Bypass Control Flow Guard Comprehensively

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Agenda

- Overview
- CFG Internals
- Attack Surface
- Universal Bypass
- Fix for the Issue

Who am I

- From Beijing, China
- Researcher of NSFOCUS Security Team
- Focus on exploit detection and prevention

Overview

- Control Flow Guard
  - Mitigation that prevent redirecting control flow to unexpected location
  - First introduced in Windows8.1 Preview
  - Disabled in Windows 8.1 RTM for compatibility
  - Enabled in Windows 10 Technical Preview and Windows 8.1 Update

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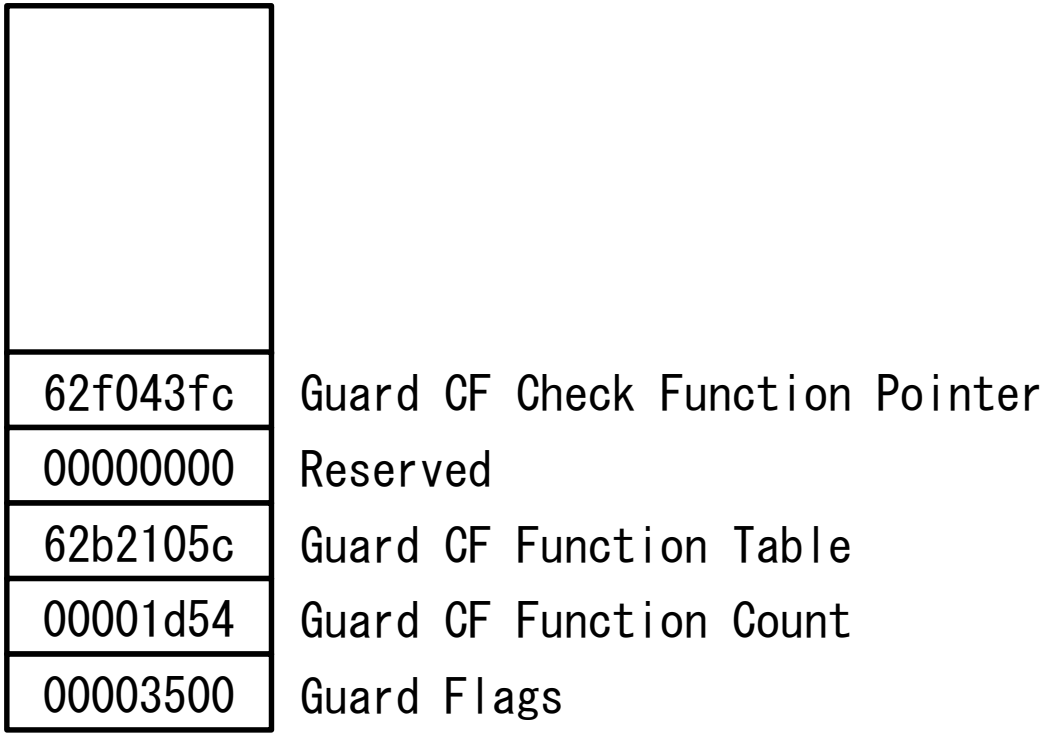
Compile Stage

