DISSECTING AN
OPERATING SYSTEM VENDOR'S
COMMITMENT TO HOST SECURITY

Windows Vista: Exploitation Countermeasures

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Introduction

- Memory corruption vulnerability exposure can be mitigated through memory hardening practices
- OS vendors have a unique opportunity to fight memory corruption vulnerabilities through hardening the memory manager
- Microsoft is raising the technology bar to combat external threats

Introduction

- Microsoft is raising the technology bar to combat external threats
- New features you've probably heard about
  - Privilege Separation
  - IE Protected Mode
  - Kernel Patch Protection
  - Code Integrity
- New features we are covering today
  - Address Space Layout Randomization
  - Windows Vista Dynamic Memory Allocator

Comparing Exploitation Countermeasures

- Red Hat Enterprise Linux
  - Images
    - Section reordering
    - DLL randomization
    - EXE randomization*
  - Stack
    - Protected control flow data*
    - Local variable protection*
    - Segment randomization
    - Non-executable
  - Heap
    - Segment randomization
    - Non-executable

Comparing Exploitation Countermeasures

- OpenBSD
  - Images
    - DLL randomization
    - Section reordering
  - Stack
    - Protected control flow data*
    - Local variable protection
    - Segment randomization
    - Non-executable
  - Heap
    - Non-executable
    - Segment randomization
- Apple OS X
  - Images
    - No protection
  - Stack
    - No protection
  - Heap
    - No protection

Comparing Exploitation Countermeasures

- Windows Vista
  - Images
    - EXE randomization
    - DLL randomization
  - Stack
    - Protected exception handlers
    - Protected control flow data
    - Local variable protection
    - Segment randomization
    - Non-executable
  - Heap
    - Protected heap management data
    - Segment randomization
    - Non-executable

Windows Exploitation Countermeasures

- A quick look at what you’ve already been exposed to:
  - Stack Cookies (/GS)
  - Heap Mitigations (XP SP2)
  - Structured Exception Handling (SafeSEH)
  - Unhandled Exception Filter (MS06-051)
  - Hardware DEP/NX

Windows Vista Exploitation Countermeasures

- New in Windows Vista
  - Address Space Layout Randomization
    - The History of ASLR
    - Architectural Considerations
    - Vista ASLR Technical Details
    - Testing Methodology

  - Dynamic Memory Allocator
    - A Short Lesson in Heap Exploitation
    - Improvements in Vista Heap Management
    - Vista Dynamic Memory Allocator Internals
    - Testing Methodology

Address Space Layout Randomization

- Windows Vista ASLR is a technology that makes exploitation of a vulnerability a statistical problem

- Address Space Layout Randomization allows for the relocation of memory mappings, making the a process’ address space layout unpredictable

The History of ASLR

- ASLR Theory
  - Exploitation relies on prior knowledge of the memory layout of the targeted process
- Published Research
  - PaX Documentation
    - PaX Team (http://pax.grsecurity.net/docs/aslr.txt)
  - “On the Effectiveness of Address Space Layout Randomization”
    - Shacham, et al Stanford University

Architectural Considerations

- Windows Vista Process Model
  - Most applications are threaded
- Windows Vista Memory Management
  - File mappings must align at 64k boundaries
  - Shared mappings must be used to keep memory overhead low and preserve physical pages
  - Fragmentation of the address space must be avoided to allow for large allocations
  - Supports hardware NX

Vista ASLR Technical Details

- Image Mapping Randomization
  - Random base address chosen for each image loaded once per boot
  - 8 bits of entropy
  - Fix-ups applied on page-in
  - Images are mapped at the same location across processes
  - 99.6% Effective

Vista ASLR Technical Details

- Heap Randomization
  - Random offset chosen for segment allocation using 64k alignment (5-bit entropy)
- Stack Randomization
  - Random offset chosen for segment allocation using 64k or 256k alignment.
  - Random offset within first half of the first page

