iDEFENSE

// THE POWER OF INTELLIGENCE

A Comparison of Buffer Overflow Prevention Implementations and Weaknesses

Written by: Peter Silberman and Richard Johnson

iDEFENSE

1875 Campus Commons Dr. Suite 210 Reston, VA 20191
Toll Free: 877.516.2974 Main: 703.390.1230 Fax: 703.390.6456
www.idefense.com | customerservice@idefense.com

Abstract

In the world of information security, buffer overflows remain the leading cause of software vulnerabilities. In recent years, the industry has seen an elevated rate of exploitation of these vulnerabilities due to readily available worm-generation software and mass-exploitation toolkits. This increasing exposure to buffer overflow attacks requires a technological solution that applies a protective layer against automated exploitation attempts.

This paper will examine two approaches to applying a generic protection against buffer overflow attacks and critique the effectiveness of available buffer overflow protection mechanisms on the Linux and Microsoft Corp.'s Windows platforms. An analysis of each technology will explain the methods by which a protection mechanism has been implemented and the technology's effectiveness in defending against both automated and targeted attacks, which specifically try to circumvent that specific protection method. Finally, a matrix will be presented that will define each technology's ability to protect against multiple classes of buffer overflow attacks including format strings, stack overflows and heap overflow.

Table of Contents

1 Introduction

Software vulnerabilities that result in a stack-based buffer overflow are not as common today as they once were. Unfortunately, it only takes a single known vulnerability in a commonly used piece of software or operating system to leave an entire infrastructure exposed. Since the release of papers detailing exploitation methods like Aleph One's "Smashing The Stack For Fun and Profit,"[1] Mudge's "How To Write Buffer Overflows"[2] and w00w00's "On Heap Overflows,"[3] buffer overflows have been a prevalent problem in the information security field. The past few years has seen volumes of information published on techniques used to exploit software vulnerabilities. This research has become readily available at local bookstores, shortening the learning curve for an attacker even further. The availability of this information has led to the development of automated worms that can reduce the required attack window down to a number of hours before tens of thousands of computers are infected. In this sense, worm technology acts as a catalyst, causing widespread exploitation and requiring an equally effective defense against common attacks.

1.1 Scope

This paper aims to explain the concepts behind buffer overflow protection software and implementation details of some of the more popular software in use and provide an objective test platform that determines the effectiveness of each piece of software. The software covered by this paper includes PaX, StackGuard, StackShield, ProPolice SSP, Microsoft Visual Studio .NET, OverflowGuard and StackDefender. The authors chose to omit Exec Shield[4], kNoX[5], RSX[6] and OpenWall Project[7] because the project ideas contributed to the formation of PaX. As a result, their best features are covered in PaX and do not need to be explained twice.

[1] Smashing the stack for fun and profit (http://secinf.net/uplarticle/1/p49-14.txt), 11/08/1996
[2] How To write buffer overflows (http://www.insecure.org/stf/mudge_buffer_overflow_tutorial.html), 10/20/1995
[3] w00w00 on Heap Overflow (http://www.w00w00.org/files/articles/heaptut.txt), 1/1999
[4] Exec Shield (http://people.redhat.com/mingo/exec-shield/), 5/11/2004
[5] kNoX (http://isec.pl/projects/knox/knox.html), 3/29/2004
[6] RSX (http://www.starzetz.com/software/rsx/), 6/19/2004
[7] OpenWall Project (http://www.openwall.com/linux/), 11/29/2003

2 Buffer Overflow Protection Technology

Buffer overflows can be addressed in a multitude of ways to protect against unwarranted code execution. The common implementations of these protection schemes have been separated into two categories: kernel-enforced and compiler-enforced protection.

2.1 Kernel-Enforced Protection

Since the kernel is unaware of the internal functionality of the executable, its influence is restricted to modifications to the environment in which the program executes. The kernel is able to do this by modifying the layout of a process' virtual memory address space and by applying access controls to pages of memory that prevent the execution of injected code. According to PaX, the goal of kernel-enforced buffer overflow protection is to prevent and contain the following exploit objectives:

- Introduce/execute arbitrary code
- Execute existing code out of original program order
- Execute existing code in the original program order with arbitrary data

The two methods described below are combined to provide sufficient protection against most remote exploit attacks.

Memory Management Unit Access Control Lists (MMU ACLs)

Non-executable (NOEXEC) protection is the most commonly used access control for memory. A non-executable stack resides on a system where the kernel is enforcing proper "memory semantics." Proper memory semantics are comprised of three components outlined in the PaX Documentation[8]. One component is the separation of readable and writable pages, as well as only allowing programs that generate code at startup to have executable memory pages. The second component is to make all available executable memory including the stack, heap and all anonymous mappings non-executable. The third component consists of enforcing ACLs, which involve denying the conversion of executable memory to non-executable memory and vice versa.

Address Space Layout Randomization (ASLR)

ASLR is based on the theory that exploits commonly rely on static values such as addresses which are known to contain specific operands or pointers to the known location of a buffer on the stack. ASLR defeats these rudimentary exploit techniques by introducing randomness into the virtual memory layout for a particular process. ASLR can introduce varying levels of randomness during the process of loading a binary so that the binary mapping, dynamic library linking and stack memory regions are all randomized before the process begins executing. Randomizing the locations of the binary image, library locations, heap and stack causes generic exploits to fail, requiring the exploit to brute-force one or more address values and increasing the chance that an attack will be unsuccessful.

[8] PaX Documentation (http://pax.grsecurity.net/docs/pax.txt), 11/29/2003

2.2 Compiler-Enforced Protection

Compiler-enforced protection mechanisms take a completely different approach to preventing the execution of arbitrary code within a protected process. Since the compiler has intimate knowledge of structure of the binary, modifications to the stack layout may be made. Special values called 'canaries' may be inserted into arbitrary points in memory to detect the corruption of saved control structures. The basic concept of overflowing a buffer to modify a return address or function pointer on the stack may be addressed by placing canary values in a location that would cause them to be overflowed before the return address may be reached. These canary values can be checked during the epilogue of a function, before a return to the saved pointer is made, to ensure the integrity of the process control structures. In addition, modifications to the stack layout can ensure that a buffer overflow is unable to overwrite saved pointers by rearranging the order in which the variables are stored on the stack. Next, we will take a closer look at stack canary values.

Stack Canaries

Stack canaries were first implemented by Immunix Inc. (formerly known as WireX) in the StackGuard GCC patches. Preserving return addresses stored on the stack is the primary goal to prevent the redirection of code execution to an attacker-controlled address space. The addition of a special canary value before the saved return address on the stack, combined with a modification to the epilogue of a function, which checks the canary value, is an effective deterrent against arbitrary code execution.

There are four types of canaries that have been used to date:

Random Canary – The original concept for canary values took a 32-bit pseudorandom value generated by the /dev/random or /dev/urandom devices on a Linux operating system.

Random XOR Canary – The random canary concept was extended in StackGuard version 2 to provide slightly more protection by performing an XOR operation on the random canary value with the stored control data.

Null Canary – Originally introduced by der Mouse on the BugTraq security mailing list, the canary value is set to 0x00000000, which is chosen based upon the fact that most string functions terminate on a null value and should not be able to overwrite the return address if the buffer must contain nulls before it can reach the saved address.

