Exploiting Hardcore Pool Corruptions in Microsoft Windows Kernel

Nikita Tarakanov

Anonymous Developer

Krakow, ConFidence 2013

Who the heck is Nikita Tarakanov?

- Independent Security Researcher from MotherLand
- Vulnerability Assassin
- Crazy Wild Russian
- Aligner of stars
- Отморозок на Nightmare
- Nice dude ☺

Agenda

- Introduction/Kernel Pool Basics
- Previous research
- DKOHM
- Conclusion
- Q&A

Introduction

- Many modern popular applications have sandbox
- Sandboxes have low attack surface
- Attacking kernel from the sandbox is convenient
- Untrusted -> r0 -> full compromise RULEZZZ (Nils (@nils) and Jon (@securitea) vs Google Chrome at pwn2own 2013)

Introduction

- Most of vulnerabilities in MS kernel are memory corruptions
- Most of them are Pool Corruptions
- MS enhances security of Pool Allocator
- Windows 7 – “Safe” unlinking
- Windows 8 – almost every technique is dead

Kernel Pool research MUST READ

- Following slides are basics (copy&paste aka plagiarism of previous work) of Kernel Pool mechanisms
- Read slides of Tarjei Mandt aka @kernelpool which is the most comprehensive work on Kernel Pool Internals
- Newest research by Zhenhua 'Eric' Liu at NoSuchCon (yesterday’s talk) about advanced Pool Manipulation techniques on win8

Kernel Pool Basics

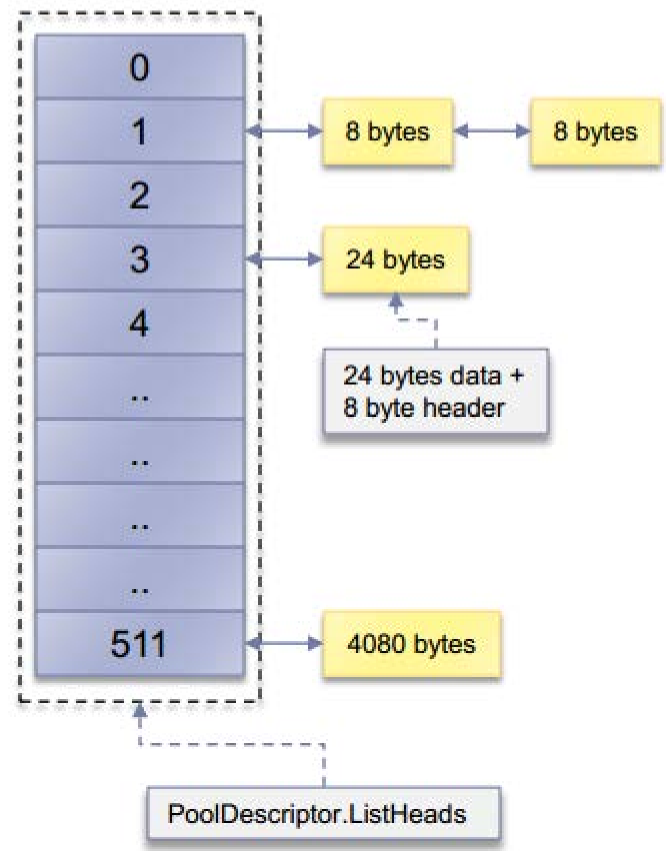
- Kernel pools are divided into types: Non-Paged, Paged, Session, etc.
- Each kernel pool is defined by a pool descriptor (**POOL_DESCRIPTOR** structure)
- The initial descriptors for paged and non-paged pools are defined in the **nt!PoolVector** array

Kernel Pool Descriptor (Win 8 x86)

- dt nt!_POOL_DESCRIPTOR
- +0x000 PoolType : _POOL_TYPE
- +0x004 PagedLock : _FAST_MUTEX
- +0x004 NonPagedLock : Uint4B
- +0x040 RunningAllocs : Int4B
- +0x044 RunningDeAllocs : Int4B
- +0x048 TotalBigPages : Int4B
- +0x04c ThreadsProcessingDeferrals : Int4B
- +0x050 TotalBytes : Uint4B
- +0x080 PoolIndex : Uint4B
- +0x0c0 TotalPages : Int4B
- **+0x100 PendingFrees : _SINGLE_LIST_ENTRY**
- +0x104 PendingFreeDepth : Int4B
- **+0x140 ListHeads : [512] _LIST_ENTRY**

ListHeads

- Each pool descriptor has a ListHeads array of 512 doubly linked lists of free chunks of the same size
- Free chunks are indexed into the ListHeads array by block size
- Each pool chunk is preceded by an 8-byte **pool header**
-



Pool Header (x86)

- kd> dt nt!_POOL_HEADER
- +0x000 PreviousSize : Pos 0, 9 Bits
- +0x000 PoolIndex : Pos 9, 7 Bits
- +0x002 BlockSize : Pos 0, 9 Bits
- +0x002 PoolType : Pos 9, 7 Bits
- +0x004 PoolTag : Uint4B
- PreviousSize: BlockSize of the preceding chunk
- PoolIndex: Index into the associated pool descriptor array
- BlockSize: (NumberOfBytes+0xF) >> 3
- PoolType: Free=0, Allocated=(PoolType|2) PoolTag: 4 printable characters identifying the code responsible for the allocation