Vista ASLR Technical Details

- Three pieces to the strategy
  - Address Space Randomization
  - Non-Executable Pages
  - Service Restart Policy

Testing Methodology

- Assumptions
  - ASLR will only protect against remote exploitation
  - ASLR requires NX to remain effective
  - ASLR requires a limit on the number of exploitation attempts to remain effective

Bypassing NX

- Prior to Windows Vista, NX could be disabled in a process if PERMANENT flag was not set
  - Loading a DLL that is not NX compatible
    - No relocation information
    - Loaded off removable media
    - Open handle to a data mapping of the file

  - Call NtSetInformationProcess with the MEM_EXECUTE_OPTION_ENABLE flag

Bypassing NX

- In Windows Vista, NX cannot be disabled once turned on for a process
- Most processes enable NX by default

Bruteforcing ASLR

- Reducing the brute force space
  - Code symmetry
    - Each location shifts stack pointer 20 bytes

```
kernel32+0xa1234:   kernel32+0xb1234:   user32+0x01234:     advapi32+0x51234:
retn 16             pop ebx             jz 0x12345678       lea esp, [esp+20]
                    pop ebp             sub esp, 16         pop eax
                    retn 8              xor eax, eax        call eax
                                        ret
```

  - Advanced return address location
    - Emulation - EEREAP

Bruteforcing ASLR

- Partial overwrites
  - Given known addresses at known offsets, partial overwrites yield predictable results without full knowledge of the address space layout
  - With randomization in play, only bounded overflows can be used reliably for a single partial overwrite

Bruteforcing ASLR

- Partial overwrites
  - A single partial overwrite can be used to execute a payload or gain additional

```
D:\>partial
banner1: 0040100a banner2: 0040100f
hello world!

D:\>partial own
banner1: 0040100a banner2: 0040100f
owned!
```

Bruteforcing ASLR

- Partial overwrites
  - A single partial overwrite can be used to execute a payload or gain additional

```
int main(int argc, char **argv)
{
              struct Object obj1;
              char buf[32];
              struct Object obj2;
…
              printf("banner1: %08x banner2: %08x\n", banner1, banner2);
              if(argv[1] != 0)
                            strncpy(buf, overflow, sizeof(overflow));
              obj1.func();

              return 0;
}
partial!main+0x5a:
004011ea 6a30             push    30h
004011ec 68b8114200       push    offset partial!overflow
004011f1 8d4dc4           lea     ecx,[ebp-3Ch]
004011f4 51               push    ecx
004011f5 e816060000       call    partial!strncpy (00401810)
004011fa 83c40c           add     esp,0Ch
```

Bruteforcing ASLR

- Partial overwrites
  - A single partial overwrite can be used to execute a payload or gain additional

```
0:000> bp 004011f5
0:000> g
banner1: 0040100a banner2: 0040100f
Breakpoint 0 hit
partial!main+0x65:
004011f5 e816060000      call    partial!strncpy (00401810)
0:000> dt obj1
Local var @ 0x12ff38 Type Object
   +0x000 next             : (null)
   +0x004 val              : 17895697
   +0x008 func             : 0x0040100a     partial!ILT+5(_banner1)+0
0:000> p
partial!main+0x6a:
004011fa 83c40c          add     esp,0Ch
0:000> dt obj1
Local var @ 0x12ff38 Type Object
   +0x000 next             : 0x41414141 Object
   +0x004 val              : 1094795585
   +0x008 func             : 0x0040100f     partial!ILT+10(_banner2)+0
0:000> g
owned!
```

Residual Weaknesses

- Information Leaking
  - Uninitialized memory
  - Use multiple attempts to gain address layout information that will get you code execution
  - Additional image map locations can usually be inferred from one DLL address
- Heap spraying reduces the need for accuracy
- Non-randomized data as arguments to functions
  - SharedUserData / ReadOnlySharedMemoryBase
  - Non-relocatable resource dlls

