 1, location A.), the traced process will often times continue to execute normally since REcon does not use any instrumentation.
SHUTTING DOWN (figure 1, location D.)	To shutdown REcon and remove the driver, simply close the REcon GUI application using the DONE button. The system should continue to operate normally and REcon will be completely removed from the system. At this point, the trace log will be complete and will be located at <b>C:\RECON.FBJ</b>

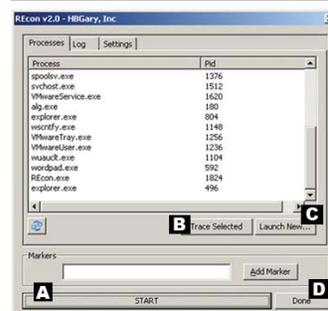


Figure 1 - REcon.EXE

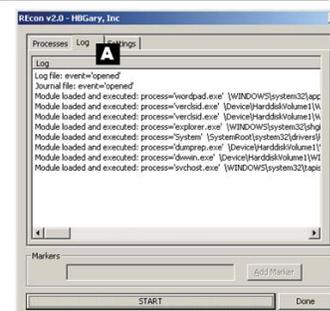


Figure 2 - REcon.EXE Log Window

RECON.LOG (figure 2, location A.)	The file located at C:\RECON.LOG contains high level messages about program behavior as the trace is executing. THIS IS NOT THE RECON TRACE. The REcon trace itself can be found in the RECON.FBJ file.
RECON.FBJ	The file located at C:\RECON.FBJ is the full binary trace of the system. This file can sometimes be quite large. This file is intended for import into Responder PRO.
RECONX86.SYS	This is the REcon device driver which is created on-the-fly by RECON.EXE.

**PERFORMING A TRACE**

The easiest way to use REcon is to first start **RECON.EXE**, press **START**, and then launch the program you want to trace. If you are performing exploitation assessment, you can start exercising the program (sending packets, fuzzing, etc) and the code that executes as a result will be captured. Then, once you are satisfied, you can shutdown **RECON.EXE** and load the **RECON.FBJ** file into Responder (C:\RECON.FBJ). Using the track view and search, you can often find the data you injected.

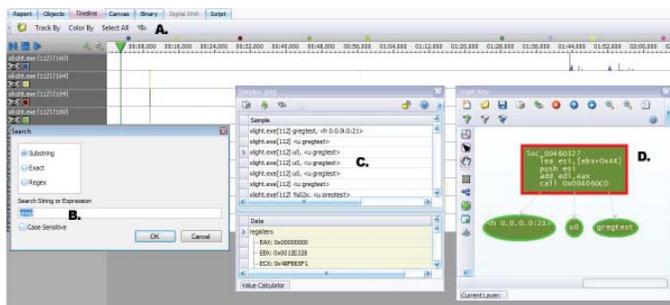


Figure 3 - Searching REcon trace for injected data & graphing code

In **figure 3** we can see how data searches can be used to locate code that processes user-supplied input. The target in this case is an FTP server program. The target was recorded while logging into the server with a username of "gregtest". Using the full track search (**point A.**) we search for the substring "greg" (**point B.**) and the results are shown (**point C.**). The results can be sent to a graph (**point D.**) and the code that accessed the data can now be explored. The code around these locations are potential exploitation points and should be examined for vulnerabilities. Read the section on CONFIGURATION to learn how to fine tune your tracing and analysis.

Once you are comfortable with REcon, you can set advanced configuration options that control how trace data will be collected. You can also launch or attach to specific processes.

**MARKERS AND TRACE-ONLY-NEW**

Identifying the purpose of each code region or function is a critical step in reverse engineering. REcon offers two features that can help you isolate regions of code that relate to specific program behaviors: **MARKERS** and **TRACE-ONLY-NEW**.

**MARKERS** are human-readable labels that you can set while recording. **MARKERS** appear in the timeline at the point when they were created. While recording, you can set a marker before you take some action with the target program. For example, assume you are tracing an FTP server. You can set a marker named "about to login" directly before you attempt to login to the FTP server. To find the code that executes in response to a server login, you simply find the marker in the track and examine the code that immediately follows.

**TRACE-ONLY-NEW** is an extension to the marker feature. Most software programs have background threads, loops, timers, and general-purpose code that is executing at all times. This layer of code execution is like "background noise" and can make it difficult to isolate code that is specific to a behavior. To help you overcome this, REcon offers **TRACE-ONLY-NEW**. When using **TRACE-ONLY-NEW**, code locations will be logged **only the first time they are seen** in a trace. As a result, background noise is effectively removed from the trace. You see the effect of **TRACE-ONLY-NEW** in **figure 4**. The top trace is collected normally. The bottom trace uses **TRACE-ONLY-NEW** to remove duplicate or repeat behaviors. The result is that only new behaviors are recorded.

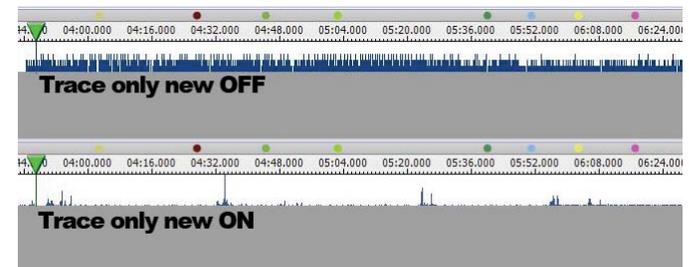


Figure 4 - REcon recording with TRACE ONLY NEW

Using our previous example, assume you trace an FTP server using **TRACE-ONLY-NEW**. As your trace commences, you set a marker named "about to login" directly before you attempt to login to the FTP server. The subsequent FTP server code that executes will include general purpose packet handling **and** code blocks specific to the login processing. Because **TRACE-ONLY-NEW** is enabled, REcon will only log the new blocks unique to the login processing.