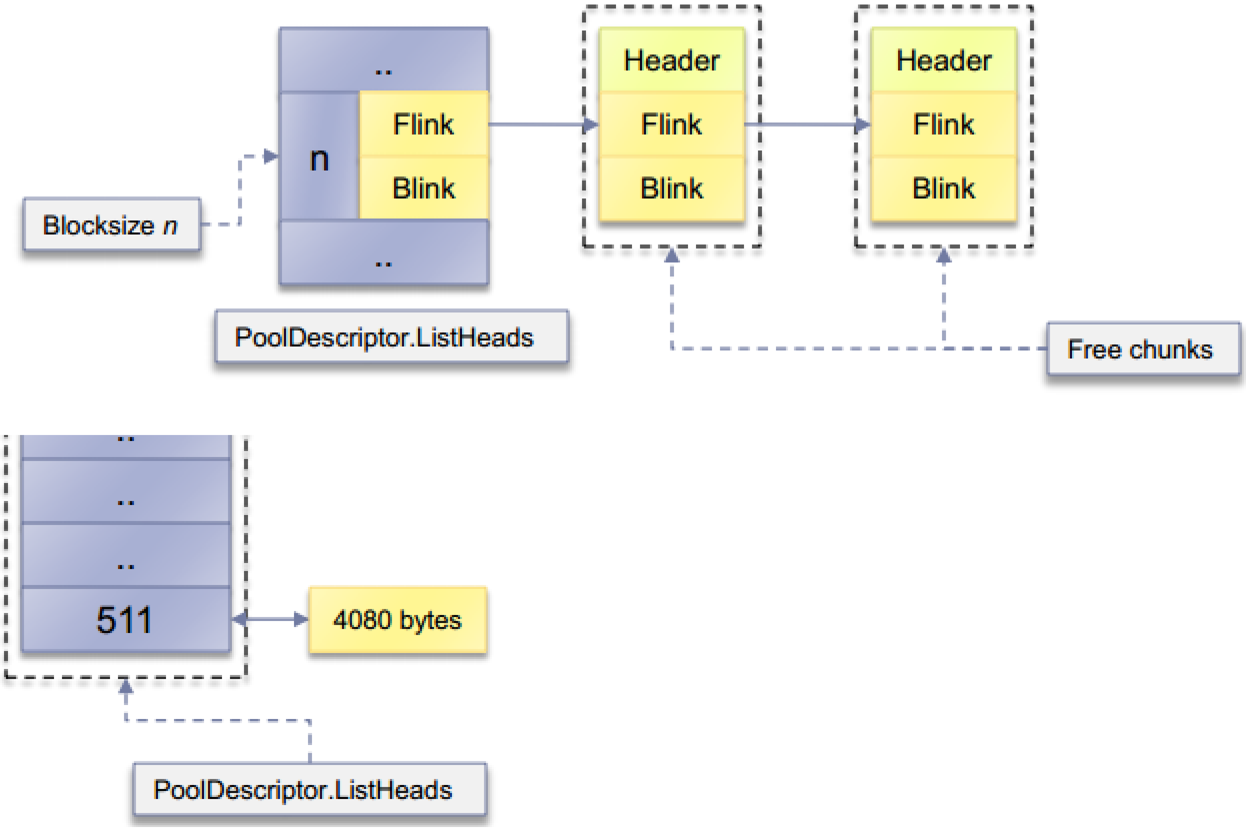
Pool Header (x64)

- kd> dt nt!_POOL_HEADER
- +0x000 PreviousSize : Pos 0, 8 Bits
- +0x000 PoolIndex : Pos 8, 8 Bits
- +0x000 BlockSize : Pos 16, 8 Bits
- +0x000 PoolType : Pos 24, 8 Bits
- +0x004 PoolTag : Uint4B
- +0x008 ProcessBilled : Ptr64 _EPROCESS
- BlockSize: (NumberOfBytes+0x1F) >> 4 (256 ListHeads entries due to 16 byte block size)
- ProcessBilled: Pointer to process object charged for the pool allocation (used in quota management)

Free Pool Chunks

- If a pool chunk is freed to a pool descriptor ListHeads list, the header is followed by a **LIST_ENTRY** structure
- Pointed to by the ListHeads doubly-linked list
- kd> dt nt!_LIST_ENTRY
- +0x000 Flink : Ptr32 _LIST_ENTRY
- +0x004 Blink : Ptr32 _LIST_ENTRY