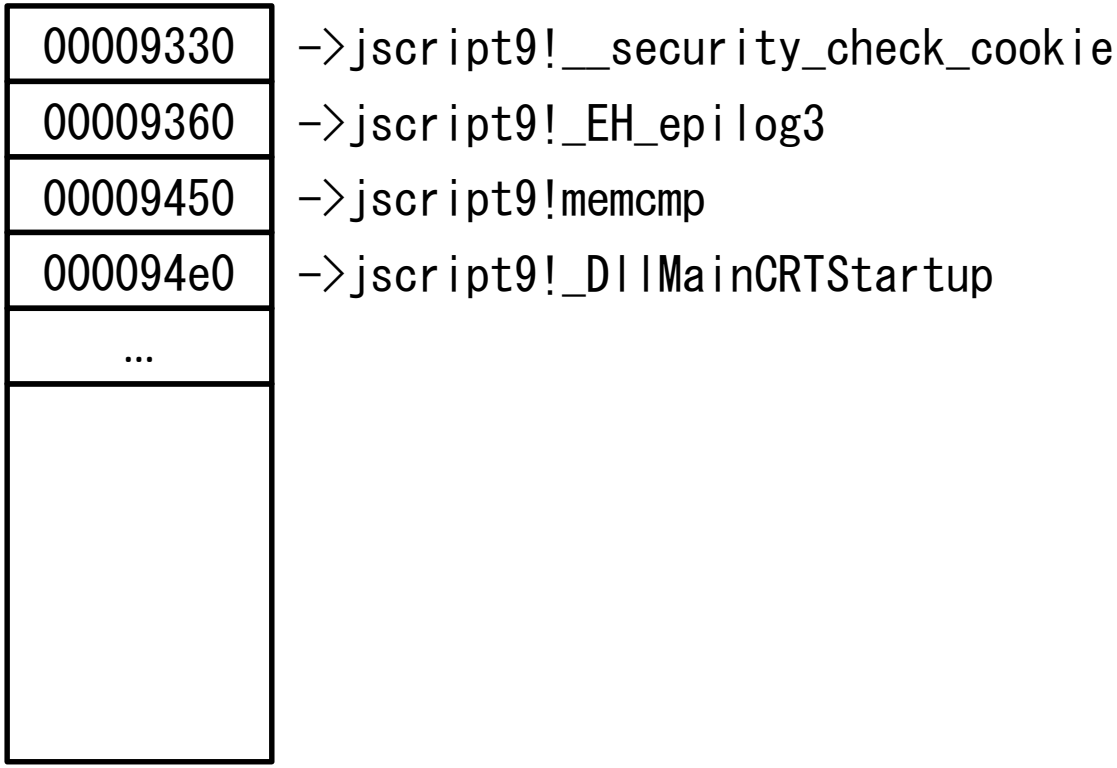
- Append 5 Load Configuration Table entries

Load Configuration Table



Compile Stage

Guard CF Function Table



Compile Stage

- Inject a check to ensure that target address is valid

```
mov     eax,dword ptr [ebx]
mov     ecx,ebx
call    dword ptr [eax+7Ch]
```