- 3rd party binaries

Putting ASLR to Work for You

- Software Development Process
  - Create NX and ASLR compatible binaries
  - Keep service restart policies in mind
  - Ensure information leak bugs are addressed
- Technology
  - Use hardware that supports NX

Windows Vista Heap Allocator

- The majority of currently exploited vulnerabilities in Microsoft products are overflows into heap memory

- Heap exploitation relies on corrupting heap management data or attacking application data within the heap

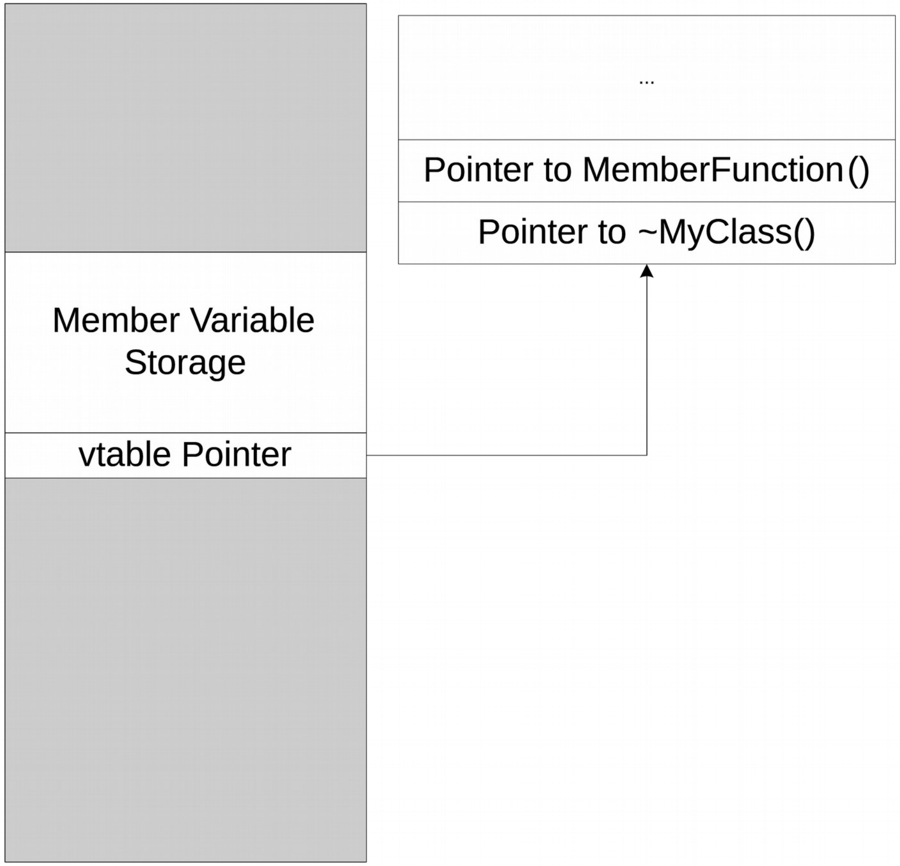
VTable Overwrites

Class objects contain a list of function pointers for each virtual function in the class called a vtable

```
class MyClass
{
public:
  MyClass();
  virtual ~MyClass();
  virtual MemberFunction();
  int MemberVariable;
};
```

Overwriting virtual function pointers is the simplest method of heap exploitation

Class Instance on the Heap



HEAP_ENTRY Overflow

- Scenario: Heap-based buffer overflow allows for writing into adjacent free heap block
- Attack: Overwrite FLINK and BLINK values and wait for HeapAlloc()

```
mov dword ptr [ecx],eax
mov dword ptr [eax+4],ecx

EAX = Flink, EBX = Blink
```