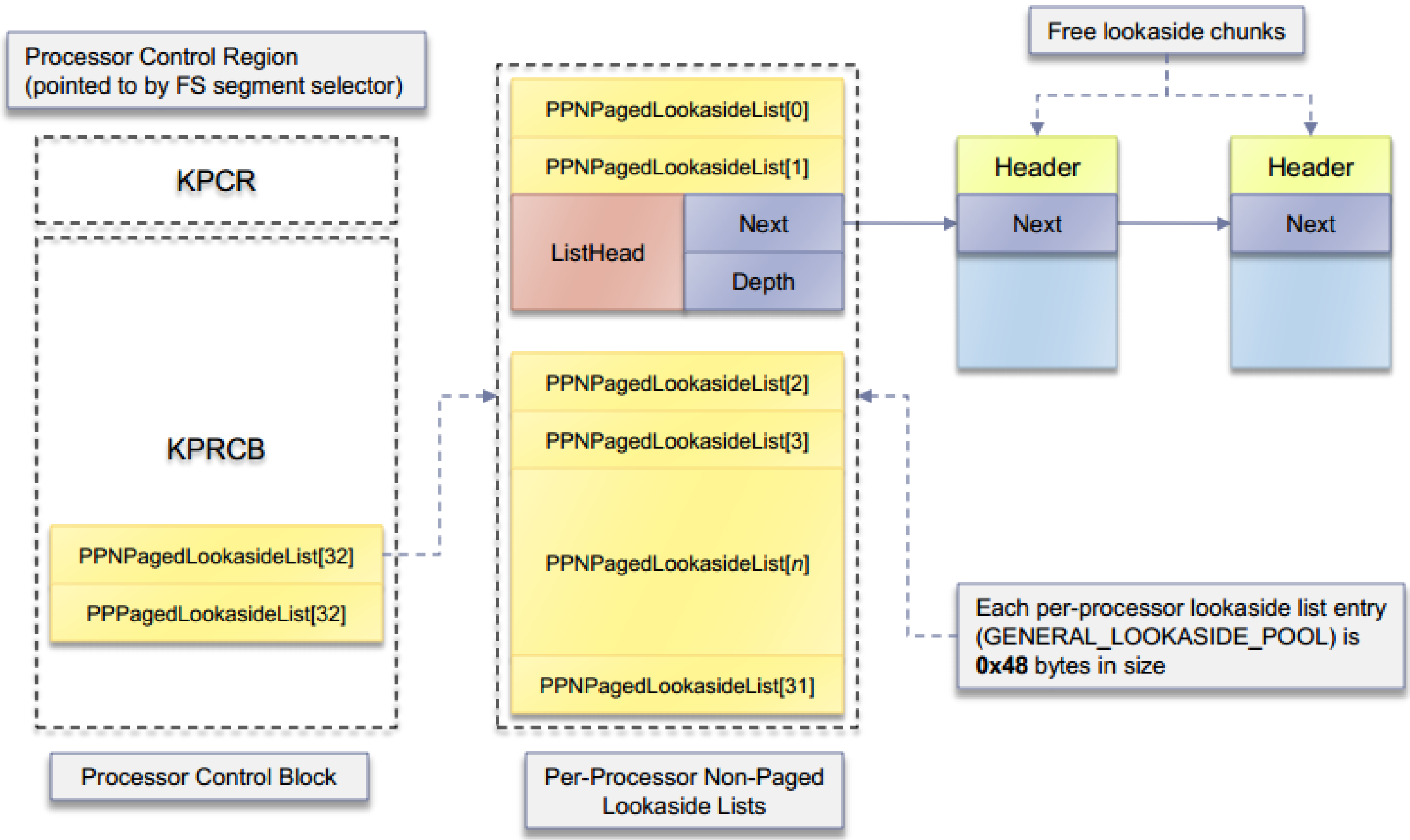
Free Pool Chunks



Lookaside Lists

- Kernel uses lookaside lists for faster allocation/deallocation of small pool chunks
- Separate per-processor lookaside lists for pagable and non-pagable allocations
- Defined in the Processor Control Block (KPRCB)
- Maximum BlockSize being 0x20 (256 bytes)

Lookaside Lists



Large Pool Allocations

- Allocations greater than 0xff0 (4080) bytes
- Handled by the function nt!ExpAllocateBigPool
- Each node (e.g. processor) has 4 singly-linked lookaside lists for big pool allocations
- 1 paged for allocations of a single page
- 3 non-paged for allocations of page count 1, 2, and 3

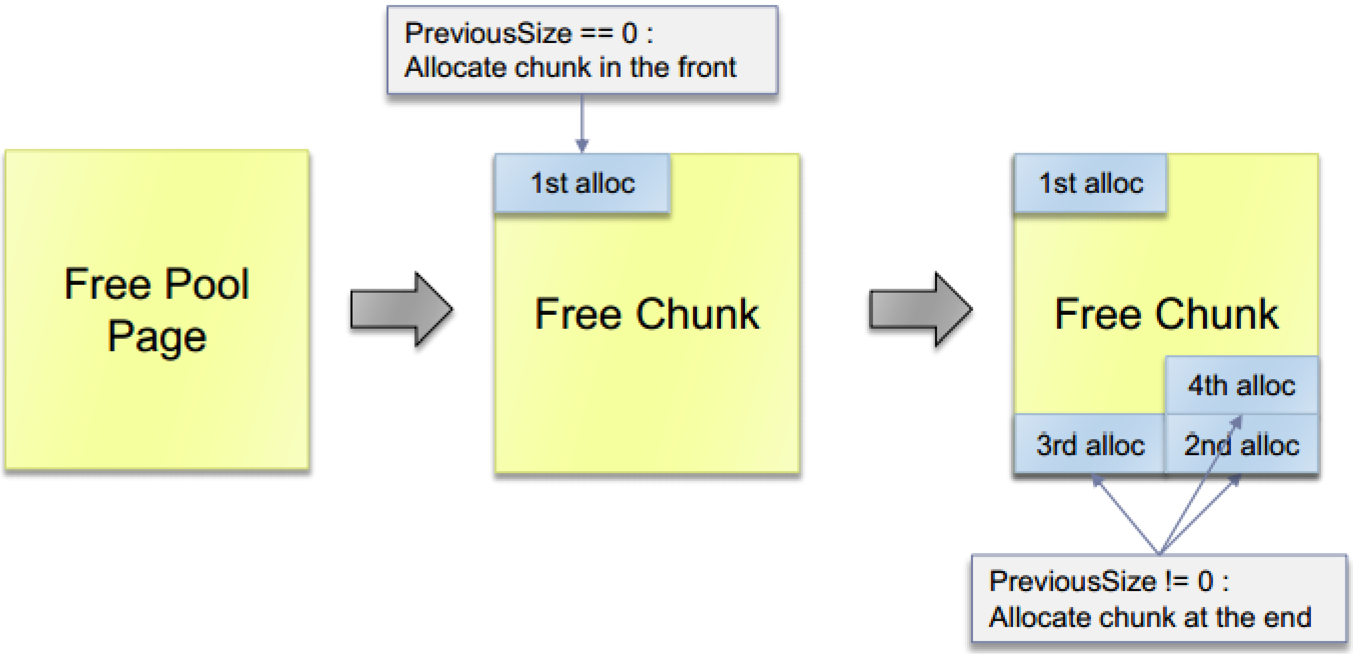
Large Pool Allocations

- If lookaside lists cannot be used, an allocation bitmap is used to obtain the requested pool pages
- The bitmap is searched for the first index that holds the requested number of unused pages
- Bitmaps are defined for every major pool type with its own dedicated memory
- The array of bits is located at the beginning of the pool memory range