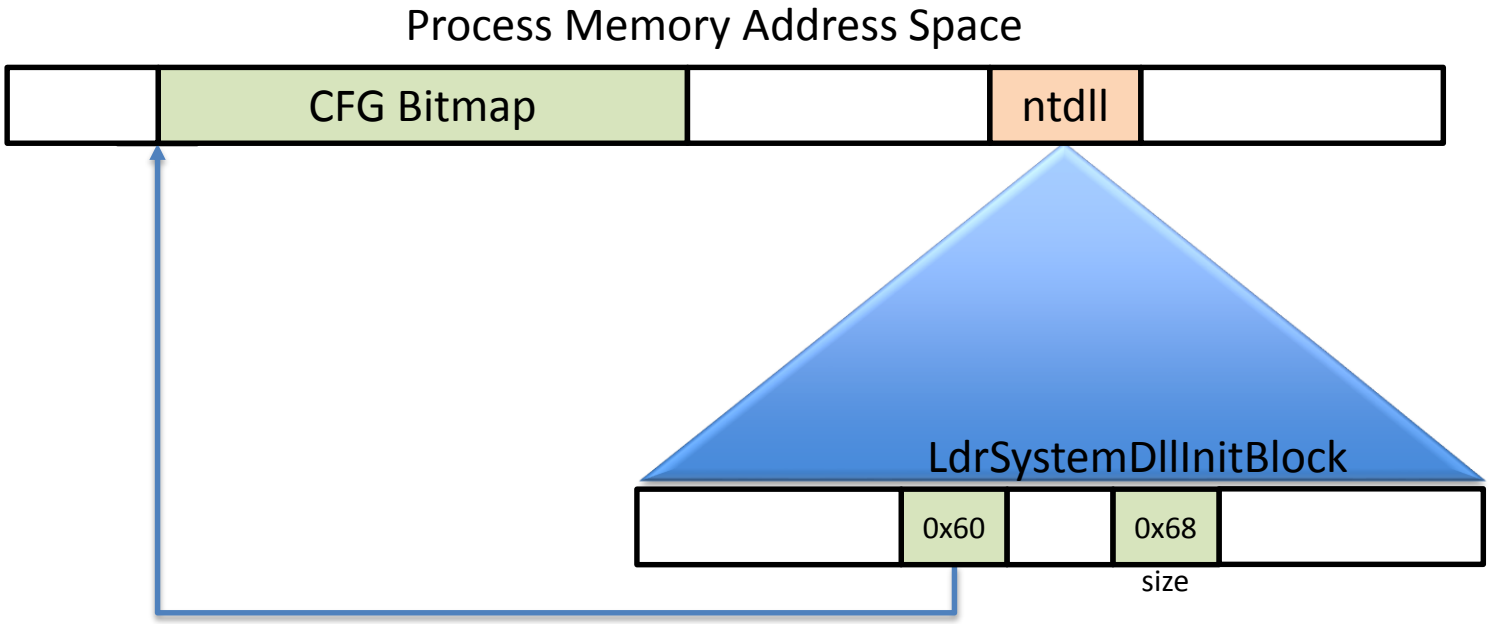
Compile Stage

- Inject a check to ensure that target address is valid

```
mov     eax,dword ptr [ebx]
mov     esi,dword ptr [eax+7Ch]
mov     ecx,esi
call    dword ptr [jscript9!__guard_check_icall_fptr (651743fc)]
mov     ecx,ebx
call    esi
```