- Allows one or two 4-byte writes to controlled locations

FREE HEAP BLOCK

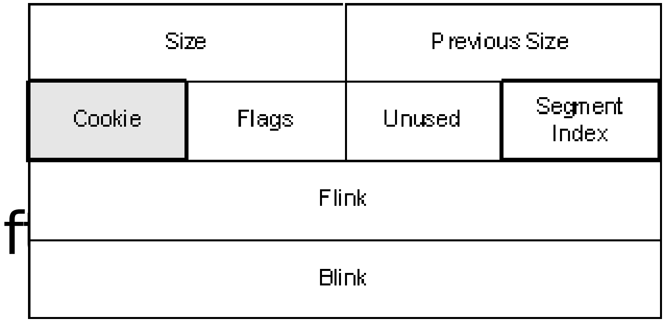
```
_HEAP_ENTRY
 +0x000 Size
 +0x002 PreviousSize
 +0x004 SmallTagIndex
 +0x005 Flags
 +0x006 UnusedBytes
 +0x007 SegmentIndex
_LIST_ENTRY
 +0x000 Flink
 +0x004 Blink
```

HEAP_ENTRY Overflow Mitigations in XP SP2

- [illegible]ocation

```
LIST_ENTRY->Flink->Blink == LIST_ENTRY->Blink->Flink == LIST_ENTRY
```

- 8-bit Cookie
  - Verified on allocation af
removal from free list



Size		Previous Size	
Cookie	Flags	Unused	Segment Index
Flink			
Blink			

HEAP_ENTRY Overflow Mitigations in XP SP2

- Defeated by attacking the lookaside list
  - First heap overwrite takes control of Flink value in a free chunk with a lookaside list entry
  - Allocation of the corrupted chunk puts the corrupt Flink value into the lookaside list
  - Next HeapAlloc() of the same sized chunk will return the corrupted pointer

Windows Vista Heap Hardening

- Heap segment randomization
- HEAP_ENTRY integrity checks
- Block entry randomization
- Linked-list validation and substitution
- Function pointer hardening
- Terminate on Error

Windows Vista Heap Hardening

- HEAP_ENTRY
  - Checksum for Size and Flags
  - Size, Flags, Checksum, and PreviousSize are XOR’d against random value

- Adds extra resilience against overflows into Flink and Blink values

Windows Vista Heap Hardening

- Linked-lists
  - Forward and backward pointer validation on unlink from any list
- Lookaside lists
  - Replaced by Low-Fragmentation Heap