Allocation Algorithm

- The kernel exports several allocation functions for kernel modules and drivers to use
- All exported kernel pool allocation routines are essentially wrappers for **ExAllocatePoolWithTag**
- The allocation algorithm returns a free chunk by
- checking with the following (in order)
- Lookaside list(s)
- ListHeads list(s)
- Pool page allocator

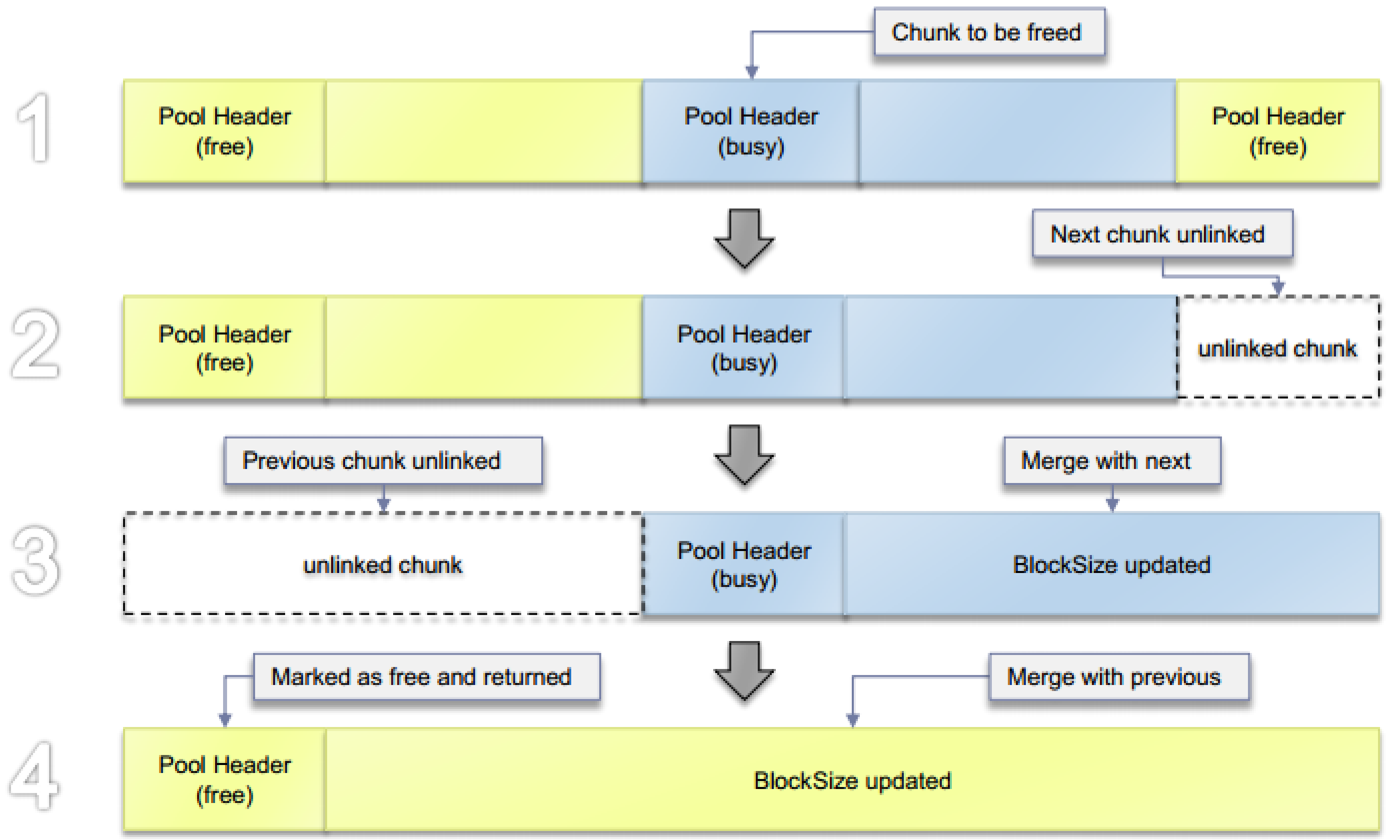
Splitting on allocation / Order of chunk allocation on page



Free Algorithm

- The Free Algorithm inspects the pool header of the chunk to be freed and frees it to the appropriate list (**ExFreePoolWithTag** function)
- Adjacent free chunks may be **merged** with the freed chunk to reduce fragmentation

Coalescence/Merging



Previous research

- SoBelt X'con 2005
- Kostya Kortchinsky SyScan 2008
- Tarjei Mandt BH DC 2011
- Tarjei Mandt BH US 2012
- Zhenhua 'Eric' Liu NoSuchCon 2013

Previous research (Kortchinsky)