**BORON TAGGING**

Tracking externally supplied input is very difficult with traditional debuggers and traditional static analysis. REcon offers a drastically simplified approach called the 'boron' track. The boron track uses runtime data samples

to determine when external / user-supplied input is being processed. Used in conjunction with the exceptions track, potential software bugs that can be induced with external input become obvious. To extend on our previous example, in **figure 5** is a trace of an FTP server. The `samplepoints.ini` file has been configured with a boron track on the substring "shawn \_ was \_ here". This causes an additional track to be placed in the track view (**figure 5, point A.**). Whenever the substring "shawn \_ was \_ here" is found within any data sample, an event will be added to this track (**figure 5, point B.**). Selecting the region on the track will display the samples in detail (**figure 5, point C.**). From this point, the code around these locations can be examined. This feature is a major time saver.

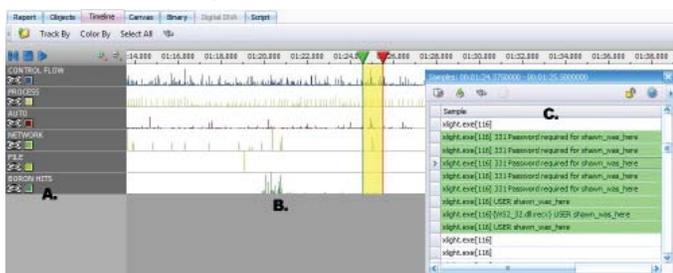


Figure 5 - "Boron" track shows when user-input is processed

## CONFIGURATION

REcon is highly configurable and the best results are obtained when you know how to tune REcon for a specific problem-set. Furthermore, many DLL's are excluded from the trace by default. When you are evaluating system DLL's for vulnerabilities you need remove the desired DLL's from the SYSEXCLUDES set. This section will help you tune REcon for the best results.

### SAMPLE POINTS

The `samplepoints.ini` file controls which API calls will be sampled automatically when tracing. If REcon is not already tracing an API call that you need, you can manually add the API call in this file. You can add any code location to sample points, including internal function entry points that are not exported. You can also specify how many arguments are passed to the function and these will be sampled as data every time the function is visited in the trace. If any arguments point to a string in memory, the string will also be sampled.

The `samplepoints.ini` file lets you sort your sample points into arbitrary tracks. You can add your own custom tracks to the track view via the `samplepoints.ini` file. A samplepoint entry has the following format:

```
<track name> <# arguments> <DLL name> <Function Name>
```

For example, if you were only evaluating a specific set of subroutines for vulnerabilities, you may want to create a custom track to log when those routines are visited.

### SYS EXCLUDES

The `sysexcludes.ini` file defines which DLL's you wish to skip over while tracing. Most system DLL's are not of interest during a trace, unless that system DLL is the one being evaluated for vulnerabilities. If you wish to evaluate a system DLL, you need to remove that DLL from the `sysexcludes.ini` file. In some cases, you may need to remove more than one DLL from the system excludes. For example, to effectively evaluate the security of RPC calls implemented in `netapi32.dll`, you would remove the `netapi32.dll` from `sysexcludes.ini` because `netapi32.dll` services the RPC call. In addition, you would also want to remove `rpcrt4.dll` so that boron-tagged data will traced on the inbound call traces to `netapi32.dll`.

**Important:** `sysexcludes.ini` and `samplepoints.ini` can both define a system exclude. Be sure to remove any excluded DLL's from both files.

### TRACE AGGRESSIVE

REcon allows you to attach to trace existing process, or launch new processes. When launched from REcon you can trace the entire program from startup. However, there are times when you won't know ahead of time what to trace. In these cases you can use the 'trace aggressive' feature. When 'trace aggressive' is enabled, any process that is launched will automatically be traced. Furthermore, any process that loads a new DLL will also be added to the trace, which can detect many forms of malicious injection. Finally, if a process loads a kernel mode device driver, that process will be added to the trace.

## FAULT EXPLORATION

The key to finding exploits is the ability to isolate memory corruption and exceptions, in particular those that are influenced by externally supplied input. Most exploits are a result of external input (such as data read from a file, or from the network) being processed in a faulty way. Using REcon, you can explore how externally injected data is used throughout the software. You can also cross reference external input with exceptions and faults. The code in and around faults or external input parsing should be examined for the vulnerability classes listed at the end of this document.

### EXCEPTIONS TRACK

REcon offers a special track of information called the 'exceptions track'. The exceptions track records any data faults, invalid memory access, or numerical errors that occur while the software executes. While some exceptions are used for error reporting and don't represent corruption, REcon offers an advanced filtering system to report only exceptions that are potential software bugs.