Terminator Canary – The canary value is set to a combination of Null, CR, LF and 0xFF. These values act as string terminators in most string functions and account for functions that do not simply terminate on nulls such as gets().

The use of canaries has been observed in three Linux compiler-based protections as well as the Microsoft Visual C++ .NET compiler protections. The details of the Linux implementations may be found in Section 4.2, and an explanation of the .NET technology can be found in Section 5.1.

3 Attack Vector Test Platform

An attack vector test platform has been used in this paper to provide objective empirical data on the effectiveness of each protection mechanism. The test platform is based on work done by John Wilander for his paper titled "A Comparison of Publicly Available Tools for Dynamic Buffer Overflow Prevention"[9] and has been modified to compile on both Windows and Linux platforms. The attack vectors are defined by a combination of exploitation technique, location where the overflow occurs and target value to overwrite. The techniques involved require the attack to overflow all the way to the target or overflow a pointer that redirects to the target. The locations are defined as the stack or heap/bss data segment. The attack targets include return address, saved base pointer, function pointer and longjmp buffers. A complete listing of the test cases follows and will be referred to later in the paper.

1. Buffer overflow on the stack all the way to the target:
    a. Return address
    b. Old base pointer
    c. Function pointer as local variable
    d. Function pointer as parameter
    e. Longjmp buffer as local variable
    f. Longjmp buffer as function parameter

2. Buffer overflow on the heap/BSS/data all the way to the target:
    a. Function pointer
    b. Longjmp buffer

3. Buffer overflow of a pointer on the stack then pointing at target:
    a. Return address
    b. Base pointer
    c. Function pointer as variable
    d. Function pointer as function parameter
    e. Longjmp buffer as variable
    f. Longjmp buffer as function parameter

4. Buffer overflow of a pointer on the heap/BSS/data and then pointing at target:
    a. Return address
    b. Base pointer
    c. Function pointer as variable
    d. Function pointer as function parameter
    e. Longjmp buffer as variable
    f. Longjmp buffer as function parameter

[9] A Comparison of Publicly Available Tools for Dynamic Buffer Overflow Prevention (http://www.ida.liu.se/~johwi/research_publications/paper_ndss2003_john_wilander.pdf), 2/7/2003

4 Linux Protection Suites

There has been much work done on the Linux kernel and the GCC compiler to implement methods that prevent the exploitation of software vulnerabilities. This prior research has been instrumental in the design of new protection schemes for the Microsoft Windows operating system and various other hardened Linux projects. This section will explain the concepts of the most robust solutions currently available for Linux to provide context. In Section 5, an analysis of the Windows protections will be given.

4.1 Kernel-Enforced Protection

We will use the PaX Project's kernel patches as an example of the most robust kernel-based protection software currently available. PaX offers prevention against unwarranted code execution via memory management access controls and address space randomization, referred to henceforth as NOEXEC and ASLR, respectively. Section 4.1.1 outlines the components of NOEXEC and Section 4.1.2 will explain the design methods behind ASLR.

4.1.1 NOEXEC

The NOEXEC component of PaX aims to prevent the injection and execution of arbitrary code in an existing process' memory space. The NOEXEC implementation consists of three features that ultimately apply access controls on mapped pages of memory.

The first feature of NOEXEC applies executable semantics to memory pages. Executable semantics can be thought of as applying least-privilege concepts to the MMU. The application of these semantics to create non-executable pages on the IA-32 architecture can take two forms, based on the paging (PAGEEXEC) and segmentation logic (SEGMEXEC) of IA-32. Once the logic required to create non-executable pages has been merged into the kernel, the next step is to apply the new features. This can be done by making the memory that holds the stack, heap, anonymous memory mappings and any section not specifically marked at executable in an ELF file, non-executable by default. Finally, the functionality of mmap() and mprotect() are modified to prevent the conversion of the default memory states to an insecure state during execution (MPROTECT). Each of these concepts is covered in more detail below.

PAGEEXEC

PAGEEXEC is an implementation of non-executable pages, which is derived from the paging logic of IA-32 processors. The IA-32 family of processors lack native hardware support for marking pages of memory non-executable. However, the implementation of a split Translation Lookaside Buffer (TLB) in Pentium and AMD K7+ CPUs can be leveraged to emulate non-executable page support. The purpose of the TLB is to provide a cache for virtual-to-physical address translation, which speeds up instruction or data fetching within the CPU. A split TLB actually has two separate translation buffers, one for instruction fetches (ITLB) and one for data fetches (DTLB). The ITLB/DTLB loading is the key feature to getting non-executable pages, as protected pages can be marked as either "non present" or "requiring supervisor level access." In both cases, access to the pages will generate a page fault. The page fault handler can then decide if it was an instruction fetch or data access. If it is an instruction fetch, it means that there was an execution attempt in a non-executable page, and the process can then be terminated accordingly. However, if the fault is triggered during data access, the pages can be changed temporarily to provide user-level access and then restored to enable the fault handler for future accesses.

SEGMEXEC

SEGMEXEC is an alternate implementation of non-executable pages that is derived from the segmentation logic of IA-32 processors. Linux runs in protected mode with paging enabled on IA-32 processors, which means that each address translation requires a two-step process. The logical address must first be converted to a linear address from which the correct physical address may be determined. This is usually transparent to users of Linux, primarily because it creates identical segments for both code and data access that cover the range of 0x00000000 – 0xffffffff and does not require translation between logical and virtual memory addresses because they share the same value. PaX leverages the segmentation logic to create separate address ranges for the data (non-executable) and code segments. The 3 GB of userland memory space is divided in half, and each segment is assigned one of the halves. The data segment lies in the 0x00000000 - 0x5fffffff range and the code segment lies in the 0x60000000 – 0xbfffffff range. Since the code and data segments are separated, accesses to the memory ranges can be monitored by the kernel and a page fault generated if instruction fetches are initiated in the non-executable pages. [10]

MPROTECT

MPROTECT is a feature of PaX that aims to prevent the introduction of new executable code to a given task's address space by applying access controls to the functionality of mmap() and mprotect(). The goal of the access controls is to prevent the following:

- Creation of executable anonymous mappings
- Creation of executable/writable file mappings
- Making executable/read-only file mapping writable except for performing relocations on an ET_DYN ELF file (non-PIC shared library)
- Conversion of non-executable mapping to executable

Every memory mapping has permission attributes that are stored in the vm_flags field of the vma structure within the Linux kernel. Four attributes are used by PaX to define the permissions of a particular area of mapped memory: VM_WRITE, VM_EXEC, VM_MAYWRITE and VM_MAYEXEC. The Linux kernel requires that VM_MAYWRITE is enabled if the VM_WRITE attribute is true, and the same also applies to the VM_EXEC and VM_MAYEXEC attributes. Under normal operation, the Linux kernel can have a mapped area of memory with both write and exec permissions enabled, but PaX must deny this combination to prevent the introduction of new code into executable pages. This reduces the number of possible states for memory permissions to be one of the following[11]:

- VM_MAYWRITE
- VM_MAYEXEC
- VM_WRITE | VM_MAYWRITE
- VM_EXEC | VM_MAYEXEC

This essentially limits mapped memory to be either executable or writable and ensures that both are never assigned at the same time. While these limits may break certain poorly designed software and software that generates code at runtime, it is an appropriate control to prevent the introduction of new code into executable areas of memory.