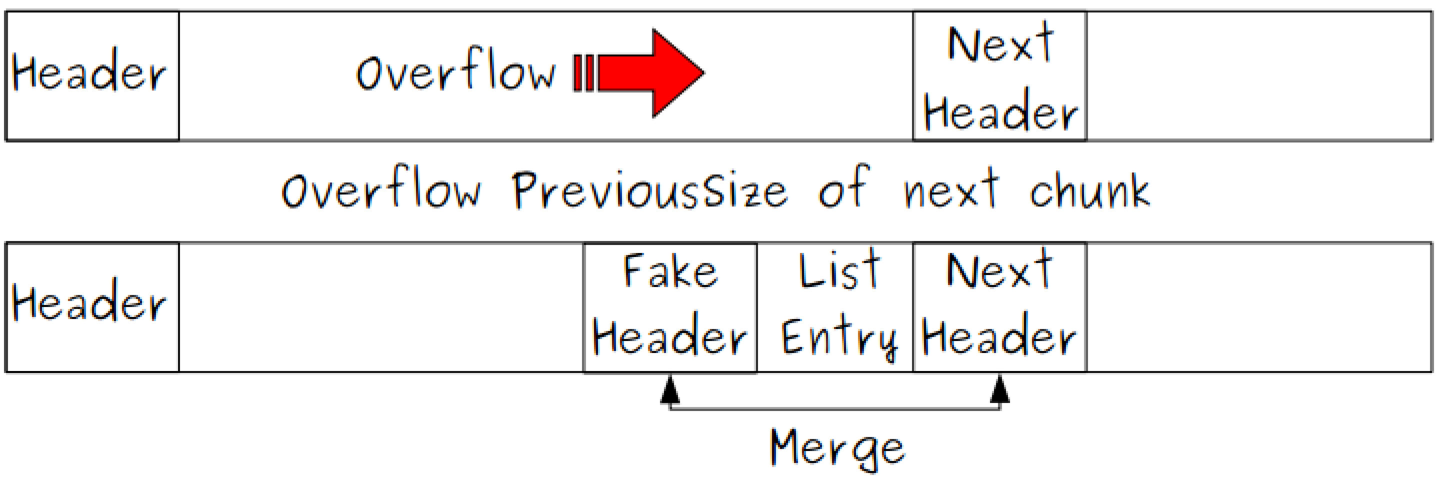
- write4 techniques:
  - Unlink attack
  - Merge with next
  - Merge with previous
  - Lisheads unlinks
  - MmNonPagedPoolFreeListHead Unlink

Kortchinsky

- Removing an entry 'e' from a double linked list:
  - PLIST_ENTRY b,f;
  - f=e->Flink;
  - b=e->Blink;
  - b->Flink=f;
  - f->Blink=b;
- This leads to a usual **write4** primitive:
  - *(**where**)=**what**
  - *(**what+4**)=**where**

Kortchinsky

- Write4 example (happens when next is freed)



Previous research (Mandt BH DC 2011)

- ListEntry Flink Overwrite
- Lookaside Pointer Overwrite
- PoolIndex Overwrite
- PendingFrees Pointer Overwrite
- Quota Process Pointer Overwrite

Previous research (Mandt BH US 2012)

- MS eliminated Tarjei’s techniques in win8
- Tarjei discovered more l33t stuff for win8:
  - BlockSize Attack
  - Split Chunk Attack