Figure 6 - Control flow leading up to an exception

In **figure 6** we can see the relationship between an exception and the control flow that immediately precedes it. The code traced at **location A**. is the code which was executing immediate prior to the exception recorded at **location B**. Thus, the code at **location A**. represents code which contains a potential flaw or vulnerability. This trace represents a significant advantage over traditional debuggers and stack traces. A traditional debugger will interactively halt when an exception occurs and the analyst must manually reconstruct the path leading to the exception. Traditional methods like reconstructing a call stack from memory can be made very difficult when memory corruption has occurred. REcon eliminates that problem as shown in the trace above.

**PINPOINTING BUGGY CODE**

Using the boron track, you can associate user supplied input with exceptions. In **figure 7** we can see user supplied input being parsed at **location A**. Immediately afterwards is an exception at **location B**. This is a strong indicator that a software bug is being exercised by the injected data.



Figure 7 - User supplied input processed near an exception

To follow up, we can select a region of control flow that is in immediate proximity to this location (**figure 8**). Suspect code regions can be graphed and expanded to illustrate potential exploits. A good practice is to audit any code region around user-supplied input for bugs similar to the ones listed at the end of this document.

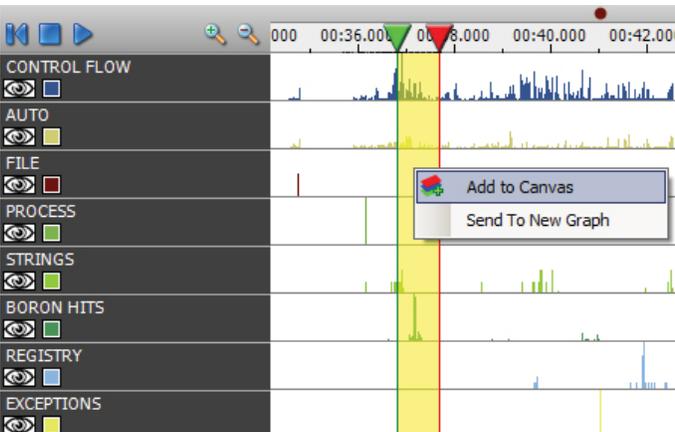


Figure 8 - Selecting code and data for subsequent graphing

**CASE STUDY**

**MICROSOFT RPC SERVICE REMOTE EXPLOIT**

Late in 2008 an exploit was released for an obscure path-parsing bug in **netapi32.dll**. The Microsoft bug code for this vulnerability is **MS08-067**. This bug was directly related to metacharacter parsing and arithmetic within a hand-coded loop. This type of bug is difficult to spot in source code and makes a great example for the kinds of exploits that can be discovered with REcon. To exercise this bug, you should use an unpatched Windows XP SP2 or SP3 build.

**VULNERABILITY DETAIL**

To exercise this vulnerability, you will need to be able to make RPC calls with a test program. Proof of concept exploits have been released for **MS08-067** and these can be used to learn how to craft an RPC testing harness. The test harness must be able to make a call against the function 'NetprPathCanonicalize'. For purposes of this illustration we will assume you want to identify all code locations that process input to this function.

**USING THE EXCEPTION TRACK**

A key component for finding the RPC exploit will be the exceptions track. The proof of concept exploit that we used to exercise the RPC call results in a single exception being logged. REcon uses smart exception filtering to show only exceptions that have value for exploit analysis. If such an exception occurs, it will be logged to a special EXCEPTIONS track (**figure 9, point A.**). At the moment an exception occurs, an event will be logged (**figure 9, point B.**). Selecting the region around the exception will reveal sample points (**figure 9, point C.**) The samples that are shown in red are directly related to the exception event. The injected exploit string is also clearly visible in the sample, further ensuring us that this exception is a result of the fault injection.



Figure 9 - Control and data flow responsible for the MS08-067 vulnerability

**CONFIGURATION TO TRACE RPC CALLS**

In order to detect exceptions, REcon must be tracing the desired target program. Although not absolutely required, you should also remove the target DLL from the **sysexcludes.ini** list. In this example, **netapi32.dll** is the vulnerable DLL. The target program to trace is **svchost.exe**. There are many copies of **svchost.exe**, so we first had to find the one that hosted **netapi32.dll**. If there are multiple candidates, you can try all of them, or crash one of them using a proof-of-concept in a VM, and then note which PID was effected.

For the best results, `netapi32.dll` and `rpcrt34.dll` should be removed from both `samplepoints.ini` and `sysexcludes.ini` files. If you leave the DLL's in the exclusion list they will not be traced. Even if excluded, the exception will still be logged, but you would not be able to graph the code leading to the exception.

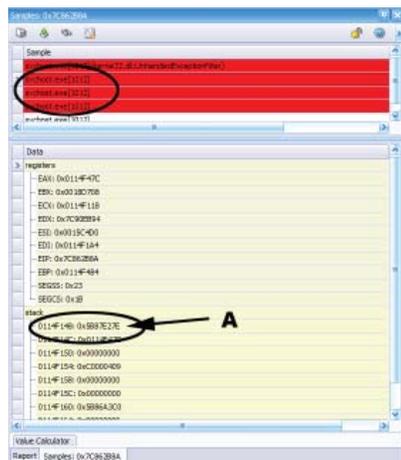


Figure 10 - Detecting source of typical exception

If you already have a proof-of-concept exploit but you don't know which DLL is being effected, you can examine the exception events to determine the source address of the exception. This can be cross referenced with the base address of the DLL to find out which module should be removed from the exclusion list. In **figure 10**, a typical exception has been logged and the topmost address on the stack reveals to source DLL that needs to be removed from the exclusion list. In **figure 11**, an unhandled exception has been logged and the stack itself resides in the address space of the DLL in question.

