Berkeley CS161

Bypassing Browser Memory Protections in Windows Vista

Alexander Sotirov
alex@sotirov.net

Part I:

Introduction

Introduction

- **Thesis**
  - Vista protections are largely ineffective at preventing browser exploitation
- **Overview**
  - Whirlwind tour of Vista protection mechanisms
    - GS, SafeSEH, DEP, ASLR
  - Techniques for exploiting protection limitations
    - All protections broken
  - Conclusion
- **Full paper available at http://www.phreedom.org/research/**

Demo

- **Exploiting IE despite all protections on Vista**
  - ASLR and DEP turned on
  - Third party plugins NOT required for exploitation
- **This works with IE8 as well**

Part II:
Vista Protection Features

Memory Protection Mechanisms

	XP SP2, SP3	2003 SP1, SP2	Vista SP0	Vista SP1	2008 SP0
GS					
stack cookies	yes	yes	yes	yes	yes
variable reordering	yes	yes	yes	yes	yes
#pragma strict_gs_check	no	no	no	?	?
SafeSEH					
SEH handler validation	yes	yes	yes	yes	yes
SEH chain validation	no	no	no	yes [1]	yes
Heap protection					
safe unlinking	yes	yes	yes	yes	yes
safe lookaside lists	no	no	yes	yes	yes
heap metadata cookies	yes	yes	yes	yes	yes
heap metadata encryption	no	no	yes	yes	yes
DEP					
NX support	yes	yes	yes	yes	yes
permanent DEP	no	no	no	yes	yes
OptOut mode by default	no	yes	no	no	yes
ASLR					
PEB, TEB	yes	yes	yes	yes	yes
heap	no	no	yes	yes	yes
stack	no	no	yes	yes	yes
images	no	no	yes	yes	yes

Memory Protection Mechanisms

- **Detect memory corruption:**
  - GS stack cookies
  - SEH chain validation
  - Heap corruption detection
- **Stop common exploitation patterns:**
  - GS (variable reordering)
  - SafeSEH
  - DEP
  - ASLR

GS Stack Cookies

- **GS prevents the attacker from using an overwritten return address on the stack**
  - Adds a stack cookie between the local variables and return address
  - Checks the cookie at the function epilogue

GS Variable Reordering

- **Prevents the attacker from overwriting other local variables or arguments**
  - String buffers go above other variables
  - Arguments copied below local variables

source code	standard stack frame	stack frame with /GS
`void vuln(char* arg)`	`buf`	`copy of arg`
`{`	`i`	`i`
`    char buf[100];`	`return address`	`buf`
`    int i;`	`arg`	`stack cookie`
`    strcpy(buf, arg);`		`return address`
`    ...`		`arg (unused)`
`}`		

SafeSEH

- **Prevents the attacker from using an overwritten SEH record. Allows only the following cases:**
  - Handler found in SafeSEH table of a DLL
  - Handler in a DLL linked without /SafeSEH
- **If DEP is disabled, we have one more case:**
  - Handler on a non-image page, but not on the stack

SEH Chain Validation

- **New protection in Windows Server 2008, much more effective than SafeSEH**
  - Puts a cookie at the end of the SEH chain
  - The exception dispatcher walks the chain and verifies that it ends with a cookie
  - If an SEH record is overwritten, the SEH chain will break and will not end with the cookie
- **Present in Vista SP1, but not enabled**

Data Execution Prevention (DEP)

- **Prevents the attacker from jumping to data:**
  - Uses the NX bit in modern CPUs
  - Modes of operation
    - OptIn – protects only apps compiled with /NXCOMPAT. Default mode on XP and Vista
    - OptOut – protects all apps unless they opt out. Default mode on Server 2003 and 2008
    - AlwaysOn/AlwaysOff – as you'd expect
  - DEP is always enabled for 64-bit processes
    - Internet Explorer on Vista x64 is still a 32-bit process with no DEP

Data Execution Prevention (DEP)

- **Can be enabled and disabled at runtime with NtSetInformationProcess()**
  - Skape and Skywing's attack against DEP
  - Permanent DEP in Vista
- **Important: DEP does not prevent the program from allocating RWX memory**