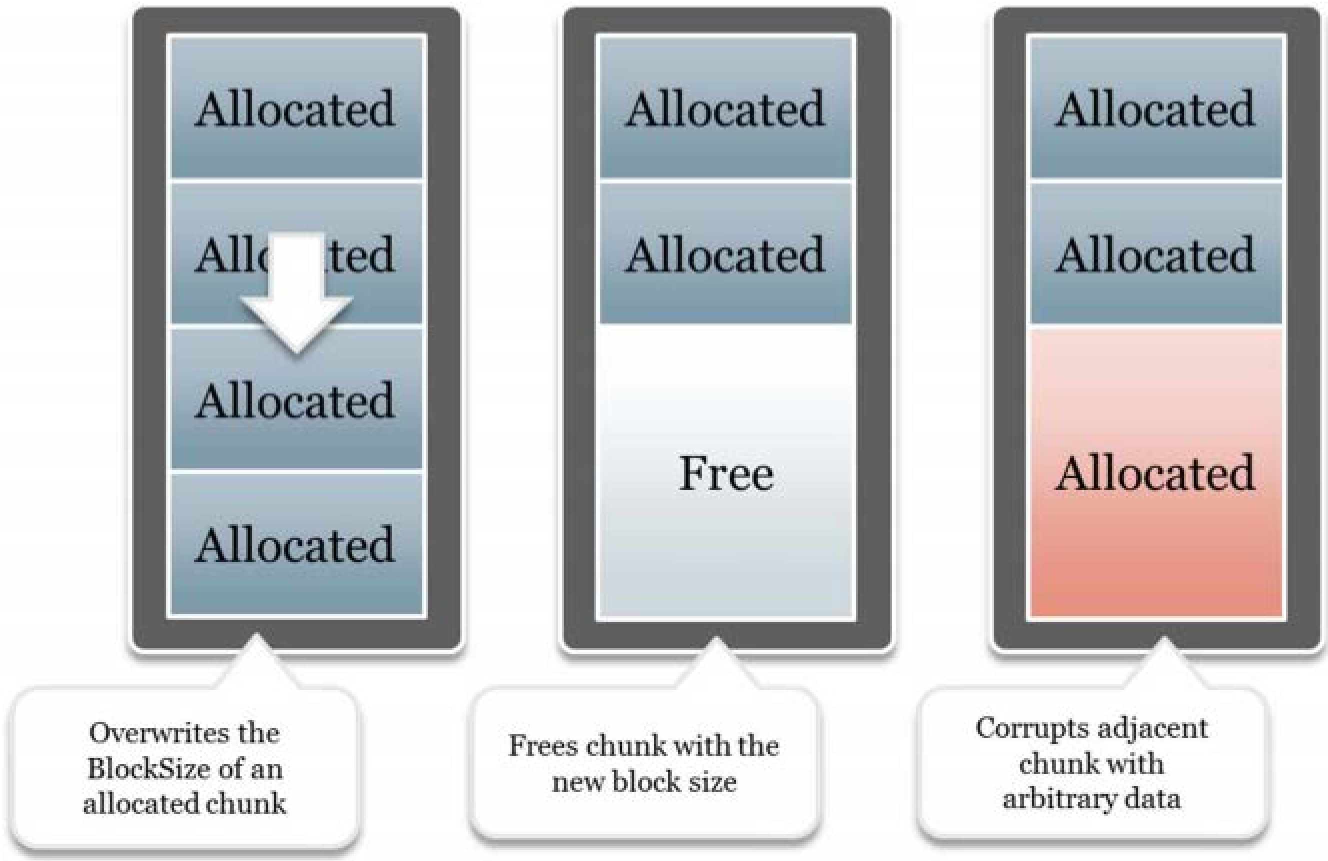
BlockSize Attack

- When a chunk is freed, it is put in to a free list or lookaside based on its block size
- An attacker can overwrite the block size in order to put it into an arbitrary free list
- Setting the block size to cover the rest of the page **avoids** the **BlockSize/PreviousSize check on free** (no checks -> no BSOD)

BlockSize Attack Steps

- Corrupt the block size of an in-use chunk (Set it to fill the rest of the page)
- Free the corrupted pool chunk
- Reallocate the freed memory using something controllable (like a unicode string)
- It leads to arbitrary pool corruption

BlockSize Attack



Previous Research (Summary)

- Attacks against Pool metadata/mechanisms
- Advanced Pool Manipulation (Feng Shui)
- Precise control over overflown data
- A lot of techniques/attacks are killed on win8 ☹
- Some types of Pool Corruptions are hard/impossible to exploit ☹

The Problem

- All these techniques have prerequisites
- What if there is no chance to fulfill prerequisites?
- Separate Pool Corruptions:
  - Sweet – satisfy exploitable conditions
  - Hardcore – don’t satisfy exploitable conditions

The Problem: examples

- No chance to build correct pool header
  - Memset(mem, 0, count)
  - Memset(mem, CONST, count)
  - Memcpy(mem, uncontrolled_mem, count)

DKOHM

- Direct Kernel Object Header Manipulation!

DKOHM

- Don’t attack Pool Allocator mechanisms
- Attack Something Else
- Kernel Objects!
- Objects have header
- Also DKOM which is known in rootkit world

Object Header (WRK)

- typedef struct _OBJECT_HEADER {
- [..]
- **POBJECT_TYPE Type;**
- [..]

- union {
- POBJECT_CREATE_INFORMATION ObjectCreateInfo;
- PVOID QuotaBlockCharged;
- };

- PSECURITY_DESCRIPTOR SecurityDescriptor;
- **QUAD Body;**
- } OBJECT_HEADER, *POBJECT_HEADER;

Object Header (Win8)

- kd> dt nt!_OBJECT_HEADER
- +0x000 PointerCount : Int4B
- +0x004 HandleCount : Int4B
- +0x004 NextToFree : Ptr32 Void
- +0x008 Lock : _EX_PUSH_LOCK
- **+0x00c TypeIndex : UChar**
- +0x00d TraceFlags : UChar
- +0x00d DbgRefTrace : Pos 0, 1 Bit
- +0x00d DbgTracePermanent : Pos 1, 1 Bit
- +0x00e InfoMask : UChar
- +0x00f Flags : UChar
- +0x010 ObjectCreateInfo : Ptr32 _OBJECT_CREATE_INFORMATION
- +0x010 QuotaBlockCharged : Ptr32 Void
- +0x014 SecurityDescriptor : Ptr32 Void
- +0x018 Body : _QUAD

Object Type (WRK)

- typedef struct _OBJECT_TYPE {
-     ERESOURCE Mutex;
-     LIST_ENTRY TypeList;
-     UNICODE_STRING Name;
-     PVOID DefaultObject;
-     ULONG Index;
-     ULONG TotalNumberOfObjects;
-     ULONG TotalNumberOfHandles;
-     ULONG HighWaterNumberOfObjects;
-     ULONG HighWaterNumberOfHandles;
-     **OBJECT_TYPE_INITIALIZER TypeInfo;**
- #ifdef POOL_TAGGING
-     ULONG Key;
- #endif //POOL_TAGGING
-     ERESOURCE ObjectLocks[OBJECT_LOCK_COUNT];
- } OBJECT_TYPE, *POBJECT_TYPE;

Object Type (win8)

- kd> dt nt!_OBJECT_TYPE
- +0x000 TypeList : _LIST_ENTRY
- +0x008 Name : _UNICODE_STRING
- +0x010 DefaultObject : Ptr32 Void
- +0x014 Index : UChar
- +0x018 TotalNumberOfObjects : Uint4B
- +0x01c TotalNumberOfHandles : Uint4B
- +0x020 HighWaterNumberOfObjects : Uint4B
- +0x024 HighWaterNumberOfHandles : Uint4B
- **+0x028 TypeInfo : _OBJECT_TYPE_INITIALIZER**
- +0x080 TypeLock : _EX_PUSH_LOCK
- +0x084 Key : Uint4B
- +0x088 CallbackList : _LIST_ENTRY