[10] SEGMEXEC Documentation (http://pax.grsecurity.net/docs/segmexec.txt), 5/1/2003

[11] MPROTECT Documentation (http://pax.grsecurity.net/docs/mprotect.txt), 11/4/2003

4.1.2 ASLR

Address Space Layout Randomization (ASLR) is the concept that attempts to render exploits that depend on predetermined memory addresses useless by introducing a certain amount of randomness to the layout of the virtual memory space. By randomizing the locations of the stack, heap, loaded libraries and executable binaries, ASLR effectively reduces the probability that an exploit that relies on hardcoded addresses within those segments will successfully redirect code execution to the supplied buffer. Again, we will use PaX, which is comprised of four main components: RANDUSTACK, RANDKSTACK, RANDMMAP and RANDEXEC as our example implementation of ASLR.

RANDUSTACK

The RANDUSTACK component of PaX is responsible for randomizing userland stack addresses. The kernel is responsible for creating a program stack upon each execve() system call. This is done in a two-step process that involves the kernel allocating the appropriate number of pages and populating them if necessary, and then mapping the allocated memory pages to the process' virtual address space. Typically, on x86 architectures, the Linux kernel maps the stack at the end of the userland address space and grows downward from virtual memory address 0xbfffffff. RANDUSTACK modifies addresses in both stages of the creation of the userland stack so that the kernel memory allocated and the virtual address mapping within the task are modified by a random value. It's noteworthy that the kernel addresses may shift by up to 4 kB, while the userland stack may shift as much as 256 MB. It is also important to note that, while forked processes will be handled by RANDUSTACK, threads within a process are randomized by the RANDMMAP component of PaX ASLR.

RANDKSTACK

The RANDKSTACK component of PaX is responsible for introducing randomness into a task's kernel stack. Each task is assigned two pages of kernel memory, which is used to handle kernel mode operations during the lifetime of the task such as system calls, hardware interrupts and CPU exceptions. Normally, when the Linux kernel returns to user space after a context switch to kernel mode during the execution of a system call or other operation, the kernel stack pointer will be at the point of initial entry to the kernel. This offers the advantage that the kernel stack pointer for a task may be randomized on each context switch rather than on each program execution, as is the case with user space stack randomization. RANDKSTACK leverages this ability to randomize every system call; reasoning that every system call is a potential attack. The amount of randomization that PaX adds to the kernel stack is limited to about a 128 byte shift. This should be enough to prevent the execution of remote kernel exploits while keeping the assigned address sane.

RANDMMAP

RANDMMAP is the component that handles the randomization of all file and anonymous memory mappings. This is done in PaX by hooking the do_mmap() interface that is responsible for mapping the memory required for assigning brk() and mmap() managed heap space as well as executables and libraries. Note that only PIE (Position Independent Executable) ELF executables are handled by RANDMMAP; ET_EXEC ELF executables are handled specifically by the RANDEXEC component of PaX. RANDMMAP randomizes the specified memory mappings in two ways. The Linux kernel usually allocates heap space by beginning at the base of a task's unmapped memory and locating the nearest chunk of unallocated space that is large enough to supply the requested size. RANDMMAP modifies this functionality by adding a random delta_mmap value to bits 12-27 of the base address and a PAGE_SHIFT value with 12 bits of entropy before searching for free memory. For executable mappings of PIE binaries, a 16 bit delta_mmap value is added to introduce entropy.

RANDEXEC

The last major component of PaX is RANDEXEC. RANDEXEC is responsible for randomizing the location of ET_EXEC ELF binaries. The relocation of an executable that is not originally designed to be relocatable, raises some special concerns that are addressed by the RANDEXEC implementation. The first step is to load the executable at the standard address with the occupied pages marked non-executable. Next, an executable copy of the binary is created at a random location in memory using the same methods outlined in RANDMMAP. Execution attempts flow back into the randomized mapping via a page fault handler if the non-executable page is accessed instead of the randomly relocated image. PaX implements "vma mirroring" that handles the specifics of how physical pages can be mapped at two different virtual addresses. For the sake of brevity, we will not cover those details here. Further information can be found in the PaX documentation[12].

4.1.3 Defeating PaX

PaX offers considerable protection against buffer overflow attempts. Much research has been put into defeating PaX with little result. NOEXEC protections effectively prevent the execution of code on the stack, heap and other data segments, while the randomization of library addresses make return-to-libc exploitation much more difficult. However, research by Nergal[13] in 2001 has shown that there are methods that may bypass the security of PaX. Since NOEXEC stack protection is difficult to circumvent, the attacker is forced to resolve randomized library addresses or use the PLT to resolve the function addresses for him. This may be done fairly simply locally, but remote exploitation may require an information leak vulnerability such as a format string bug to recover remote memory addresses. It may also be possible for an attacker to target a binary that is not compiled position independent. Such binaries may not be randomly mmap()'d, which results in a standard return to libc exploitation scenario. The following results of the Attack Vector Test Platform show how well PaX protects a system against traditional attack vectors. It should be noted that this test was performed on a Linux 2.4 kernel with SEGMEXEC and all randomization functionality enabled.

```
PaX Attack Vector Test Platform Results

A plus symbol (+) indicates that the software successfully protected against the
specified exploitation vector.

Buffer overflow on stack all the way to the target
+       Target: Parameter function pointer
+       Target: Parameter longjmp buffer
+       Target: Return address
+       Target: Old base pointer
+       Target: Function pointer
+       Target: Longjmp buffer

Buffer overflow on heap/BSS all the way to the target
+       Target: Function pointer
+       Target: Longjmp buffer

Buffer overflow of pointer on stack and then pointing to target
```

[12] VMA Mirroring Documentation (http://pax.grsecurity.net/docs/vmmirror.txt), 10/6/2003
[13] The advanced return-into-libc exploits: PaX case study (http://www.phrack.org/phrack/58/p58-0x04), 12/28/2001

```
+       Target: Parameter function pointer
+       Target: Parameter longjmp buffer
+       Target: Return address
+       Target: Old base pointer
+       Target: Function pointer
+       Target: Longjmp buffer

Buffer overflow of pointer on heap/BSS and then pointing to target
+       Target: Return address
+       Target: Old base pointer
+       Target: Function pointer
+       Target: Longjmp buffer
```

4.2 Compiler-Enforced Protection

The compiler-based approach to preventing the exploitation of buffer overflow vulnerabilities is primarily based on ensuring the integrity of control data stored on the stack. There have been three major implementations of compiler-based protections, which are all based on modifications to the stack layout and/or the use of canaries. This section will take a deeper look at the specific differences in the implementations between the StackGuard, StackShield and ProPolice Stack-Smashing Protector buffer overflow prevention mechanisms.

4.2.1 StackGuard

StackGuard is a GCC patch created by Immunix Inc. that has provided the foundation for other compiler-based protection technologies and pioneered the use of stack canaries as a method for preventing the overwriting of saved control values. The StackGuard patch adds code at the RTL level to the function_prologue and function_epilogue functions within GCC to provide the generation and validation of the stack canary. StackGuard originally modified the function_prologue to make GCC push a random canary directly before the return address. The most recent version has been modified to protect the saved registers and frame pointer in addition to the return address and implements terminator canary values. The placement has been modified from its original location right before the saved return address on the stack to be placed in a location that is harder to overwrite. The decision of where to place the canary is architecture specific. On x86 architectures, the saved frame pointer points to a location where alignment padding has been generated by GCC and provides a good address to store the canary. The stored canary will be checked by the function_epilogue before a function may return. If the stored canary does not match the canary on the stack, StackGuard will exit the program and record an error in the system log.