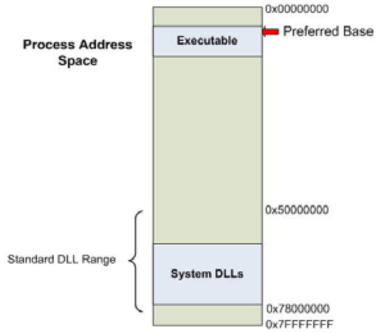
Address Space Layout Randomization (ASLR)

- **Dramatically lowers exploit reliability**
  - Relies on nothing being statically placed
- **Several major components**
  - Image Randomization
  - Heap Randomization
  - Stack Randomization
  - PEB/TEB Randomization

Address Space Layout Randomization (ASLR)

- **Binaries opted-in to ASLR will be randomized**
  - Configurable: HKEY_LOCAL_MACHINE\SYSTEM\CurrentControlSet\Control\Session Manager\Memory Management\MoveImages
- **Stragegy 1: DLL randomization**
  - Random offset from 0x78000000 up to 16M chosen ("Image Bias")
  - DLLs packed together near the top of memory (First DLL Ending with Image Bias)
  - Known DLLs order also mixed up at boot time
  - Constant across different processes (mostly..)
- **Strategy 2: EXE randomization**
  - Random image base chosen within 16M of preferred image base
  - DLLs also use this strategy if "DLL Range" is used up
- **Granularity of Address Space: 64K**

Address Space Layout Randomization (ASLR)



Address Space Layout Randomization (ASLR)

- **Heap randomization strategy: Move the heap base**
  - Address where heap begins is selected linearly with NtAllocateVirtualMemory()
  - Random offset up to 2M into selected region is used for real heap base
  - 64K alignment
- **Stack randomization strategy: Selecting a random "hole" in the address space**
  - Random 5-bit value chosen (X)
  - Address space searched X times for space to allocate the stack
- **Stack base also randomized**
  - Stack begins at random offset from selected base (up to half a page)
  - DWORD aligned

Part III:

Breaking Vista Protections

GS: Function Heuristics

- **Functions containing certain types of variables are not protected:**
  - structures (ANI vulnerability)
  - arrays of pointers or integers

```
void func(int count, int data)
{
    int array[10];
    int i;

    for (i = 0; i < count; i++)
        array[i] = data;
}
```

GS: Use of Overwritten Data

- **The function might use overwritten stack data before the cookie is checked:**

```
callee saved registers
copy of pointer and string buffer arguments
local variables
string buffers               o
gs cookie                    v
exception handler record     e
saved frame pointer          r
return address               f
arguments                    l
                             o
stack frame of the caller    w
```

GS: Exception Handling

- **Triggering an exception will give us control of the program execution before the GS cookie check.**
  - overwrite a pointer or counter variable
  - overflow to the top of the stack
  - application specific exceptions
- **SEH records on the stack are not protected by GS, but we have to bypass SafeSEH.**

Bypassing SafeSEH

- If DEP is disabled, we can just point an overwritten SEH handler to the heap
- If DEP is enabled, SafeSEH protections can be bypassed if a single unsafe DLL is loaded
  - Flash9f.ocx

DEP OptIn

- Vista runs in opt-in mode by default
  - Applications need to specifically opt-in to receive DEP protections
- No need to bypass something that isn't there..
  - DEP not enabled in IE7 or Firefox 2
  - IE8 and Firefox 3 opted-in

ASLR OptIn

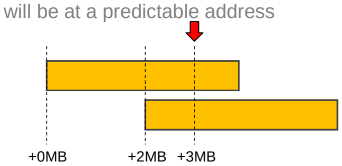
- Vista randomizes only binaries that opt-in
  - A single non-randomized binary is sufficient to bypass ASLR (and DEP)
- Some major 3rd party plugins do not opt-in
  - Flash
  - Java
- Microsoft does not utilize ASLR for all binaries
  - .NET runtime!