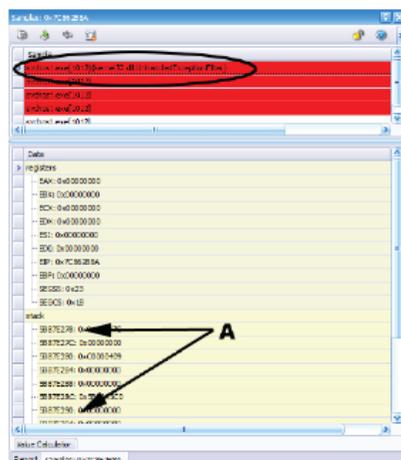


Figure 11 - Detecting source of unhandled exception

### SEARCHING FOR LOOPS, ARITHMETIC, AND PARSING

Assuming we are new to this area of code and we have not yet found an exploit, we would want to examine the code for arithmetic and other potential problems. Using the track view in conjunction with boron tags, we select regions of code around the boron tagging and pop these up to a new graph (**figure 12, location A.**) Once the graph has been created, we use the graph search feature (**figure 12, location B.**) to search these regions for arithmetic instructions, and also examine loops in detail. For example, searching for byte operations reveals several locations that parse user-supplied input. In **figure 13** we see a check for the capital 'D' character (**figure 13, location A**), a check for the '\$' character (**figure 13, location B**) and several checks for the backslash '\ character (**figure 13, location C**).

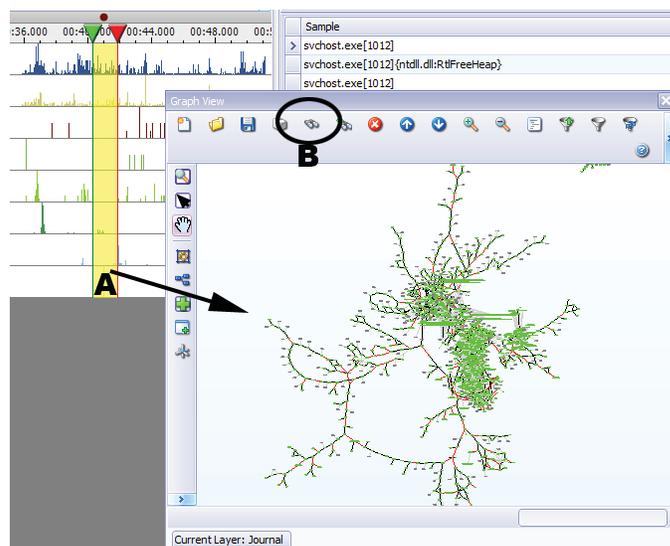


Figure 12 - Graphing the code and data around user-supplied data

Closer examination of locations such as those shown may reveal vulnerabilities and also help you craft input to exercise potential problems.

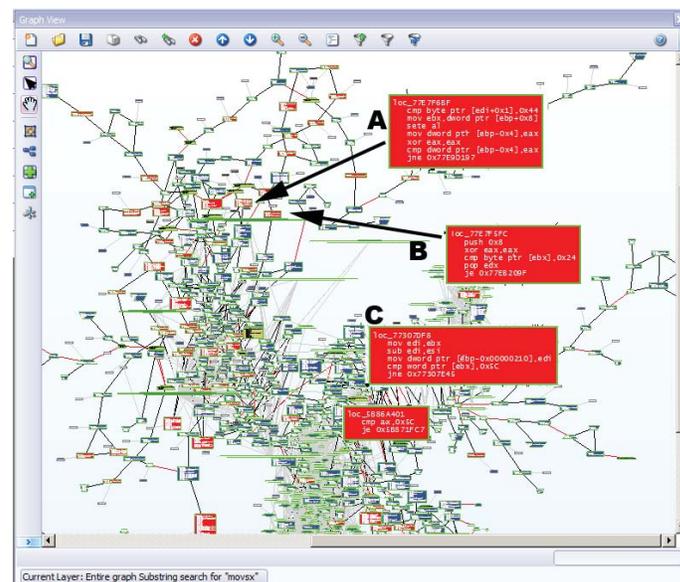


Figure 13 - Locations that perform character parsing on user-supplied input

### PINPOINTING MS08-067

Using a proof of concept for MS08-067, you should be able to cause an exception within the vulnerable function found in `netapi32.dll`. On an XP SP3 system, this function will be located at `0x5B86A51B`. There are several nested loops within this function, and if the input is crafted correctly, an exception will be thrown within one of these loops. For this example we rely on the exceptions track to locate the point of fault.

To locate the point of fault, drag-and-drop the exception events to the graphing canvas (**figure 14, point A.**). This will graph the code around the fault location. Growing the graph upwards from the fault location should lead you directly to the vulnerable code block (**figure 14, point B.**). Further growing the graph upwards will reveal the code path that leads to the vulnerable location (in **figure 14, point B.** grows up to **point C.**).