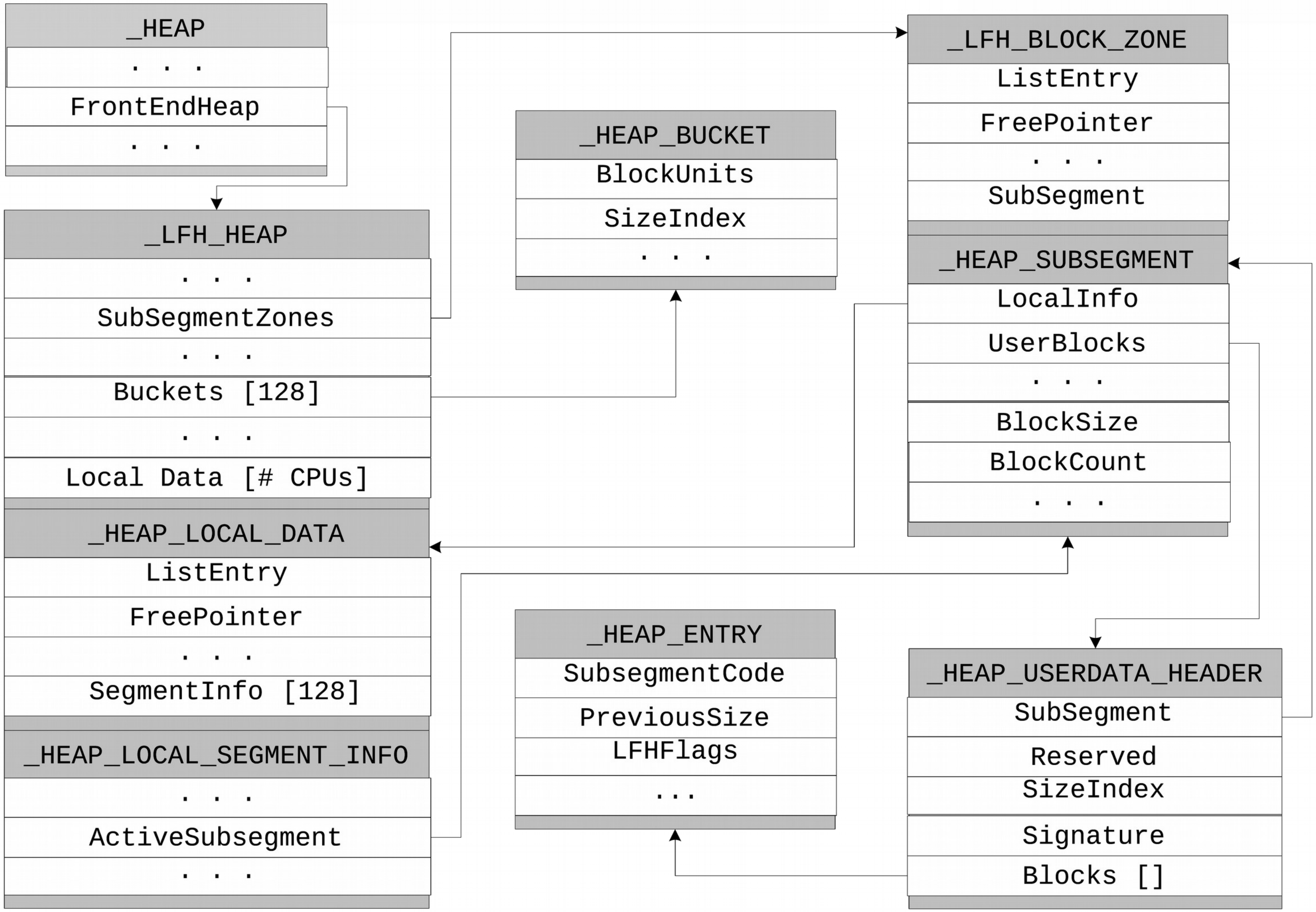
Windows Vista Heap Hardening

- Function pointer hardening
  - CommitRoutine and InterceptRoutine function pointers encoded
  - CRT atexit() destructors encoded
- Terminate on Error
  - Opt-in API that cannot be disabled
  - Ensures program cleanup does not utilize tainted heap structures

Windows Vista Low-Fragmentation Heap

- The Low-Fragmentation Heap is enabled by default in Windows Vista
- The LFH replaces lookaside lists and is similar in nature
  - 128 buckets of static sized buffers
  - Utilized for reoccuring allocations of the same size

Windows Vista Low-Fragmentation Heap



_HEAP
. . .
FrontEndHeap
. . .

_LFH_HEAP
. . .
SubSegmentZones
. . .
Buckets [128]
. . .
Local Data [# CPUs]

_HEAP_LOCAL_DATA
ListEntry
FreePointer
. . .
SegmentInfo [128]

_HEAP_LOCAL_SEGMENT_INFO
. . .
ActiveSubsegment
. . .

_HEAP_BUCKET
BlockUnits
SizeIndex
. . .

_HEAP_ENTRY
SubsegmentCode
PreviousSize
LFHFlags
...

_LFH_BLOCK_ZONE
ListEntry
FreePointer
. . .
SubSegment

_HEAP_SUBSEGMENT
LocalInfo
UserBlocks
. . .
BlockSize
BlockCount
. . .