Heap Spraying

- **Heap spraying**
  - JavaScript (bypasses ASLR)
  - Java (bypasses ASLR and DEP)

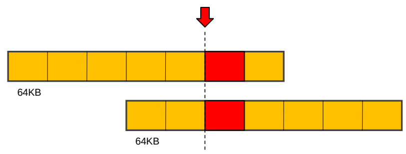
Heap Spraying

- **Heap spraying can bypass ASLR**
  - Consume large amounts of address space with controllable data
- **Only the beginning of the heap is randomized**
  - The maximum offset is 2MB
  - If we allocate a chunk larger than 2MB, some part of it will be at a predictable address



Heap Spraying - JavaScript

- **JavaScript heap spraying**
  - Defeats ASLR (but not DEP)
- **64KB-aligned allocations allow us to put arbitrary data at an arbitrary address**
  - Allocate multiple 1MB strings, repeat a 64KB pattern



Heap Spraying - Java

- **The Sun JVM allocates all memory RWX**
  - DEP not an issue
  - ASLR mitigated

Executable heap spraying code:

```
public class Test extends Applet {
    static String foo = new String("AAAA...");
    static String[] a = new String[50000];

    public void init()  {
        for (int i=0; i<50000; i++) {
            a[i] = foo + foo;
        }
    }
}
```

Heap Spraying - Java

- **Screenshot**

```
0:031> !vadump
BaseAddress:        22cc0000
RegionSize:         058a0000
State:              00001000  MEM_COMMIT
Protect:            00000040  PAGE_EXECUTE_READWRITE
Type:               00020000  MEM_PRIVATE
```

Stack Spraying

- **Alternative to heap spraying**
  - High degree of control over stack contents
  - Creating pointers is simple too: objects/arrays/etc as parameters/local variables
  - Also usable to exhaust large parts of the address space
- **Stack size is controlled by the attacker in .NET and Java!**
  - Thread constructors allow stack size of your choosing

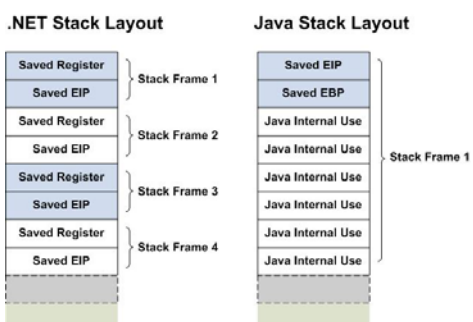
Stack Spraying

- **Method 1: Generate Code**
  - Large amount of local variables
  - Fill with executable code
  - DEP will prevent execution, but this is also true of heap spraying

Stack Spraying

- **Method 2: Overwrite Targets**
  - Fill the stack with useful pointers to overwrite
  - Saved EIPs are probably most useful
  - Create a recursive function to fill the entire stack
  - Overwrite anywhere in the memory region for the win!

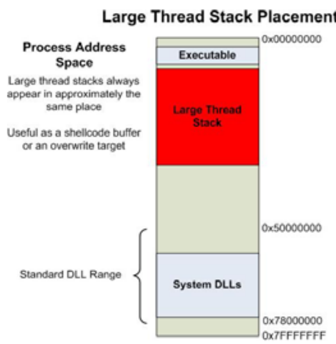
Stack Spraying



Stack Spraying

- **Method 3: Pointer Spraying**
  - Languages don't allow pointer creation directly
  - Declaring objects/arrays will create pointers
  - Useful for exploits requiring indirection

Stack Spraying and ASLR



.NET and IE

- **IE allows embedding of .NET "User Controls"**
  - .NET equivalent of a Java applets
  - Embedded in a web page using the <OBJECT> tag

```
<OBJECT classid="ControlName.dll#Namespace.ClassName">
```

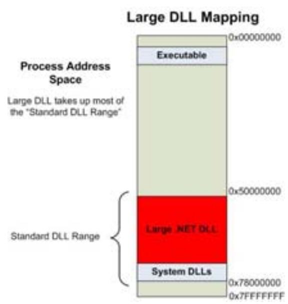
  - Unlike ActiveX, no warning in "Internet Zone"
- **User controls are .NET DLLs**
  - That's right – DLLs can be embedded in web pages!
  - Similar to native DLLs with some additional metadata
  - They can't contain native code (IL-Only)
  - Loaded into the process with LoadLibrary