Defeating StackGuard

While StackGuard may effectively stop standard stack overflows which overwrite a saved return address, there are other attack vectors that may easily bypass the canary check. Since the day after StackGuard was originally released, methods for bypassing StackGuard protected binaries have been publicly discussed.[14] Tim Newsham explored the possibility of bypassing StackGuard by overwriting local variables that could then be used to compromise the protection. Additional research has shown that overwriting function pointers and frame pointers stored on the stack can also lead to compromise[15]. Protection against nonstack-based attack vectors such as heap overflows is also beyond the scope of StackGuard. The reader

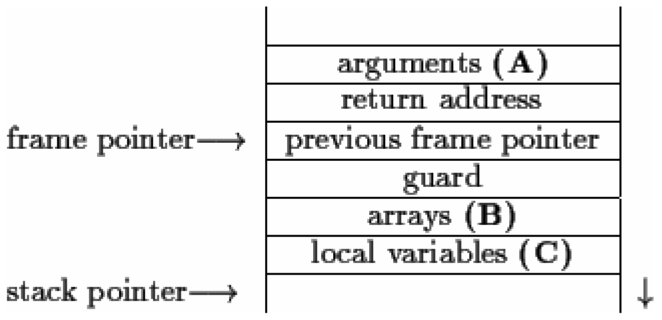
[14] Re: StackGuard (http://online.securityfocus.com/archive/1/8260), 12/19/1997
[15] Different tricks to bypass StackShield and StackGuard protection (http://www2.corest.com/files/files/11/StackguardPaper.pdf), 6/3/2002

may view the results of the Attack Vector Test Platform below to better understand the protection coverage provided by StackGuard.

```
StackGuard Attack Vector Test Platform Results

A plus symbol (+) indicates that the software successfully protected against the
specified exploitation vector.

Buffer overflow on stack all the way to the target
-        Target: Parameter function pointer
-        Target: Parameter longjmp buffer
+        Target: Return address
+        Target: Old base pointer
-        Target: Function pointer
-        Target: Longjmp buffer

Buffer overflow on heap/BSS all the way to the target
-        Target: Function pointer
-        Target: Longjmp buffer

Buffer overflow of pointer on stack and then pointing to target
-        Target: Parameter function pointer
-        Target: Parameter longjmp buffer
-        Target: Return address
+        Target: Old base pointer
-        Target: Function pointer
-        Target: Longjmp buffer

Buffer overflow of pointer on heap/BSS and then pointing to target
-        Target: Return address
+        Target: Old base pointer
-        Target: Function pointer
-        Target: Longjmp buffer
```

4.2.2 ProPolice Stack-Smashing Protection (SSP)

Unlike other compiler methods, which just place canaries in front or behind the return address, SSP proactively monitors stack changes. SSP's approach re-arranges argument locations, return addresses, previous frame pointers and local variables. SSP has come up with the following "safe stack model" that helps decide where variables, arguments and the canaries should be placed on the stack:



As the reader can see from the figure above, the array and local variables are all below the return address. If an overflow were to occur in the array, nothing important would be overwritten, and the overflow would be useless. This also helps with pointers. Take a look at a vulnerable code segment (provided by SSP documentation):

```
void bar( void (*func1)() )
{
        void (*func2)();
        char buf[128];
        .......
        strcpy (buf, getenv ("HOME"));
        (*func1)(); (*func2)();
}
```

Without stack layout modifications, an overflow in buf could overwrite the function pointers. However, SSP will change this code to:

```
void bar( void (*tmpfunc1)() )
{
        char buf[128];
        void (*func2)();
        void (*func1)(); func1 = tmpfunc1;
        .......
        strcpy (buf, getenv ("HOME"));
        (*func1)(); (*func2)();
}
```

Here the reader will see that, by following the SSP safe stack diagram, the passed function pointer is put in a register, if possible. If there is no register available, SSP puts the function pointer in a local variable, making it safe. The re-arrangement will, in the case of an overflow, overwrite nothing important.[16]

Defeating ProPolice SSP

ProPolice has proved to offer much better protection against stack overflows than the other compiler patches, yet inherent design flaws still leave certain attack vectors exposed. ProPolice does not protect arrays with less than eight elements. An overflow of a small buffer will go unchallenged and may redirect the return address to shellcode stored elsewhere in memory. An additional design limitation may leave members of structures unprotected as well, since the reordering of variables within the structure is not possible. Standard attacks that leverage a pointer overwrite to control arbitrary memory locations may be used if the pointer is contained within a structure. Again, the protecting the heap is not within the scope of the ProPolice software, so it is not expected that those attacks will be defeated. An overview of the protection provided by ProPolice is presented below.

[16] Stack Protection Method (http://www.trl.ibm.com/projects/security/ssp/node4.html), 11/8/2000

```
ProPolice SSP Attack Vector Test Platform Results

A plus symbol (+) indicates that the software successfully protected against the
specified exploitation vector.

Buffer overflow on stack all the way to the target
+        Target: Parameter function pointer
-        Target: Parameter longjmp buffer
+        Target: Return address
+        Target: Old base pointer
+        Target: Function pointer
+        Target: Longjmp buffer

Buffer overflow on heap/BSS all the way to the target
-        Target: Function pointer
-        Target: Longjmp buffer

Buffer overflow of pointer on stack and then pointing to target
+        Target: Parameter function pointer
+        Target: Parameter longjmp buffer
+        Target: Return address
+        Target: Old base pointer
+        Target: Function pointer
+        Target: Longjmp buffer

Buffer overflow of pointer on heap/BSS and then pointing to target
-        Target: Return address
+        Target: Old base pointer
-        Target: Function pointer
-        Target: Longjmp buffer
```

4.2.3 StackShield

While development on StackShield has appeared to cease, we will cover the basic concepts here as an additional approach to compiler-based protection. StackShield is similar to the other compiler-based protections, but also has some unique features. The first feature is the Global Return Stack, which acts as a specialized stack for return addresses. Every time a function is called, the return address is copied to the Global Ret Stack. When a function is ready to return, the return address is copied from the Global Ret Stack to the applications stack, overwriting any possible compromise. Since this method will not detect attacks, the Ret Range Check feature may be used instead, which copies the return address to an unwriteable area rather than pushing a canary on the stack during the function_proglogue. When function_epilogue is reached, StackShield will check the stored return address. If an inconsistency is found, StackShield will exit the program and allow for the detection and logging of overflow attempts. StackShield also offers protection of function pointers. This method is simple but breaks programs that allocate memory dynamically. StackShield's protection of function pointers only allows function pointers to point to the .text section, since any injected code would have to be in the .data section. This method completely denies attempts to run malicious code that is unable to overwrite the .text segment.

Defeating StackShield

Methods for defeating StackShield are similar to those used to bypass StackGuard protection. The use of the Global Return Stack does provide some additional protection against pointer overwrites that StackGuard does not offer. Pointer overflows that later modify the return address directly on the stack will fail, since the modified value is overwritten when the saved return is restored from the Global Return Stack. Other than this one exception, pointer overwrites may still be used to execute arbitrary code by controlling saved function pointers or overwriting Global Offset Table (GOT) entries. The similarities in protection coverage to StackGuard can be seen in the results of the Attack Vector Test Platform.