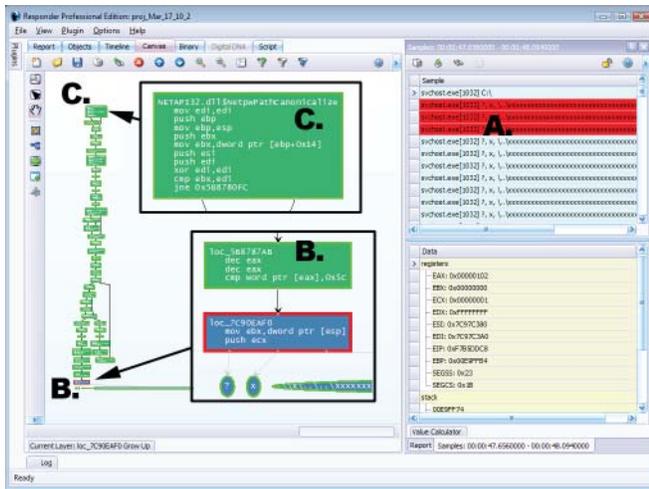


Figure 14 - Pinpointing the vulnerable MS08-067 function

Because REcon is recording data samples at every location, the code path leading to the vulnerability can be examined in detail, both code and data states (**figure 14, all blocks between point C. and point B.**). This can help you understand the arithmetic factors that play a part in the exploit. If you follow the code path back far enough, you can also reveal the name of the exposed API function which is vulnerable (**figure 14, point C.**).

## VULNERABILITY CLASSES

There are many different types of vulnerability. This section details some of the problems that can be detected in closed source software, specifically those that can lead to exploitable buffer overflows. While not exhaustive, this section provides some of the most common attack patterns.

### STRING OVERFLOWS

This type of bug occurs when an overly long string is provided to an application. If this string is assumed to be within a certain size, and the size can be exceeded, a buffer overflow will occur. This can lead to an exploitable condition. Format string overflows are a variation of this problem. There are many functions which are considered unsafe for string handling and these are well documented elsewhere. One interesting variation of this problem are off-by-one problems in combination with routines such as strncpy which are sometimes used as a 'safe' string copy.

### INTEGER CASTING AND TRUNCATION

This type of bug is especially common in c/c++ code where the developers use casting between types. Numbers which are assumed to have certain value ranges can end up truncated, or smaller than expected. Any subsequent arithmetic can cause values to be much larger or much smaller than expected. If said values are used in conjunction with memory allocation or movement, buffer overflows can arise.

Consider the following code (asm and pseudo-c inlined) where two signed shorts are multiplied together:

```
signed short a,b;

a = 5;
00411A4E mov     word ptr [a],5
b = 0xF000;
00411A54 mov     word ptr [b],0F000h
a = a * b;
00411A5A movzx   eax,word ptr [a]
00411A5E movzx   ecx,word ptr [b]
```

Registers at this point:  
 EAX = 00000005 EBX = 7FFDE000  
 ECX = 0000F000 EDX = 00000001

```
Now perform the multiplication:
00411A62 imul   eax,ecx
00411A65 mov     word ptr [a],ax
```

At this point, the variable 'a' contains a truncated value:

```
EAX = 0x0004B000      (full 32 bits)
a =      0xB000      (unsigned short)
```

When casting to a smaller value type information can be lost. For example, downcasting from 32 to 16 bits is very common. If arithmetic is included in operation so that the value can exceed 0xFFFF in size, the lower 16 bits can be made to represent a very small value or even zero.

Consider the following code that reads a 32 bit value and downcasts it to a WORD (16 bit short) size. The code adds 2 to the 32 bit value prior to downcast, so the final value could end up truncated with data loss:

```
movzx   eax, word ptr [ebx+2]
add     eax, edx
mov     [ebp+arg_4], eax
cmp     ecx, edi
jnz    loc_75093AEA
push   [ebp+arg_4] // size_t
call   _MIDL_user_allocate@4
```

Here is another example:

```
movzx   eax, word ptr [ebx+0Ah]
add     [ebp+arg_4], eax
```

The following example truncates to word size into the **ecx** register which controls the size of the buffer move operation:

```
movzx   ecx, word ptr [ebx+0Ah]
mov     esi, [ebx+0Ch]
mov     edx, ecx
shr     ecx, 2
rep movsd
```

And another example of the same:

```
movzx ecx, word ptr [esi]
mov esi, [esi+4]
mov eax, ecx
shr ecx, 2
lea edi, [ebx+6]
rep movsd
```

And the following is similar to the above but also performs arithmetic on the truncated value before use, which increases the likelihood of finding a bug since there are two source values in play:

```
movzx eax, word ptr [ebp+var _ 8]
mov ecx, edx
sub ecx, eax
add edi, eax
mov eax, ecx
shr ecx, 2
mov esi, offset AA
rep movsd
```

## INTEGER PROMOTION AND SIGNED CONVERSION ERRORS

This type of bug occurs when a signed value is used with an unsigned value. When numbers are converted between the two forms, improper values can result. If used near memory allocation or length checks, buffer overflows may occur.