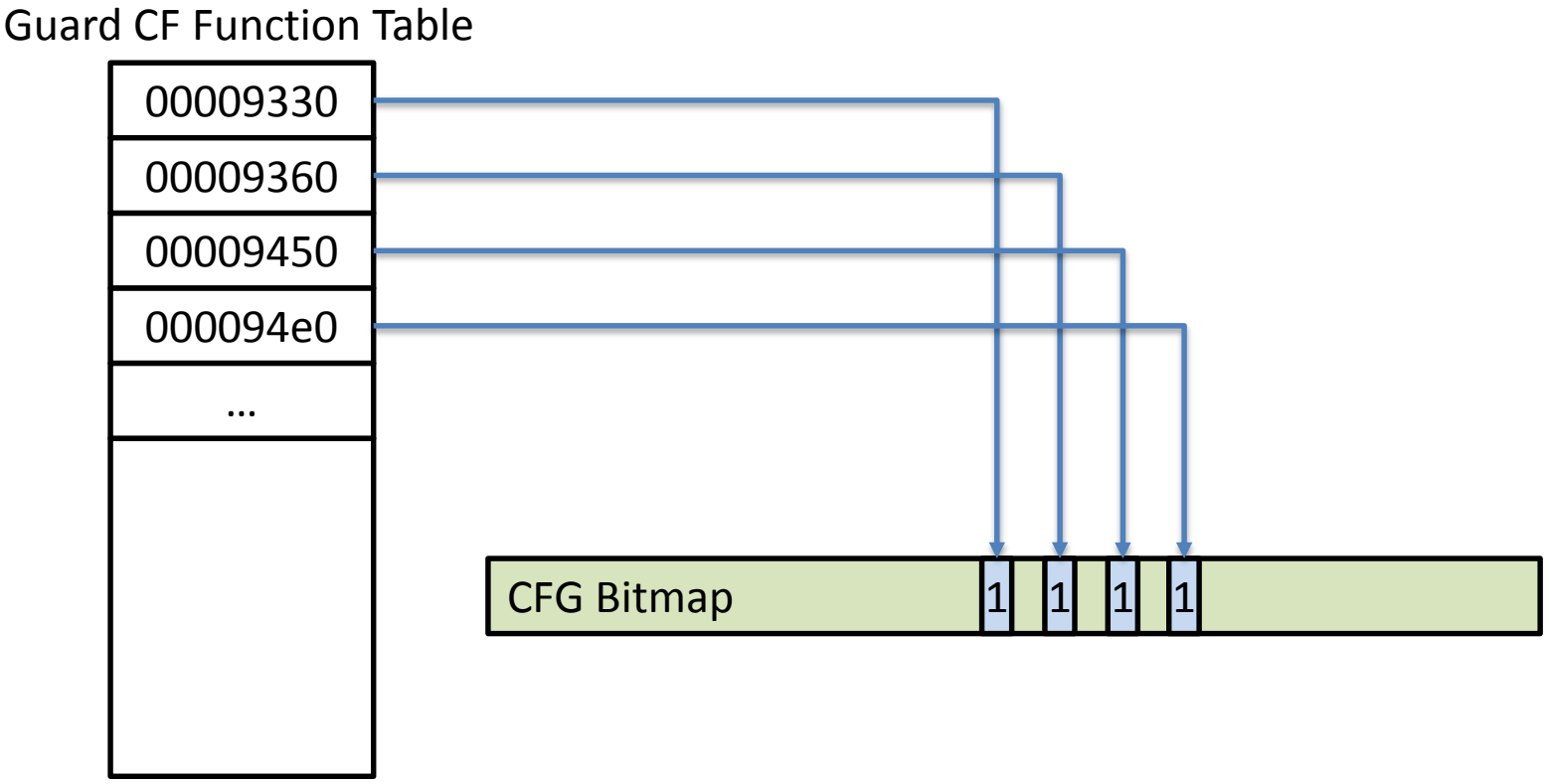
Load Stage

- CFG Bitmap
  - Track all valid target address
  - Mapped into process memory address space