StackShield Attack Vector Test Platform Results

A plus symbol (+) indicates that the software successfully protected against the specified exploitation vector.

```
Buffer overflow on stack all the way to the target
-       Target: Parameter function pointer
-       Target: Parameter longjmp buffer
+       Target: Return address
+       Target: Old base pointer
-       Target: Function pointer
-       Target: Longjmp buffer

Buffer overflow on heap/BSS all the way to the target
-       Target: Function pointer
-       Target: Longjmp buffer

Buffer overflow of pointer on stack and then pointing to target
-       Target: Parameter function pointer
-       Target: Parameter longjmp buffer
+       Target: Return address
+       Target: Old base pointer
-       Target: Function pointer
-       Target: Longjmp buffer

Buffer overflow of pointer on heap/BSS and then pointing to target
+       Target: Return address
+       Target: Old base pointer
-       Target: Function pointer
-       Target: Longjmp buffer
```

5 Windows Protection Suites

Microsoft has been plagued with vulnerabilities throughout its history. Many companies have come up with products to offer Windows users more protection. However, if a flaw is released before a patch is put out, these firewalls that monitor traffic or prevent certain programs from connecting to the Internet, will not prevent exploitation of a buffer overflow. Microsoft, being notoriously slow in patching their products, forces the need for a third-party application that will prevent exploitation of Windows vulnerabilities that are known but not patched.

5.1 Windows 2003 Stack Protection

As a response to increased exposure of unprotected computers running the Windows operating system during the Summer of 2003 and the release of several high-impact vulnerabilities, Microsoft implemented a compiler-based protection solution to ensure that their products were secure out of the box. Microsoft's solution is very similar to Crispin Cowan's StackGuard covered earlier in this paper. In the new .NET compilers, Microsoft provides the /GS command line switch. When enabling this command-line switch, a security cookie (canary), is placed in front of the return address and saved ebp. By default, Windows 2003 is compiled with stack protection enabled.

How The Protection Works

When a program that is compiled with the /GS switch returns from a function, the canary authentication mechanism loads the canary that was on the stack into ecx and compares it to the original canary, which is stored in the .data section of the program. If these canaries match each other, the program continues. However, if these canaries do not match, the program checks to see if a security handler is specified in the .data section of the program. If a security handler is specified, the program calls that security handler. However, if no security handler is specified, then the UnHandledExceptionFilter is set to 0x00000000 and called. The UnHandledExceptionFilter will load faultrep.dll and call an exported function named ReportFault.

Defeating Windows 2003 Stack Protection

Prior research efforts have shown that the protection offered by Windows 2003 can be bypassed trivially. If a local buffer is overflowed, the attacker may try to overwrite the EXCEPTION_REGISTRATION structure and within that overwrite the exception handler. The EXCEPTION_REGISTRATION structure looks like:

EXCEPTION_REGISTRATION
Pointer to next structure on the stack
Pointer to the exception handler

Microsoft recognized that the exception handler was being abused in attacks. Microsoft came up with an implementation outline to prevent this from happening. All registered exception handlers are stored in the program's Load Config Directory. If the exception handler is not in the Load Config Directory array, the exception handler is not called. The exception handler is also not called if the handler points to the stack. However, Microsoft allows exception handlers that point outside the modules range to be called, and Microsoft also allows exception handlers that point to the heap to be executed.

Two reliable avenues for attack against Window 2003 protection are known to exist. The first attack method is to point the exception handler to a registered exception handler and abuse the registered exception handler. The second method is to point the exception handler to a code block outside the address range that will, when executed, point back into the attacker's code.

After compromising the exception handler, the attacker only needs to cause an exception. This can be done by either causing a memory access violation by forcing the program to read or write to an address that does not exist or by writing passed the end of the stack, causing an exception.

Windows 2003 Stack Protection Attack Vector Results

Windows 2003 Stack Protection preformed very well in our Attack Vector Test Platform results. This is mainly due to the fact that the Attack Vector Test Platform only at this moment tests stack related overflows. The Attack Vector Test Platform was not designed to utilize special shellcode or scenarios therefore the Test Platform did not try to exploit any of the weakness in the Windows 2003 stack protection implementation.

```
Windows 2003 Stack Protection Attack Vector Test Platform Results

A plus symbol (+) indicates that the software successfully protected against the
specified exploitation vector.

Buffer overflow on stack all the way to the target
+      Target: Parameter function pointer
+      Target: Return address
+      Target: Function pointer

Buffer overflow of pointer on stack and then pointing to target
+      Target: Parameter function pointer
+      Target: Return address
+      Target: Function pointer
```

5.2 NGSEC StackDefender 1.10

StackDefender offers driver-based stack protection. Previously in the paper, this method was referred to as Kernel-Enforced protection. StackDefender is able to offer protection against malicious code execution because StackDefender monitors specific API calls and checks these API calls to make sure they are not made from the stack. StackDefender installs a driver called StackDefender.sys that implements a hooking solution known as "NT System-Call Hooking."[17][18] StackDefender hooks both ZwCreateFile and ZwOpenFile by replacing the KeServiceDescriptorTable address that point them. By hooking these system functions, StackDefender can see all files opened and created. When either ZwCreateFile or ZwOpenFile are called, the driver looks to see if the file executed is one of the following: msvcrt.dll, ntdll.dll or kernel32.dll. If it is one of these files, the driver replaces the last six characters with NG.fer; this will then load SD's own version of these DLL's. The DLL's that StackDefender loads have all been rebased, using Microsoft's ReBaseImage[19] API.

Kernel System-Call Hooking

Before we can understand how Kernel System-Call Hooking works, we must understand how a kernel system-call is made. The system-call is made through the int 2e handler, which is internally called KiSystemService. Before the int 2e instruction is executed, certain registers must be filled in. The eax

[17] Mark Russinovich and Bryce Cogswell, "Windows NT System-Call Hooking", Dr. Dobb's Journal January 1997
[18] Windows NT System Service Table Hooking (http://www.wiretapped.net/~fyre/sst.html), 5/4/2003
[19] MSDN ReBaseImage (http://msdn.microsoft.com/library/default.asp?url=/library/en-us/debug/base/rebaseimage.asp), 5/11/2004

register must contain the service id number, and edx must contain a frame pointer to the userland stack where the parameters are stored so that the kernel can copy the parameters off the userland stack and onto the kernel stack. Once the int 2e instruction is executed, the processor switches to kernel mode and executes the int 2e handler. The int 2e handler indexes the ServiceTableBase member of the structure KeServiceDescriptorTable.
The structure itself looks like:

```
typedef struct ServiceDescriptorTable
{
       PVOID ServiceTableBase;
       PVOID ServiceCounterTable(0);
       unsigned int NumberOfServices;
       PVOID ParamTableBase;
}
```

Here is an example of a Kernel System-Call:

```
__asm
{
       mov eax, 0x64  //System Service ID (Function Number To Call)
       lea edx, [esp+0x04] //Pointer to parameters on stack
       int 2eh  //switch to kernel mode and execute handler
}
```

This gets translated into the following; a pseudo code example will show how the kernel calls the system-call:

```
call KeServiceDescriptorTable->ServiceTableBase[function_id]
```

The hook itself is implemented by a driver simply overwriting the pointer at ServiceTableBase + function_id to point to the driver's version of that function. The driver can then call the original function that would have been stored during the overwriting of the KeServiceDescriptorTable.