Consider the following code (asm and pseudo-c inlined) where an unsigned and signed integer are used together:

```
unsigned int a;
int long b;

a = 5;
00411A4E mov     dword ptr [a],5
b = 0xF0000000;
00411A55 mov     dword ptr [b],0F0000000h
```

*The result of the next operation will be treated as an unsigned int and the compare operation will be treated as unsigned:*

```
if(b * a < 0)
00411A5C mov     eax,dword ptr [b]
00411A5F imul   eax,dword ptr [a]
00411A63 test    eax,eax
00411A65 jae    main+48h (411A78h)
{
...
}
```

Even when all variables are the same bit-size, the signed / unsigned mismatch can cause promotion. Consider the next code example as well (asm and pseudo-c inlined) where the compare statement is signed, but the integers are promoted to 32 bits during the compare, thus introducing a bug:

```
signed short t1 = 3;
signed short t2 = 100;
unsigned short modifier = -1;
```

*This compare is signed but promoted to 32 bit:*  
**if( t2 < t1 + modifier)**

```
00411B48 movsx   eax,word ptr [t2]
00411B4C movsx   ecx,word ptr [t1]
00411B50 movzx   edx,word ptr [modifier]
00411B54 add     ecx,edx
00411B56 cmp     eax,ecx
```

*The registers at this point:*

```
EAX = 00000064
ECX = 00010002
```

*In the above, CX isn't bigger than AX, but top word isn't masked because of the promotion, thus the following branch can be exploited:*

```
00411B58 jge     main+137h (411B67h)
```

Finally, signed values used along with arithmetic in a term can be promoted during an arithmetic rollover:

```
signed short t2 = 0x7FFF;
```

```
if( (t2+1) < t1 )
0040105E 0F BF F6     movsx   esi,si
00401061 0F BF EF     movsx   ebp,di
00401064 8D 46 01     lea    eax,[esi+1]
00401067 3B C5       cmp    eax,ebp
00401069 7D 0B       jge    _main+67h
(401076h)
{
...
}
```

In the above example, assuming t2 is **0x7FFF** (32,767 decimal), the value of (**t2 + 1**) should overflow and become -32,768 decimal, but pay close attention to the **movsx** instructions. The **movsx** instructions load the 16 bit values into 32 bit registers and zero out the upper word. The subsequent addition, implemented as a **lea**, causes EAX to contain the value **0x00008000** as a 32 bit number. Because the number is treated as 32 bits, **0x00008000** does not equal -32,768 as expected, but instead is treated as +32,768. This effectively negates the effect of any signiness against the branch, which results in a potential vulnerability.

## INLINE LOOPS

This type of bug occurs when a loop is hand-coded with certain exit conditions. If the exit conditions are not carefully enforced, the loop can run past the end of an array or buffer and cause an overflow.

Consider the following code (asm and pseudo-c inlined) where a buffer is being walked backwards until a backslash is located<sup>3</sup>:

```
while (*q != L'\' && q != path)
00E23953 mov     eax,dword ptr [q]
00E23956 movzx   ecx,word ptr [eax]
00E23959 cmp     ecx,5Ch
00E2395C je     ms08_067+1E1h (0E23971h)
00E2395E mov     eax,dword ptr [q]
00E23961 cmp     eax,dword ptr [path]
00E23964 je     ms08_067+1E1h (0E23971h)
```

```

q--;
00E23966 mov     eax,dword ptr [q]
00E23969 sub     eax,2
00E2396C mov     dword ptr [q],eax
00E2396F jmp     ms08_067+1C3h (0E23953h)

```

The above code represents the part of the vulnerable code responsible for MS08-067.

### NONLOCAL MEMCPY LENGTH

When the length used with a memcopy is not calculated in direct proximity to the memcopy but is obtained from some other routine, the chance of a bug is greatly increased. This is because the programmer(s) cannot see the length calculation at the same time they see the copy operation. The length calculations may be made by a library or a subroutine that was written by a different developer. Arithmetic and parsing is difficult to keep track of even when all the calculations are local to one function. Spreading these calculations out just makes the problem worse.

The following code obtains the value of var\_C from the subroutine sub\_4010E0, as you can see from the argument push (highlighted):

```

lea     edx, [ebp+var_C]
push   edx
lea     eax, [ebp+var_18]
push   eax
lea     ecx, [ebp+var_4]
push   ecx
call   sub_4010E0
...
mov     eax, [ebp+var_C]
push   eax
mov     ecx, [ebp+arg_0]
push   ecx
mov     edx, [ebp+arg_4]
push   edx
call   _memcpy

```

Eventually, the memcopy is called and the length of the copy is controlled by var\_C. This is a situation where the length is calculated in a separate function. The subroutine that calculates length needs to be audited to determine if assumptions made about size are enforced.

### ARITHMETIC AROUND MALLOC / MEMCPY

Arithmetic anywhere around malloc / memcopy pairs should be checked closely for any addition / subtraction to values that are derived from user input. For example, subsequent arithmetic on the result of a strlen call. In many cases, arithmetic is not strongly audited and a buffer overflow condition can be crafted.

When auditing for arithmetic, pay special attention to any calculations that are greater than 1. For example, the code is adding or subtracting 2, 3, or some other small integer value. Parsing loops are prone to error when the

index increment size is greater than one. For example:

```

lea     eax, [ebx + 6 ] // add six
add     eax, 14h // add 0x14
sub     eax, 2 // subtract two

```

Finally, be aware of other forms of malloc. There are many different routines and functions which allocate memory. For example:

```

push   esi // size_t
mov    [ebp+var_4], esi
call   _MIDL_user_allocate@4

```

The above is a call to MIDL\_user\_allocate(x) where x is the length of the buffer. We see that esi contains this length.