.NET shellcode

- **Loading User Controls is interesting in the context of memory protections**
  - We can define memory region sizes
  - Page protections are arbitrary
  - In XP, Image base is directly controllable by the attacker
  - On Vista, ASLR prevents direct load address control
    - IL-Only binaries are always randomized, despite opting out of ASLR
    - Load address can still be influenced

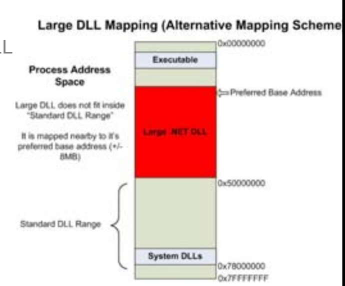
.NET Controls - Large DLLs

- **Large DLL Method 1**
  - Create a large DLL (~100MB)
  - Must consume less than “Standard DLL range”
  - Approximate load location easily guessable



.NET Controls - Large DLLs

- **Large DLL Method 2**
  - Create even larger DLL (~200MB)
  - Approximate load location easily guessable
  - Additional bonus: Select addresses that will bypass character restrictions

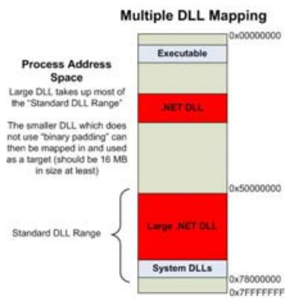


.NET Controls - Large DLLs

- **Problem: 100M+ is too much to download**
  - Pages will take too long to load
- **Solution 1: Binary Padding**
  - For a given section, make the VirtualSize very large, and SizeOfRawData 0 or small
  - Zero-padded when mapped
  - Repeating instruction “add byte ptr [eax], al”
  - Needs EAX to point to writable memory
- **Solution 2: Compression**
  - HTTP can zip up content on the fly
  - Achieved with Content-Encoding header

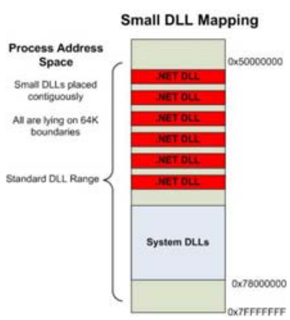
.NET Controls - Large DLLs

- **Large DLL Method 3**
  - Create large DLL (Virtual Padding)
  - Create smaller 16M DLL with shellcode etc
  - Compress smaller DLL with HTTP



.NET Controls - Small DLLs

- **Small DLL Method**
  - Embed a large number of small DLLs (4-8K)
  - About 300 of them is enough (~20M)
  - They all get placed on 64K boundaries in “Standard DLL Range”
  - Target any one of the DLLs in range



.NET Controls – Statically Located DLLs

- **Ideal situation is to have statically positioned, self-supplied .NET DLLs**
- **ASLR enforced on IL-Only binaries**
  - Loader checks if binary is a .NET IL-Only binary and relocates it anyway (no opting out)
  - Is this effective? Not quite…
- **Flagging an IL-Only binary depends on version information read from .NET COR header!**

.NET Controls – Statically Located DLLs

Code from MiCreateImageFileMap():

```
if( (pCORHeader->MajorRuntimeVersion > 2 ||
   (pCORHeader->MajorRuntimeVersion == 2 && pCORHeader->MinorRuntimeVersion >= 5) ) &&
       (pCORHeader->Flags & COMIMAGE_FLAGS_ILONLY) )
{
       pImageControlArea->pBinaryInfo->pHeaderInfo->bFlags |= PINFO_IL_ONLY_IMAGE;

       …
}
```

- **Statically position DLL in 3 Simple steps**
  - Opt out of ASLR (unset IMAGE_DLL_CHARACTERISTICS_DYNAMIC_BASE)
  - Select ImageBase of your choosing
  - Change version in COR header (2.5 -> 2.4 is sufficient)

.NET Controls – Statically Located DLLs

- **Demo**

Part IV:

Conclusion

Conclusion

- **Vista memory protections are ineffective at preventing browser exploitation**
  - Large degree of control attacker has to manipulate process environment
  - Open plugin architecture
  - Single point of failure
- **More work needed on secure browser architecture**
  - Google Chrome is an interesting new development
- **Questions?**