StackDefender.sys

StackDefender.sys makes up half of the NGSEC StackDefender protection suite. StackDefender.sys is the component that performs the system-call hooking and file redirection.

StackDefender.sys has two phases. The first phase is to setup a system-call hook on both ZwCreateFile and ZwOpenFile. These hooks force any file opened or created to go through StackDefender's driver. StackDefender's second phase occurs when files are opened/created. StackDefender looks at the file being created/opened. If the file is either msvcrt.dll, ntdll.dll or kernel32.dll, StackDefender will overwrite the last 6 bytes of the filename with NG.fer. This turns the file name into msvcNG.fer, ntdNG.fer and kernelNG.fer. The *NG.fer files are put on the system during the installation process, so they do exist and are successfully loaded into the process space.

stackdefender_service.exe

stackdefender_service.exe, installs and creates the service on the system the user wants to protect. The service executable registers StackDefender.sys as the service's driver so that the driver can modify the KeServiceDescriptorTable. Finally, the executable interacts with the Service Control Manager (SCM) to stop, start and disable the service as the user wants.

System DLL Rebasing

During the installation of StackDefender, StackDefender will place three NG.fer files on the user's system. Two of the three NG.fer files that are installed by StackDefender are replicas of the DLL's they replace. During the installation processes, StackDefender will copy msvcrt.dll and ntdll.dll to files called msvcNG.fer and ntdNG.fer, which are then rebased to provide additional protection against return to libc attacks. The rebase process gives the DLL's a random image base, using an algorithm designed to come up with random numbers.

When a DLL is loaded into the memory of a process via LoadLibrary or other similar API function, the system will load the DLL at the preferred address range, which is known as the image base specified in the PE Optional Header section. If the memory is taken up, and the DLL has .reloc information, the DLL is reloaded into a different address space. However, if the file is a system DLL (e.g. ntdll.dll), the DLL may not be relocated. Thus, if the preferred load address is taken for a system DLL, the application will not be loaded.

StackDefender is able to load the DLL into a new memory region by creating a copy of the DLL and rebasing the copy of that system DLL. NGSEC StackDefender uses an API known as ReBaseImage[20], documented in the MSDN library, to rebase the three DLL's it replaces.

kernelNG.fer

The kernelNG.fer is different from the other two NG.fer files because it is not just a copy of the DLL from the user's system that was rebased. StackDefender's first phase in modifying kernelNG.fer is to modify the relocation section (.reloc). StackDefender changes .reloc section flags from 42000040 (Readable + Discardable + Initialized Data) to E2000060 (Executable + Writable + Readable). StackDefender then hooks functions that it believes will be used in shellcode. NGSEC believes that by watching any functions that will be used by shellcode, it can prevent the successful exection of injected code. The following functions are hooked using a method called "Export Address Table Relocation":

- WinExec
- CreateProcessA
- CreateProcessW
- CreateThread
- CreateRemoteThread
- GetProcAddress
- LoadModule
- LoadLibraryExA
- LoadLibraryExW
- OpenFile
- CreateFileA
- CreateFileW
- _lopen
- _lcreat
- CopyFileA
- CopyFileW
- CopyFileExA
- CopyFileExW

[20] ReBaseImage (http://msdn.microsoft.com/library/default.asp?url=/library/en-us/debug/base/rebaseimage.asp), 5/12/2004

- MoveFileA
- MoveFileExW
- MoveFileWithProgressA
- MoveFileWithProgressW
- DeleteFileA
- LockFile
- GetModuleHandleA
- VirtualProtect
- OpenProcess
- GetModuleHandleW

This method of hooking is very different from the system-call hooking method that StackDefender.sys implements. Instead, this implementation modifies the Export Address Table (EAT) so that the hooked function's EAT entries point into the .reloc section, where the new function's handling code is contained. The EAT is a structure that contains the entry points to APIs that are contained in the DLL. The code put in the .reloc section is the same for each function. The code will load proxydll.dll and then call a function exported in proxydll.dll named StackDefender. Proxydll.dll will then decide whether or not the application has been compromised through the methods explained below.

proxydll.dll

Proxydll.dll is the other half of the overflow protection suite that NGSEC offers. Proxydll.dll plays a pivotal role in the detection of malicious code execution. KernelNG.fer hooks certain API functions that NGSEC believes will be used in the average shellcode (such as CreateProcessA or LoadLibrary). When a program calls one of these hooked functions, the function loads and calls proxydll.dll. Proxydll.dll exports one function, which is called StackDefender. StackDefender takes four parameters. All four of these parameters are integers. The paper will refer to them as arg1, arg2, arg3 and arg4. These arguments are as follows: arg1 is [esp + 0x0C], arg2 address from where API is called, arg3 is single integer and arg4 is the stack address of a given parameter that was fed into that specific API. The key parameters that the reader should focus on are arg1 and arg2. These two parameters are how StackDefender decides if the program has been compromised.

The next phase in the detection process of malicious code execution is checking where the functions were called from. NGSEC designed an algorithm that helps detect if a program was compromised. StackDefender then checks where the API call originated from by calling VirtualQuery[21] on arg1 and arg2. Arg1 is the stack address 0x0C from the esp, and arg2 is the address from where the API is called. If arg1's page allocation base is equal to arg2's page allocation base, then the function call is coming from the stack. The page allocation base can be determined by looking at the MEMORY_BASIC_INFORMATION[22] structure that is passed into VirtualQuery. This tells the program that the calls are on the stack. Therefore, StackDefender marks the program as exploited and exits it.

The second step StackDefender performs before marking the program safe is to check if the caller's address space is writeable. If the API call is made from an executable, the executables image has been VirtualProtected[23] so that the write flags are off. StackDefender is able to check this by calling IsBadWritePtr[24]. If IsBatWritePtr returns zero, it means that the calling address is writeable, and

[21] VirtualQuery (http://msdn.microsoft.com/library/default.asp?url=/library/en-us/memory/base/virtualquery.asp), 5/14/2004
[22] MEMORY_BASIC_INFORMATION (http://msdn.microsoft.com/library/default.asp?url=/library/en-us/memory/base/memory_basic_information_str.asp), 5/14/2004
[23] VIrtualProtect (http://msdn.microsoft.com/library/default.asp?url=/library/en-us/memory/base/virtualprotect.asp), 5/14/2004
[24] IsBadWritePtr (http://msdn.microsoft.com/library/default.asp?url=/library/en-us/memory/base/isbadwriteptr.asp), 5/14/2004

StackDefender will mark it as an application that has been overflowed and exit accordingly. If all these checks pass, StackDefender will let the application execute normally without much cost to system resources and speed.

Defeating StackDefender 1.10

While StackDefender showed the best protection coverage in the standard Attack Vector Test Platform out of the Windows protection suites, it is an illusion to think StackDefender 1.10 is invulnerable. The reason StackDefender 1.10 did so well in our tests is that the Attack Vector Test Platform uses standard shellcode that any attacker would use (the shellcode used is taken from Matt Miller's paper on win32 shellcode[25]). However, if an attacker knew the system was protected with StackDefender 1.10, the attacker could simply write their own GetProcAddress and LoadLibrary functions that do not call the hooked APIs. The attacker could then call ZwAllocateVirtualMemory, memcpy, ZwProtectVirtualMemory to allocate memory, write shellcode to the memory and then protect the memory so that StackDefender would not know the memory was at one point writable.