Load Stage

- Update the CFG Bitmap



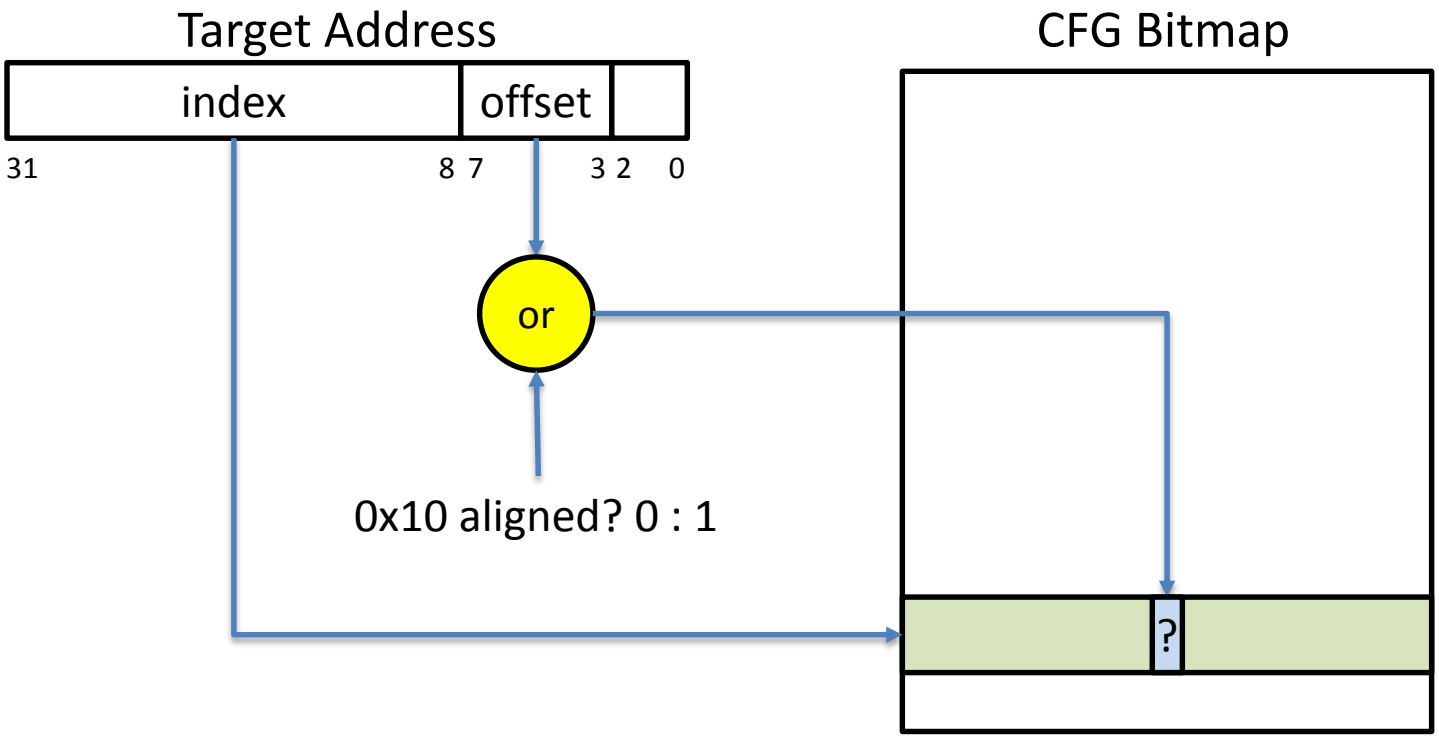
Load Stage

- Update the check function pointer

```
0:017> dds jscript9!__guard_check_icall_fptr l1
62f043fc  77acd970 ntdll!LdrpValidateUserCallTarget
```

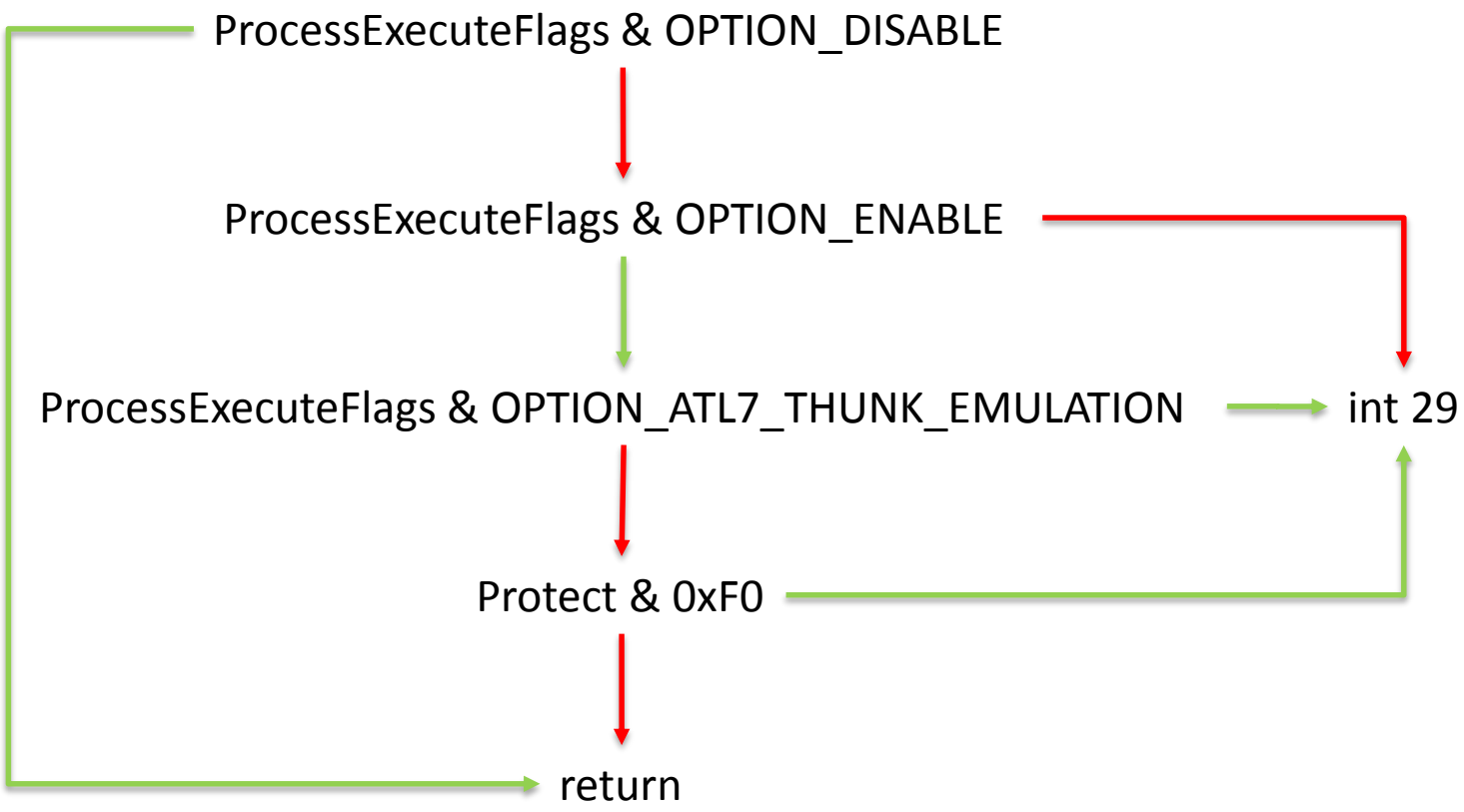
Runtime

- ntdll!LdrpValidateUserCallTarget



Runtime

- ntdll!RtlpHandleInvalidUserCallTarget



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Attack Surface

- Non-CFG Module
- JIT Generated Code
- Indirect Jump
- Return Address
- Valid API Function