Procedures (WRK)

- typedef struct _OBJECT_TYPE_INITIALIZER {
- [..]
- **OB_DUMP_METHOD DumpProcedure;**
- **OB_OPEN_METHOD OpenProcedure;**
- **OB_CLOSE_METHOD CloseProcedure;**
- **OB_DELETE_METHOD DeleteProcedure;**
- **OB_PARSE_METHOD ParseProcedure;**
- **OB_SECURITY_METHOD SecurityProcedure;**
- **OB_QUERYNAME_METHOD QueryNameProcedure;**
- **OB_OKAYTOCLOSE_METHOD OkayToCloseProcedure;**
- } OBJECT_TYPE_INITIALIZER, *POBJECT_TYPE_INITIALIZER;

Procedures (win8)

- kd> dt nt!_OBJECT_TYPE_INITIALIZER
- [..]
- **+0x030 DumpProcedure : Ptr32 void**
- **+0x034 OpenProcedure : Ptr32 long**
- **+0x038 CloseProcedure : Ptr32 void**
- **+0x03c DeleteProcedure : Ptr32 void**
- **+0x040 ParseProcedure : Ptr32 long**
- **+0x044 SecurityProcedure : Ptr32 long**
- **+0x048 QueryNameProcedure : Ptr32 long**
- **+0x04c OkayToCloseProcedure : Ptr32 unsigned char**

Procedures (example)

- kd> dt nt!_OBJECT_TYPE_INITIALIZER 849670c0
- +0x000 Length : 0x58
- +0x002 ObjectTypeFlags : 0x10 ''
- +0x002 MaintainHandleCount : 0y1
- +0x024 PoolType : 200 (NonPagedPoolNx)
- +0x02c DefaultNonPagedPoolCharge : 0x154
- **+0x030 DumpProcedure : (null)**
- **+0x034 OpenProcedure : 0x81b8f5df long nt!AlpcpOpenPort+0**
- **+0x038 CloseProcedure : 0x81add15f void nt!AlpcpClosePort+0**
- **+0x03c DeleteProcedure : 0x81adcdf3 void nt!AlpcpDeletePort+0**
- **+0x040 ParseProcedure : (null)**
- **+0x044 SecurityProcedure : 0x81b183c3 long nt!SeDefaultObjectMethod+0**

Object Type Index Table (x86)

Memory

Virtual: nt!ObTypeIndexTable

```
81251dc0 00000000
81251dc4 bad0b0b0
81251dc8 84162308
81251dcc 841a7f70
81251dd0 8415ce30
81251dd4 8416d130
81251dd8 84160040
81251ddc 8419f378
81251de0 84171cc0
```

Object Type Index Table (x64)

Memory

Virtual: nt!ObTypeIndexTable

```
fffff801`fda9ede0 0000000000000000
fffff801`fda9ede8 00000000bad0b0b0
fffff801`fda9edf0 fffffa800cc8d920
fffff801`fda9edf8 fffffa800cca9c60
fffff801`fda9ee00 fffffa800cca0d20
fffff801`fda9ee08 fffffa800ccb3ea0
fffff801`fda9ee10 fffffa800cc7d100
fffff801`fda9ee18 fffffa800ccbbf20
fffff801`fda9ee20 fffffa800ccbeea0
fffff801`fda9ee28 fffffa800cc68f20
fffff801`fda9ee30 fffffa800cc78ea0
fffff801`fda9ee38 fffffa800cc6a080
fffff801`fda9ee40 fffffa800cc81760
fffff801`fda9ee48 fffffa800ccae550
fffff801`fda9ee50 fffffa800cc87790
fffff801`fda9ee58 fffffa800cc77080
fffff801`fda9ee60 fffffa800cca5ea0
fffff801`fda9ee68 fffffa800ccafc00
```

DKOHM Attack

- Smash object header
- Call magic syscall
- Magic syscall triggers dereference of smashed pointer
- It leads to hijack of control flow

DKOHM Steps

- Spray Pool with Objects
- Fragment Pool (make holes at the **bottom** of the pages)
- Trigger Overflow/Corruption
- Call magic syscall
- EIP/RIP is under control, game over

DKOHM

- There are some magic syscalls
- They trigger dereference of object type procedures
- But there is one unique magic syscall ;)

NtQuerySecurityObject

- Is Not so Secure! :D

```
call    _ObReferenceObjectByHandle@
test    eax, eax
js      short loc_637C7F

mov     edi, [ebp+Object]
movzx   eax, byte ptr [edi-0Ch] ; eax is under control
mov     ecx, _ObTypeIndexTable[eax*4] ; ecx is under control
mov     edx, [ecx+6Ch]
push    dword ptr [ebp+AccessMode]
lea     eax, [ecx+34h]
push    eax
push    dword ptr [ecx+4Ch]
lea     eax, [edi-4]
push    eax
lea     eax, [ebp+Length]
push    eax
push    [ebp+Address]
lea     eax, [ebp+RequestedInformation]
push    eax
xor     esi, esi
inc     esi
push    esi
push    edi
call    edx                ; jump to r0 shellcode/ROP
```

DKOHM Attacks

- ObTypeIndexTable out of bounds access
- ObTypeIndexTable backdoor/magic entry (0xBAD0B0B0)
- DKOM / Object Type Confusion