Consider the following code where the value in var\_10 is being added to the length used for the memory allocation. The values in eax and var\_10 both should be audited:

```

add     eax, [ebp+var_10]
lea     eax, [eax+ecx+28h]
push   eax // size_t
mov    [ebp+var_18], eax
call   _MIDL_user_allocate@4

```

### INTEGER OVERFLOW / UNDERFLOW

This vulnerability occurs when an integer value can be made to wrap around, becoming so large that it wraps to a negative number, or back to zero. The opposing case can also occur, where a number is made so small that it wraps around to become a very large number. As usual, any numerical problems that control loops, copies, or bounds checks can result in exploitable conditions.

Consider the following code that calls wcslen to get the length of a wide string in memory, then doubles the length and adds two. Depending on the length of the string, it might be possible to cause a derivative value from ecx to overflow:

```

call   _wcslen
lea    ecx, [eax+eax+2]

```

Also, consider how the following code adds 0x14 to the value in eax. Whenever arithmetic is performed in quantities greater than one, bugs have a tendency to arise. If you can influence the value of eax such that adding 0x14 causes an overflow, this memory allocation could be made too small:

```

lea     esi, [eax+14h]
push   esi // size_t
mov    [ebp+var_4], esi
call   _MIDL_user_allocate@4

```

### SUBTRACTION UNDERFLOW BEFORE MEMCPY

This vulnerability occurs when an integer value can be made so small that it wraps around becoming a very large number, and this number is then used for a subsequent memcpy operation. This condition will usually cause an exception but the attacker may be able to control an exception frame and gain control of the CPU.

The following code uses `var _ 10` to store the length of a buffer copy. However, the code subtracts 8 from this value prior to use. If the value in `var _ 10` can be made less than 8, then the length value will underflow and become a very large number, thus causing a buffer overflow when memcpy is called:

```
mov     eax, [ebp+var _ 10]
mov     ecx, [eax]
sub     ecx, 8
push   ecx
mov     edx, [ebp+arg _ 0]
add     edx, 8
push   edx
mov     eax, [ebp+var _ 8]
push   eax
call   _ memcpy
```

### MULTIPLICATION CAUSES WRAP

This vulnerability occurs when an integer value is multiplied causing a wrap around. Because a multiply has the potential to change the integer by substantial values, an attacker can potentially get precise control over this buffer overflow and cause the CPU to use a value that was overwritten.

### BYTE PARSER MISSES METACHARACTER

This occurs when a hand-coded loop is parsing for a specific character, such as a backslash (0x5C or '\\'). If the routine increments/decrements more than a single character under certain conditions, it might be possible to trick such a routine to skip over a metacharacter and thus bypass a filter or run off the end of a buffer.

Consider this loop:

```
loc _ :
mov cl, byte ptr [eax]
cmp cl, \'
jne loc _
lea eax, [eax+2]
jmp loc _
```

The routine reads forward looking for a '\\\' character. If a '\\\' is found in the buffer, the buffer pointer is incremented by two. Depending on the rest of the algorithm, this may cause the pointer to skip over a

character that should have been parsed. Or, consider what happens if the last character in the buffer is a '\\\' - the routine would skip over the terminating null and read off the end of the buffer. Finally, consider if the string "AAA.\0AAAAA" could be supplied. The string has an embedded NULL after the '\\\' character. If the string was used with strlen to determine the length of a malloc, and then the above loop was used for the copy operation, a buffer overflow would occur.

### CHARACTER EXPANSION

This problem occurs when a single character is converted to two or more replacement characters. When this occurs during a loop, the target buffer may be overwritten. If the target buffer size was calculated without regard to this expansion, then a buffer overflow is possible.

Consider the following code:

```
mov     edx, [ebp+var _ 4]
movsx   eax, byte ptr [edx]
cmp     eax, 5Ch
jnz     short loc _ 40107E
mov     ecx, [ebp+var _ 4C]
mov     byte ptr [ecx], 5Ch
mov     edx, [ebp+var _ 4C]
mov     byte ptr [edx+1], 5Ch
mov     eax, [ebp+var _ 4]
add     eax, 1
mov     [ebp+var _ 4], eax
mov     ecx, [ebp+var _ 4C]
add     ecx, 2
mov     [ebp+var _ 4C], ecx
jmp     short loc _ 40109A
```

The source string is stored in `var_4`. Whenever a backslash is encountered ('\\') two backslashes are written to the target buffer ('\\'). If the target buffer is not resized accordingly, a buffer overflow may occur.

### FAILURE TO CHECK RETURN CODE

This is a fairly common problem. Programmers assume function calls will succeed and don't check for an error. If an error can be induced, the code will enter an invalid state and exploits might be possible.

### CHARACTER CONVERSION DEFEATS FILTERS

This is a basic attack where a character, such as '\\/' is converted to a different character, such as '\\'. If there is a filter on the input string, these conversions may allow an invalid string to bypass the filter. Consider that all three URLs refer to microsoft.com:

```
http://msdn.microsoft.com
http://207.46.239.122
http://3475959674 (octal format)
```

For many years, URL's and paths were attacked in this manner. URL's allow many alternate representations for characters. For example, '%25' in a URL is converted into '.' and UNICODE and MULTIBYTE characters can be intermixed w/ ASCII characters:

```
C0AE is '.' (unicode)
F080AE is '.' (UTF-8)
C0AF is '/'
E080AF is '/' (UTF-8)
C19C is '\'
F0819C is '\' (UTF-8)
```

Sometimes characters are stripped entirely. File paths have several characters and character sequences that are stripped or ignored. For example, './???secret.bin' can become '/secret.bin' because the leading characters are meaningless to the path. Even the '..' relative path notation may be stripped instead of being considered invalid. There are many other variations of this attack, including cross-site-scripting and javascript injection.