Non-CFG Module

- Contain unprotected indirect call

```
0:006> u slc!SLConsumeWindowsRight+0xe3
slc!SLConsumeWindowsRight+0xe3:
73127463 8b06            mov     eax,dword ptr [esi]
73127465 56              push    esi
73127466 ff5008          call    dword ptr [eax+8]
```

Non-CFG Module

- All bits in the CFG Bitmap are set

```
0:006> lmm slc
start    end        module name
73110000 73138000   slc        (deferred)
0:006> dd poi(ntdll!LdrSystemDllInitBlock+0x60) + 731100 * 4
025e4400  ffffffff ffffffff ffffffff ffffffff
025e4410  ffffffff ffffffff ffffffff ffffffff
025e4420  ffffffff ffffffff ffffffff ffffffff
025e4430  ffffffff ffffffff ffffffff ffffffff
025e4440  ffffffff ffffffff ffffffff ffffffff
025e4450  ffffffff ffffffff ffffffff ffffffff
025e4460  ffffffff ffffffff ffffffff ffffffff
025e4470  ffffffff ffffffff ffffffff ffffffff
```

Non-CFG Module

- Will exhaust eventually
  - Vendors trend to compile new modules with CFG enable

JIT Generated Code

- Just like a non-CFG module
  - Contain unprotected indirect call
  - All bits in the CFG Bitmap are set

JIT Generated Code

- Both are no longer the case in Edge
  - JIT code is instrumented
  - JIT code pages don't have all bits set

Indirect Jump

- Redirect control flow like indirect call

```
jscript9!NativeCodeGenerator::CheckCodeGenThunk:
62b3c5e2 55              push    ebp
62b3c5e3 8bec            mov     ebp,esp
62b3c5e5 ff742408        push    dword ptr [esp+8]
62b3c5e9 e812ffffff      call    jscript9!NativeCodeGenerator::CheckCodeGen
62b3c5ee 5d              pop     ebp
62b3c5ef ffe0            jmp     eax
```

Indirect Jump

- Protect using the same mechanism as indirect call

```
chakra!NativeCodeGenerator::CheckCodeGenThunk:
621b4020 55              push    ebp
621b4021 8bec            mov     ebp,esp
621b4023 ff742408        push    dword ptr [esp+8]
621b4027 e8c4b4f6ff      call    chakra!NativeCodeGenerator::CheckCodeGen
621b402c 50              push    eax
621b402d 8bc8            mov     ecx,eax
621b402f ff1504154f62    call    dword ptr [chakra!__guard_check_icall_fptr]
621b4035 58              pop     eax
621b4036 5d              pop     ebp
621b4037 ffe0            jmp     eax
```

Return Address

- Overwrite return address
  - Locate the stack
  - Search the stack for an appropriate frame
  - Replace the stack frame with crafted one

Valid API Function

- ntdll!NtContinue
- KERNELBASE!SetThreadContext
- msvcrt!longjmp
- KERNEL32!WinExec
- SHELL32!ShellExecuteExA
- KERNEL32!LoadLibraryA

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Objective

- ☐ Bypass CFG Comprehensively

Guard CF Check Function

- Called through Guard CF Check Function Pointer

```
62c31e18 8b707c          mov     esi,dword ptr [eax+7Ch]
62c31e1b 8bce            mov     ecx,esi
62c31e1d ff15fc43f062    call    dword ptr [jscript9!__guard_check_icall_fptr]
```