Object Type Index Table

- kd> dd nt!ObTypeIndexTable L40
- 81a3edc0 **00000000 bad0b0b0** 8499c040 849aa390
- 81a3edd0 84964f70 8499b4c0 84979500 84999618
- 81a3ede0 84974868 849783c8 8499bf70 84970b40
- 81a3edf0 849a8888 84979340 849aaf70 849a6a38
- 81a3ee00 8496df70 8495b040 8498cf70 84930a50
- 81a3ee10 8495af70 8497ff70 84985040 84999e78
- 81a3ee20 84997f70 8496c040 849646e0 84978f70
- 81a3ee30 8497aec0 84972608 849a0040 849a9750
- 81a3ee40 849586d8 84984f70 8499d578 849ab040
- 81a3ee50 84958938 84974a58 84967168 84967098
- 81a3ee60 8496ddd0 849a5140 8497ce40 849aa138
- 81a3ee70 84a6c058 84969c58 8497e720 85c62a28
- 81a3ee80 85c625f0 **00000000 00000000 00000000**

ObTypeIndexTable out of bounds

- Uses non-existent object type
- Prerequisite: **one byte** of overflown data must be in some range
- Triggers Null Pointer Dereference
- Does not work MS13-031(x64) & win8 ☹

MS13-031 security fix

- Woke up on the day of HITB2013AMS talk…

ObTypeIndexTable 0xBAD0B0B0 magic

- Uses magic entry (CIA backdoor from 1994?)
- x86 – spray pool till 0xBAD0B000 Page is allocated(if /3GB(rare) this is in r3!)
- Double Page Fault technique (Intel only)
- x64 0xBAD0B0B0 is extended by **zeroes!!!** Just alloc fake Object Type entry in r3
- **SMAP** will eliminate this technique ☹ (x64)

ObTypeIndexTable 0xBAD0B0B0 magic

- x64:
  - nt!NtQuerySecurityObject+0x89:
  - mov r10,qword ptr [rdx+98h] ds:002b:00000000`bad0b148 userland!!!
- x86:
  - nt!NtQuerySecurityObject+0x80:
  - mov edx,dword ptr [ecx+6Ch] ds:0023:bad0b11c (Paged Pool spray)

Object Type Confusion

- kd> dt nt!_OBJECT_TYPE_INITIALIZER 849a9778
  - +0x044 SecurityProcedure : 0x81b6b085 long **nt!IopGetSetSecurityObject**
- kd> dt nt!_OBJECT_TYPE_INITIALIZER 84967190
  - +0x044 SecurityProcedure : 0x81b6b4c0 long **nt!CmpSecurityMethod**
- kd> dt nt!_OBJECT_TYPE_INITIALIZER 849aa3b8
  - +0x044 SecurityProcedure : 0x81b183c3 long **nt!SeDefaultObjectMethod**

Object Type Confusion / DKOM

- Change Type/Data of Kernel Object
- Redirect execution flow with fake object type/data
- Achieve write4 primitive or hijack of execution flow
- Prerequisite: precise control over overflown data ☹

Feedback from oldskul l33t

grsecurity
@grsecurity

Читать

Funny that people in Windows exploitation are just now catching on about "useful" magic values and corrupting the data of adjacent heap objs

Ответить Ретвитнуть В избранное Ещё

Debate with oldskul l33t

Nikita Tarakanov @NTarakanov 13 апреля
@grsecurity Why it's funny?
Подробнее

grsecurity @grsecurity 13 апреля
@NTarakanov Regardless of novelty, it's funny how these things come back around years later. Useful magics were generally addressed in 2008
Подробнее

Nikita Tarakanov @NTarakanov 13 апреля
@grsecurity 0xBAD0B0B0 magic value was implemented in 1994 :) Any info about talks/papers in 2008 about magics?
Подробнее

grsecurity @grsecurity 13 апреля
@NTarakanov Grep any PaX/grsec patch around that time for LIST_POISON etc, but let me find some more mentions
Подробнее

grsecurity @grsecurity 13 апреля
@NTarakanov @subreption tried to upstream some of the changes in 2009: mentby.com/larry-h/patch-...
Подробнее

grsecurity @grsecurity 13 апреля
@NTarakanov Was also mentioned in @subreption's 2009 Phrack 66 paper on KERNHEAP ("The values used for list pointer poisoning [...]")
Подробнее

Debate with oldskul l33t

Nikita Tarakanov @NTarakanov 13 апреля
@grsecurity @subreption I see. Port grsecurity to windows blue! :P
Подробнее

grsecurity @grsecurity 13 апреля
@NTarakanov Well the point is more that it doesn't pay to be willfully ignorant about research just because it's for another OS
Подробнее

grsecurity @grsecurity 13 апреля
@NTarakanov There are far more similarities than differences in security lessons to be learned and methods to fix them
Подробнее

Nikita Tarakanov @NTarakanov 13 апреля
@grsecurity agree!
Подробнее

grsecurity @grsecurity 13 апреля
@NTarakanov It's the same reason why I read your paper, for instance ;)
Подробнее

Conclusions

- 2013, but still generic techniques DO exist
- Windows kernel does not protect Object Manager / kernel object headers at all
- MS should implement cookie in object header
- SMAP(Windows 8.1/9?) will eliminate some techniques ☹ (0xBAD0B0B0 on x64)
- Anyway, we will be pwning Windows Kernel Pool Corruptions

Q&A

- @NTarakanov

References

- SoBelt X’con 2005
- Kostya Kortchinsky SyScan 2008
- Tarjei Mandt BH DC 2011
- Tarjei Mandt BH US 2012
- Zhenhua 'Eric' Liu NoSuchCon 2013
- Must read: j00ru’s work on windows kernel objects