However, simplistic this protection scheme is, StackDefender nonetheless proved to offer the best protection for Windows platforms. Below are the Attack Vector Test Platform results to help the reader better understand how well this application protects third-party programs.

```
StackDefender 1.10 Attack Vector Test Platform Results

A plus symbol (+) indicates that the software successfully protected against the
specified exploitation vector.
Buffer overflow on stack all the way to the target
+      Target: Parameter function pointer
+      Target: Return address
+      Target: Function pointer

Buffer overflow of pointer on stack and then pointing to target
+      Target: Parameter function pointer
+      Target: Return address
+      Target: Function pointer
```

5.3 OverflowGuard

OverflowGuard is a protection suite that claims to offer "strong Unix style buffer overflow protection for Windows." OverflowGuard is a driver-based memory protection suite. This protection method is known as Kernel-Enforced. OverflowGuard is based on the PaX Project[26] document and attempts to offer similar PaX-like protection to Windows users. OverflowGuard is able to offer this kind of protection by performing a number of kernel-level operations before the user ever executes a program. OverflowGuard modifies the Interrupt Descriptor Table, to point to its own handlers for certain exceptions and implements non-executable pages by setting supervisor permission bits on the Page Table Entries (PTE) for the protected pages. Any future access to the protected pages will cause a page fault which will be handled by the newly installed page fault handler code and allow OverflowGuard to examine the memory state to determine if the program has been compromised.

Interrupt Descriptor Table (IDT)

[25] Win32-Shellcode (http://www.hick.org/code/skape/papers/win32-shellcode.pdf), 12/8/2004
[26] PaX Project (http://pax.grsecurity.net), 11/29/2003

The interrupt descriptor table contains interrupts that act as one method of communication between user space and kernel space. The processor/OS will look up the IDT table, and each exception or error is related to a number. That number is used in the IDT to index the proper interrupt handler. For example, if the user executes a program that tries to read memory from an address that does not exist, the OS will index the IDT at 14 (0x0e). The page fault handler is located in this index. The handler is called and in turn handles the exception. When the handler is called, the interrupt pushes the old EIP as well as the error code of the fault onto the stack. This is done before switching into the kernel mode and gives the page handler more information about the fault.

When an instruction accesses memory, the process has to convert the supplied virtual memory address to a physical memory location. This is done by looking up the Page Directory Entry (PDE). The PDE is an array of pointers to the Page Table Entry (PTE). When an application tries to write to the page referenced by the PTE with the privileges of a service or regular application, the application will page fault if the page pointed to by the PTE has supervisor permissions set. This page fault will be handled by OverflowGuard's page fault handler.

Control Registers and Debug Registers

Certain registers are only modifiable from ring0 context. These registers are as follows:

- cr0 – Contains system control flags, operating modes and state of the processor
- cr1 – Reserved
- cr2 – Contains the page fault linear address (where the page fault occurred).
- cr3 – Contains physical address of the base of the Page Directory Entry (PDE) table.
- cr4 – Contains a group of flags that enable architectural extensions, and indicate operating system or executive support for specific processor capabilities.
- dr4 & dr5 – reserved, previous processors alias these registers to debug registers dr6 and dr7 respectively.
- dr6 – reports the conditions that were in effect when a debug exception occurred.
- dr7 – contains the type of breakpoint that was hit.

The PaX Effect

OverflowGuard's non-executable stack is heavily based on PaX PAGEEXEC. PaX outlines how to prevent compromise of a system by marking the system's heap/stack/and other anonymous memory pages as either Supervisor or non-present. These flags effectively mark the pages as non-executable because code will not be able to write or read from these pages. Whenever an instruction execution or data access occurs on a page that is in supervisor mode or not present, it causes a fault. Next, a simple compare is done. If the old EIP is equal to where the fault occurred, it was an instruction execution on a page that should not be executable. If the EIP is not equal to where the fault occurred, it is a data access; this routine will be referred to as execution verification. If it is a data access, PaX resets the supervisor bit so the page may be accessed from userland and marks the entry as "dirty", causing the DTLB entry to be flushed upon next access. Next, a manual walk of the memory loads the address the application requested into the DTLB, which is the Data Translation Lookaside Buffer. PaX then resets permissions on the page and returns to the application. The application can then access the Data Translation Lookaside Buffer, which contains the address and not the page. Next time a data access occurs, a walk is done to the PTE, which has supervisor permissions set and PaX will perform this operation over again.

OverflowGuard has a different take on PaX Page protection. Instead of marking all pages as supervisor, OverflowGuard initially marks them all as read-only. This is done to cut down on faults occurring and saves overhead. If OverflowGuard marked all the pages as supervisor, then any time an instruction situated in the image base's page that is suppose to execute code page faulted, this would slow the system. Instead, OverflowGuard will mark all pages as read-only. Any page that has a fault occur and is read-only will be modified and marked as supervisor mode. This effectively marks the heap and stacks as supervisor and leaves the executable images as read-only. The detection and data access are basically the same as PaX.

OGCenter.exe and OGConfig.exe

These are two files that OverflowGuard (OG) installs on the user's system. The files act as a front-end for configuring OG and for receiving notifications on overflow attempts. OGCenter.exe sits in the user's system tray and pops up when clicked on or if there was an overflow attempt. OGConfig.exe is executed through OGCenter.exe and offers the user all configuration options, like "Monitor Stack Only." OGConfig.exe also allows the user to perform tests such as stack overflow or heap overflow.

OGRebase.exe

As mentioned in previous sections, OverflowGuard (OG) rebases system files as an added protection method. However, by default OG does not rebase system files. The user must enter the %windir%\system32\ and execute OGRebase. OGRebase takes in no arguments and performs all the rebasing. OGRebase modifies the image base field in the Optional PE Header section. This method has many drawbacks. First, it appears that the OGRebase.exe copies shell32.dll, kernel32.dll, ntdll.dll and msvcrt.dll into a different name. OGRebase.exe then manually rebases these DLLs. However, even on reboot the rebase does not affect the actual files, and it is not certain if this tool does anything.

OverflowGuard.sys

OverflowGuard.sys driver is what sets up and enforces the PaX-like buffer overflow protection scheme. The driver's first phase is to overwrite the Interrupt Descriptor Table's (IDT) handlers with its own handlers. OverflowGuard hooks the debug exception (int 0x01) and page fault (int 0x0e) handlers to add additional functionality which accounts for page faults triggered by accesses to protected pages similar to PaX. Once the hooks are in place, the physical pages containing the new interrupt handler code is resolved and marked supervisor mode. This is done to prevent malicious applications from overwriting OverflowGuard's interrupt handlers with their own.

If the user has selected ret-libc protection, OverflowGuard will then set up four system-call hooks, which were explained in the previous section. The following functions are hooked:

- NtCreateSection
- NtCreateFile
- NtOpenFile
- NtProtectVirtualMemory

Setting Memory Permissions

For OverflowGuard to be effective as a memory protection suite, it must prevent the introduction of foreign code in a process. To do this, OverflowGuard has to modify default memory permissions on allocated pages to be read only. Future write access attempts will cause a page fault. OverflowGuard will handle the fault and allow data to be written, but the pages will then be set to supervisor mode. This change in page permissions will prevent pages that have been written to from future execution.