_HEAP_USERDATA_HEADER
SubSegment
Reserved
SizeIndex
Signature
Blocks []

Windows Vista Heap Testing Methodology

HEAP_ENTRY

- Doubly-linked list pointers are only validated when unlinking a node

Attack

- If list head pointers can be corrupted prior to an insert, the destination of a 4-byte write can be controlled
- The address of the free chunk being inserted into the list will be written to the corrupted linked list pointer

Assessment

- Writing the address of the chunk may be only be helpful in limited circumstances
- It is difficult to find a list head to overwrite

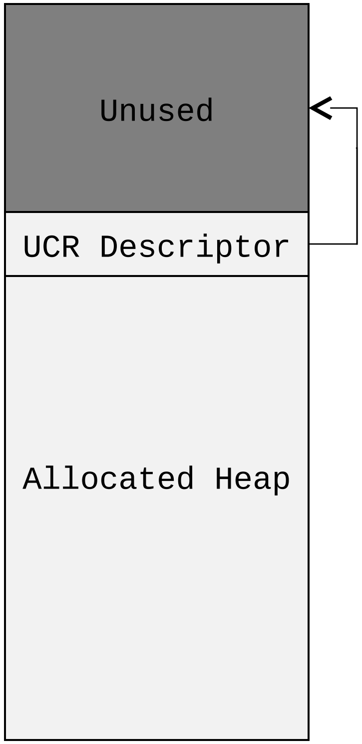
```
InsertHeadList(ListHead, Entry)
 Flink = ListHead->Flink;
 Entry->Flink = Flink;
 Entry->Blink = ListHead;
 Flink->Blink = Entry;
 ListHead->Flink = Entry;


InsertTailList(ListHead, Entry)
 Blink = ListHead->Blink;
 Entry->Flink = ListHead;
 Entry->Blink = Blink;
 Blink->Flink = Entry;
 ListHead->Blink = Entry;
```

Windows Vista Heap Testing Methodology

HEAP_UCR_DESCRIPTOR

- **Attack**
  - Repeated large allocations will result in the allocation of a new segment
  - HEAP_UCR_DESCRIPTOR is at a static offset from first allocation in a segment
  - If fake descriptor points at allocated memory, the next heap allocation will write a HEAP_UCR_DESCRIPTOR to a controlled address
- **Assessment**
  - Limited control of the data written should effectively reduce this to a partial DWORD overwrite
  - Increased complexity with multi-stage attack requires a high degree of control such as active scripting



Windows Vista Heap Testing Methodology

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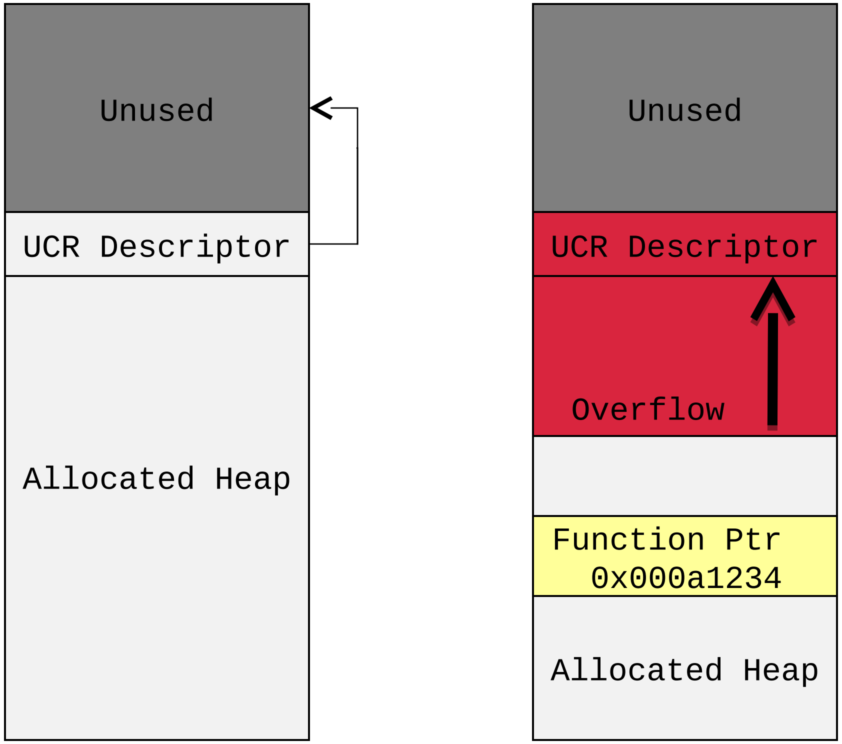