Guard CF Check Function

- Behavior when target address is valid

```
mov     edx,dword ptr [ntdll!LdrSystemDllInitBlock+0x60 (7753e170)]
mov     eax,ecx
shr     eax,8
mov     edx,dword ptr [edx+eax*4]
mov     eax,ecx
shr     eax,3
test    cl,0Fh
jne     ntdll!LdrpValidateUserCallTargetBitMapRet+0x1 (774bd98e)
bt      edx,eax
jae     ntdll!LdrpValidateUserCallTargetBitMapRet+0xa (774bd997)
ret
```

Objective

- ☐ Overwrite Guard CF Check Function Pointer
- ☐ Bypass CFG Comprehensively

Overwrite Guard CF Check Function Pointer

Objective

- ☐ Make Read-only Memory Writeable
- ☐ Overwrite Guard CF Check Function Pointer
- ☐ Bypass CFG Comprehensively

CustomHeap::Heap

```
+0x000  HeapPageAllocator        :    PageAllocator
+0x060  HeapArenaAllocator       :    Ptr32 ArenaAllocator
+0x064  PartialPageBuckets       :    [7] DListBase<CustomHeap::Page>
+0x09c  FullPageBuckets          :    [7] DListBase<CustomHeap::Page>
+0x0d4  LargeObjects             :    DListBase<CustomHeap::Page>
+0x0dc  DecommittedBuckets       :    DListBase<CustomHeap::Page>
+0x0e4  DecommittedLargeObjects  :    DListBase<CustomHeap::Page>
+0x0ec  CriticalSection          :    LPCRITICAL_SECTION
```

Destructor Behavior

- CustomHeap::Heap::~Heap
  - CustomHeap::Heap::FreeAll
    - CustomHeap::Heap::FreeBucket
      - CustomHeap::Heap::EnsurePageReadWrite<1,4>
        - VirtualProtect(address, 0x1000, 0x4, &flOldProtect)

Locate CustomHeap::Heap

- CustomHeap::Heap is a member of InterpreterThunkEmitter at offset 0xC

```
0:018> dd 0441d380 l4
0441d380  00000000 0c6cdd28 00000000 679521d8
0:018> dds 0441d380 + c l1
0441d38c  679521d8 jscript9!HeapPageAllocator::`vftable'
```

Locate CustomHeap::Heap

- InterpreterThunkEmitter is pointed by a member of Js::ScriptContext at offset 0x4b0

```
0:018> dd 0c6cdb80 + 4b0 l4
0c6ce030  0441d380 0c66e860 00000000 00000000
```

Locate CustomHeap::Heap

- Js::ScriptContext is pointed by a member of ScriptEngine at offset 0x4

```
0:018> dds 0441d138 l1
0441d138  6794a5f4 jscript9!ScriptEngine::`vftable'
0:018> dd 0441d138 l4
0441d138  6794a5f4 0c6cdb80 00000009 043591a8
```

Locate CustomHeap::Heap

- ScriptEngine is pointed by a member of ScriptSite at offset 0x4

```
0:018> dd 0c629d18 l4
0c629d18  00000003 0441d138 0441d138 00000000
```

Decommit Issue

- All Buckets are empty when destructor is called
  - All CustomHeap::Page are decommitted in Js::ScriptContext::Close
  - Decommitted CustomHeap::Page is removed from Bucket
  - Js::ScriptContext::Close is called before CustomHeap::Heap::~Heap

Decommit Issue

- Resolution
  - Insert a fake CustomHeap::Page into Bucket
  - Prevent a CustomHeap::Page from being decommitted

Objective

- ☑ Make Read-only Memory Writeable
- ☑ Overwrite Guard CF Check Function Pointer
- ☑ Bypass CFG Comprehensively

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Timeline

- Jan 22 2015: Report to MSRC
- Jan 30 2015: Confirmed
- Mar 10 2015: Patch Released

HeapPageAllocator::ProtectPages

- Wrapper of VirtualProtect
- Check before call VirtualProtect
  - lpAddress is 0x1000 aligned
  - lpAddress >= Segment address
  - lpAddress + dwSize <= Segment address + Segment size
  - dwSize <= RegionSize
  - Protect == Expected Protect

EnsurePageReadWrite<1,4>

- Call HeapPageAllocator:: ProtectPages instead of VirtualProtect
- Expected Protect is PAGE_EXECUTE

Black Hat Sound Bytes

- No Silver Bullet
- Read-only ≠ Secure
- Control the Data Control the Execute


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