Ret-Libc Protection

OverflowGuard claims to offer ret-libc protection. Ret-libc stands for return-into-libc, which was discussed prominently by Solar Designer[27]. The exploit demonstrated how to bypass non-executable stacks. This was done by overflowing the stack. Instead of overwriting the return address to point to the attacker's shellcode, the return address would point to a libc function, most likely system. Below the return address the attacker would place the parameter, usually a pointer, to /bin/sh. Ret-libc exploits are not that common on win32 platforms, and they have not be explored in great detail. The Ins1der posted a ret-libc exploit[28] for the RPC DCOM vulnerability found by LSD. This exploit as of June 7, 2004, bypasses both OverflowGuard and StackDefender 1.10 and StackDefender 2.00.

Page Fault Exception Handler

When a page fault occurrs, OverflowGuard will check to see if the page's permissions are set to read-only. This is done by translating the linear fault address to its PTE. Once this is done OverflowGuard checks the 1 bit in the PTE. If it is zero, then that page is read-only. If this is the case, OverflowGuard remove the read-only flag, and allow the data to be written. Next, OverflowGuard marks the page as supervisor, which will cause any access from anything other than the kernel to cause a page fault. OverflowGuard does this by changing the second bit of the PTE to zero.

If the page is already set to supervisor mode when the page fault handler is called, OverflowGuard checks to make sure that the fault address is not equal to the old EIP. If this is the case, OverflowGuard will mark this as an attempt to execute code on a non executable page e.g. stack or heap. However, if the fault is not equal to the old EIP, OverflowGuard decides that it was a data access and allows write access as described above.

Defeating OverflowGuard

OverflowGuard says on its website that "In 'Protect Only Selected Services' mode, which is enabled by default, OverflowGuard only protects services which have been tested to work properly with OverflowGuard. When 'Protect Only Selected Services' is disabled, all installed services are protected." In other words, OverflowGuard says it only protects services. Therefore, they offer no protection to third-party applications that do not run as services and, as a result, OverflowGuard failed when tested against the Attack Vector Test Platform. The results below illustrate the ineffectiveness of protecting third party non-service applications. These tests were preformed with ret-libc detection enabled and selected service protection turned off.

```
OverflowGuard Attack Vector Test Platform Results

A plus symbol (+) indicates that the software successfully protected against the
specified exploitation vector.

Buffer overflow on stack all the way to the target
-       Target: Parameter function pointer
-       Target: Return address
-       Target: Function pointer
```

[27] Solar Designer Ret-Libc (http://www.groar.org/expl/intermediate/ret-libc.txt), 8/10/1997
[28] The ins1der ret-libc exploit (http://www.k-otik.com/exploits/11.07.rpcexec.c.php), 11/7/2003

```
Buffer overflow of pointer on stack and then pointing to target
-      Target: Parameter function pointer
-      Target: Return address
-      Target: Function pointer
```

5.4 NGSEC StackDefender 2.00

Note: Due to an unexpected update of NGSEC's StackDefender, a full analysis of StackDefender 2.0 was not possible for this paper. The details of our initial analysis follows.

The initial analysis of StackDefender 2.00 shows that NGSEC has switched to a protection approach heavily based off of PaX. StackDefender hooks ZwAllocateVirtualMemory and ZwProtectVirtualMemory to prevent the allocation of executable heaps, as outlined in the PaX guidelines. StackDefender also hooks to interrupt handlers similar to OverflowGuard; these two handlers are the page fault handler (0x0e) and the syscall entry handler (0x2e). StackDefender calls PsSetCreateThreadNotifyRoutine to set the new thread's stack to non-executable, following the guidelines set forth by PaX.

Defeating StackDefender 2.00

StackDefender 2.00 pales in comparison to its previous version 1.10. StackDefender 2.00 does not catch any third-party applications in our tests. StackDefender 2.00 also has a significant CPU overhead that is noticeable after the first install. Just like OverflowGuard, StackDefender 2.00 does not catch any third-party applications. The Attack Vector Test Platform results are as follows:

```
StackDefender 2.00 Attack Vector Test Platform Results

A plus symbol (+) indicates that the software successfully protected against the
specified exploitation vector.

Buffer overflow on stack all the way to the target
-      Target: Parameter function pointer
-      Target: Return address
-      Target: Function pointer

Buffer overflow of pointer on stack and then pointing to target
-      Target: Parameter function pointer
-      Target: Return address
-      Target: Function pointer
```

A Vulnerability in StackDefender 2.00

StackDefender 2.00 is vulnerable to a local/remote denial of service condition that will allow a malicious attacker to blue screen the computer and force an automatic reboot with out any warning. This vulnerability lies within the code that hooks ZwProtectVirtualMemory. Within the code, StackDefender calls the real ZwProtectVirtualMemory, StackDefender then calls an internal function when this internal function returns. StackDefender does the following:

```
cmp eax, [esi]
```

Eax is the return value of the internal function, esi is the second parameter in ZwProtectVirtualMemory, which is the base address of the memory to be protected. By specifying an invalid pointer, StackDefender will without checking the pointer dereference it. This causes the blue screen of death and effectively reboots the computer.

6 Attack Vector Test Platform Results

	PaX	StackGuard	StackShield	ProPolice SSP	Visual Studio .NET	OverflowGuard	StackDefender 1.10	StackDefender 2.00
Stack overflow to target								
Parameter function pointer	+	-	-	+	+	-	+	-
Parameter longjmp buffer	+	-	-	-	N/A	N/A	N/A	N/A
Return address	+	+	+	+	+	-	+	-
Old base pointer	+	+	+	+	N/A	N/A	N/A	N/A
Function pointer	+	-	-	+	+	-	+	-
Longjmp buffer	+	-	-	+	N/A	N/A	N/A	N/A
Heap/BSS overflow to target								
Function pointer	+	-	-	-	N/A	N/A	N/A	N/A
Longjmp buffer	+	-	-	-	N/A	N/A	N/A	N/A
Pointer on stack								
Parameter function pointer	+	-	-	+	+	-	+	-
Parameter longjmp buffer	+	-	-	+	N/A	N/A	N/A	N/A
Return address	+	-	+	+	+	-	+	-
Old base pointer	+	+	+	+	N/A	N/A	N/A	N/A
Function pointer	+	-	-	+	+	-	+	-
Longjmp buffer	+	-	-	+	N/A	N/A	N/A	N/A
Pointer on heap/BSS								
Return address	+	-	+	-	N/A	N/A	N/A	N/A
Old base pointer	+	+	+	+	N/A	N/A	N/A	N/A
Function pointer	+	-	-	-	N/A	N/A	N/A	N/A
Longjmp buffer	+	-	-	-	N/A	N/A	N/A	N/A

7 Conclusion

Many options are available for users seeking a solution to the widespread exploitation of buffer overflow vulnerabilities. The test results show that there are varying coverage capabilities between the different software titles analyzed, and our research has shown that attackers are still one step ahead with methods available to defeat almost every protection mechanism available. The combination of kernel and compiler-based protection software is currently the best defense. Compiler protections are able to modify the structure of the generated binary itself and implement run-time checks, while the kernel is able to protect the environment in which the program runs and reduce the reliability of exploits that require hardcoded addresses. Although the currently available solutions may not be perfect, they are certain to help combat the proliferation of automated exploitation by worms and amateur attackers.