### RACE CONDITIONS

Race conditions are a bit harder to detect reliably, but global variables can be audited to determine if they are accessed from multiple threads. Locations that use critical sections or interlocked exchange are often shared between threads, and auditing these functions may reveal unprotected shared resources. Any data\_XXXX objects recovered from the binary that are accessed during the trace can be checked for multiple thread access in the samples view.

## FREQUENTLY ASKED QUESTIONS

### Q. WHAT IS RECON? WHY IS RECON IMPLEMENTED AS KERNEL MODE DRIVER?

A: REcon was developed as a kernel mode driver based solution for capturing application runtime data from Windows Systems. REcon was implemented as a kernel driver because it gives us more direct control over the windows operating system, and also allows us to not be bound to the very known target dependency that is the Windows Userland Debugging API. By performing all our debugging from kernel space manually we are able to completely hide or mask many of the "debugger" evidence fragments that result from using the userland, Microsoft provided debugging API's that similar userland based tracing tools use.

Simply put, there are dozens if not hundreds of ways for a malicious usermode application to detect if it is presently being debugged by a usermode debugger. For example, something as simple as "attaching" to a target application will cause modification to the memory footprint. In performing all our debugging based operations from kernel space it will be much more difficult for a user application to detect/prevent against, especially if the REcon.sys driver is loaded on to REAL sacrificial hardware.

### Q. IS THE RECON DRIVER A KERNEL MODE DEBUGGER? WHAT IS IT?

A: The REcon driver employs multiple kernel mode debugging tricks such as using the DRO-7 hardware debugging registers, modification of thread specific/saved trap frames, etc, however it is misleading to think of it as a kernel mode debugger (like SoftICE or WinDBG). REcon does not contain the full standard debugging feature set. Instead, REcon is designed to be a high-speed, instrumented data collector that is capable of sampling and capturing data on a system wide multi process, multi threaded basis. REcon was also specifically designed to automatically trace code that moves between or modifies other processes.

### Q. DOES THE RECON DRIVER SUPPORT SETTING OF BREAKPOINTS?

A: Yes and No. The REcon driver utilizes breakpoints internally but they are used as "trigger points" to start automated traces or to automatically "trigger" the sampling of data for a specific location (Samplepoints). REcon doesnt support the traditional debugging breakpoint semantics because pausing the system for any length of time (while waiting for a user-controlled continue operation), is undesirable. Users of REcon are able to set custom "samplepoints" of their choosing which as mentioned previously which can be used to collect data.

### Q. WHAT PLATFORMS DOES THE RECON DRIVER WORK WITH?

A: Presently the REcon driver is supports Windows XP – Single Processor –Service pack2 – 32 bit (x86). (Virtual installation highly recommended, HBGary uses VMWare Workstation 6.5.3 in-house)

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**Q: CAN RECON BE MADE TO RECORD AT BOOT TIME?**

A: REcon doesn't presently support boot-time loading or tracing. There isn't anything specifically preventing this use case from being successful, but it has not been tested by HBGary at this time.

**Q: WHAT DOES THE TRACEONLYNEW FEATURE DO?**

A: The TraceOnlyNew feature can be used to record each code path only once. When TraceOnlyNew is enabled the driver will only journal new/additional code block and data sample entries.

**Q: WHAT IS A SAMPLEPOINT? WHAT IS SAMPLEPOINT.INI USED FOR?**

A: Samplepoints are a way of defining which API/System calls the REcon driver should watch out for. The current set of samplepoints is defined in the samplepoint.ini file. Each samplepoint entry in samplepoints.ini defines the following data:

- Exported function name (Ex. "Sleep")
- DLL Name that the function lives in (Ex. "kernel32.dll")
- Number of function call arguments to sample off of the stack (Ex: 1)
- Samplepoint Group Name: (Ex: PROCESS)

**Q: HOW DOES THE "STEP OVER SYSTEM CALLS" FEATURE WORK?**

A: The "Step Over System Calls" feature was introduced to provide better overall tracing performance. This feature uses thread specific, CPU hardware breakpoints to actually skip over system calls entirely. When this feature is enabled, REcon will automatically recognize when a traced thread is about to CALL into a system DLL and will set a hardware breakpoint on the return-address after the call completes. Finally once the hardware breakpoint is hit by the RET of the system call, we automatically re-enable single-step tracing.

## MORE INFORMATION

### ABOUT HBGARY, INC

HBGary, Inc is the leading provider of solutions to detect, diagnose and respond to advance malware threats in a thorough and forensically sound manner. We provide the active intelligence that is critical to understanding the intent of the threat, the traits associated with the malware and information that will help make your existing investment in your security infrastructure more valuable.

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### ABOUT HBGARY FEDERAL

HBGary Federal, Inc is a spin off of HBGary's U.S. government cybersecurity services group. HBGary Federal delivers HBGary's malware analysis and incident response products and expert classified services to the Department of Defense, Intelligence Community and other U.S. government agencies. HBGary Federal can help both government and commercial customers to counter the advanced persistent threat.

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## REFERENCES

- i 'A CISO's Guide to Application Security' - CIO Solutions Group, Fortify
- ii 'State of Software Security Report' - Veracode
- iii 'Decompiling the vulnerable function for MS08-067' - Alexander Sotirov, Oct 25, 2008



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