Windows Vista Heap Testing Methodology

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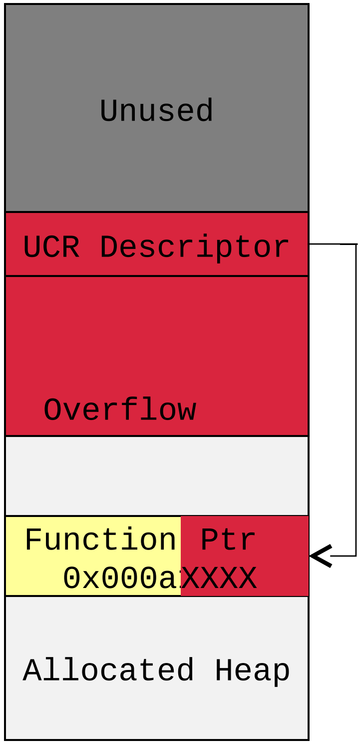
```
_HEAP_UCR_DESCRIPTOR
   +0x000 ListEntry
   +0x008 SegmentEntry
   +0x010 Address
   +0x014 Size

Address points to the
next reserved region
and defines where a
HEAP_UCR_DESCRIPTOR will
be written on the next
segment allocation
```



Windows Vista Heap Testing Methodology

_LFH_BLOCK_ZONE

- **Attack**
  - New SubSegments are created at the location specified by the FreePointer in the LFH_BLOCK_ZONE structure
  - Control of the FreePointer allows writing a HEAP_SUBSEGMENT to an arbitrary location
  - Allocation size and number of allocations affect fields in the HEAP_SUBSEGMENT structure
- **Assessment**
  - Limited control of the data written should effectively reduce this to a partial DWORD overwrite
  - Increased complexity attack requires a high degree of control such as active scripting

```
_LFH_BLOCK_ZONE
 +0x000 ListEntry
 +0x008 FreePointer
 +0x00c Limit

_HEAP_SUBSEGMENT
 +0x000 LocalInfo
 +0x004 UserBlocks
 +0x008 AggregateExchg
 +0x010 BlockSize
 +0x012 Flags
 +0x014 BlockCount
 +0x016 SizeIndex
 +0x017 AffinityIndex
 +0x010 Alignment
 +0x018 SFreeListEntry
 +0x01c Lock
```

Windows Vista Exploitation Countermeasures

Default exploit mitigations on popular client operating systems

		Windows Vis	Windows XP S	Red Hat Enterprise Lin	OpenB	Apple O
Images						
	Section Reordering			▓	▓	
	EXE Randomization	▓		░		
	DLL Randomization	▓		▓	▓	
Stack						
	Frame Protection	▓	░	░	░	
	Exception Protection	▓	░			
	Local Var Protection	▓	░	░	░	
	Randomization	▓		▓	▓	
	Non-Executable	▓	░	▓	▓	
Heap						
	Heap Metadata Protection	▓	▓			
	Randomization	▓		▓	▓	
	Non-Executable	▓	░	▓	▓	

▓ Full Coverage
░ Partial Coverage

Conclusion

- OS vendors have a unique opportunity to fight memory corruption vulnerabilities through hardening the memory manager
- Microsoft is committed to closing the gap as much as possible and Windows Vista will have the strongest pro-active vulnerability defense of any Windows release
- These protections will continue to evolve to prevent wide-spread exploitation of software vulnerabilities
- Exploitation mitigations do not solve the problem of software vulnerabilities, but do provide a stop-gap during times of exposure

Questions?

- Thank you for attending
- Please contact us at switech@microsoft.com for feedback on Microsoft’s mitigation technologies