Shellcodes Are for the 99%

Bing Sun, Sr. Security Researcher @ McAfee
Stanley Zhu, Sr. Security Researcher @ Didi Chuxing
Chong Xu, Sr. Director @ McAfee

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Abstract

- Today most memory vulnerability exploits execute their second-stage exploit or final payload either by creating an executable memory page with shellcode or by loading a third-party executable module. However, as the new exploitation mitigation features ACG (Arbitrary Code Guard) and CIG (Code Integrity Guard) are introduced to high-risk applications on modern operating systems (for example, Microsoft Edge on Windows 10 x64), current memory vulnerability exploitation methods that rely on executing customized code will no longer function. As a result, a code-reuse attack (such as ROP, COOP, etc.) seems to be the only option that can survive these new mitigations. The main drawback of a code-reuse attack, however, lies in its limited flexibility and extensibility. Due to these limitations, it is extremely difficult to implement complex logic, such as multithreading, with pure code reuse. As a countermeasure to the new mitigation, we propose a new browser exploitation framework that leverages and extends JavaScript to complete tasks that would otherwise need to be done by native code. With this framework, we can basically achieve almost anything that native code can do. Moreover, unlike previous works that abuse JavaScript, such as "JS god mode" or "interdimensional execution," our new technique covers the whole exploitation kill chain (from initial RCE to EoP stage to final payload), without using any native code. In this talk, we will discuss various challenges of implementing this new exploitation framework in detail. In the demo section, we will present some examples that show how this new exploitation framework can be easily adopted in real-world exploitation scenarios.

About the Speakers

- Bing Sun is a senior security researcher. He leads the IPS security research team of McAfee. He has extensive experiences in operating system low-level and information security technique R&D, with especially deep diving in advanced vulnerability exploitation and detection, rootkits detection, firmware security, and virtualization technology. Bing is a regular speaker at international security conference such as XCon, Black Hat, and CanSecWest.

- Stanley Zhu is a security researcher of Didi Chuxing. A designer of the Bytehero Heuristic Detection Engine, he provided the BDV engine with VirusTotal and OPSWAT platform. He has many years of experience in information security techniques research and is interested in advanced vulnerability exploitation and detection, virus and rootkits reverse engineering. He has spoken at security conferences such as CanSecWest2014, AVAR2012, XCon2010, XCon2015, and XCon2016.

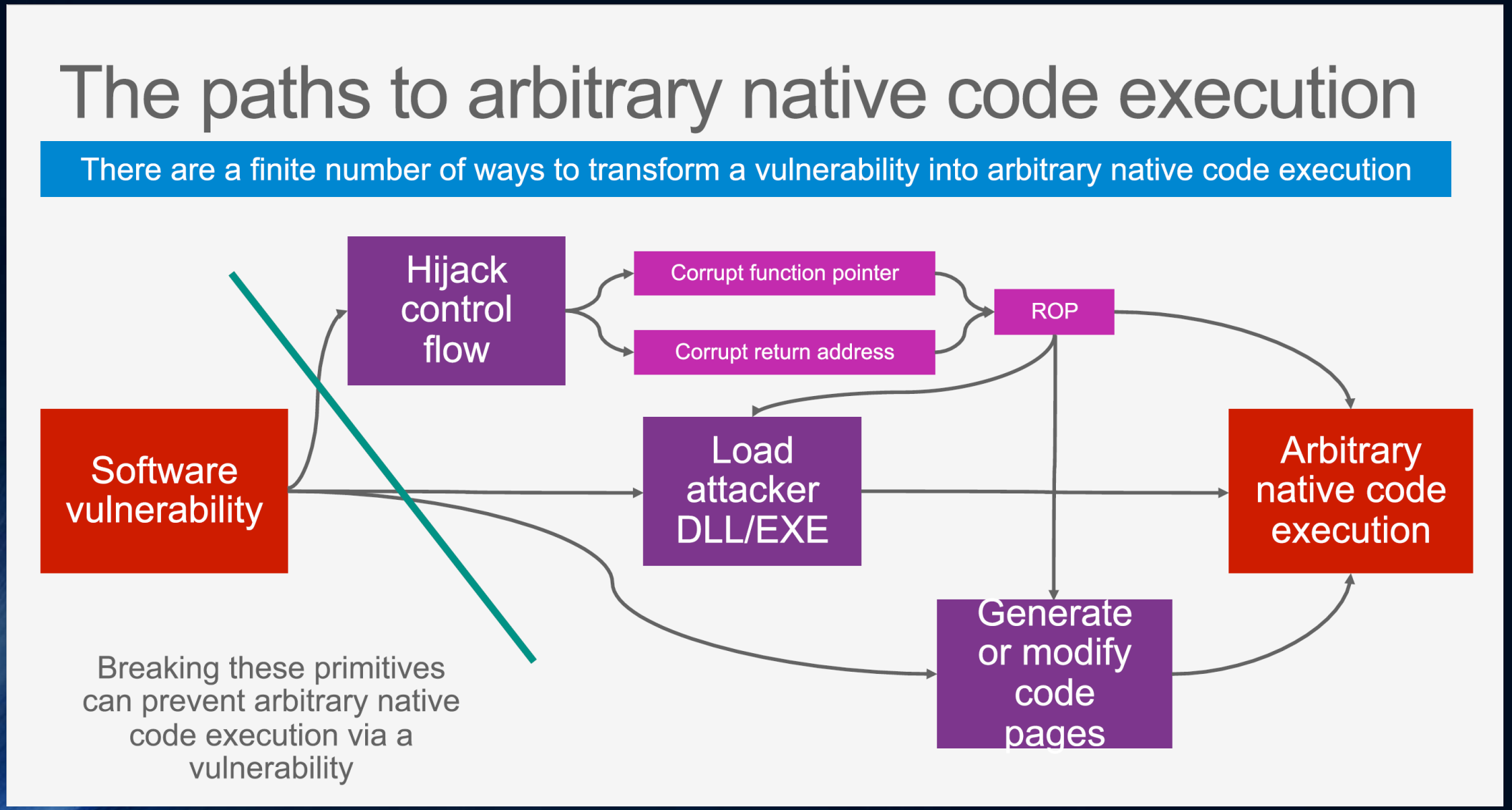
- Chong Xu received his Ph.D. degree in networking and security from Duke University. His current focus includes research and innovation on intrusion and prevention techniques as well as threat intelligence. He is a senior director of the McAfee IPS team, which leads McAfee vulnerability research, malware and APT detection, and botnet detection. The team feeds security content and innovative protection solutions into McAfee's network IPS, host IPS, and sandbox products, as well as McAfee Global Threat Intelligence (GTI).

Agenda

1. An Overview of Microsoft Exploitation Mitigation Features and Bypasses
2. A JavaScript-Based Browser Exploitation Framework
3. Demo
4. Conclusion
5. Q&A

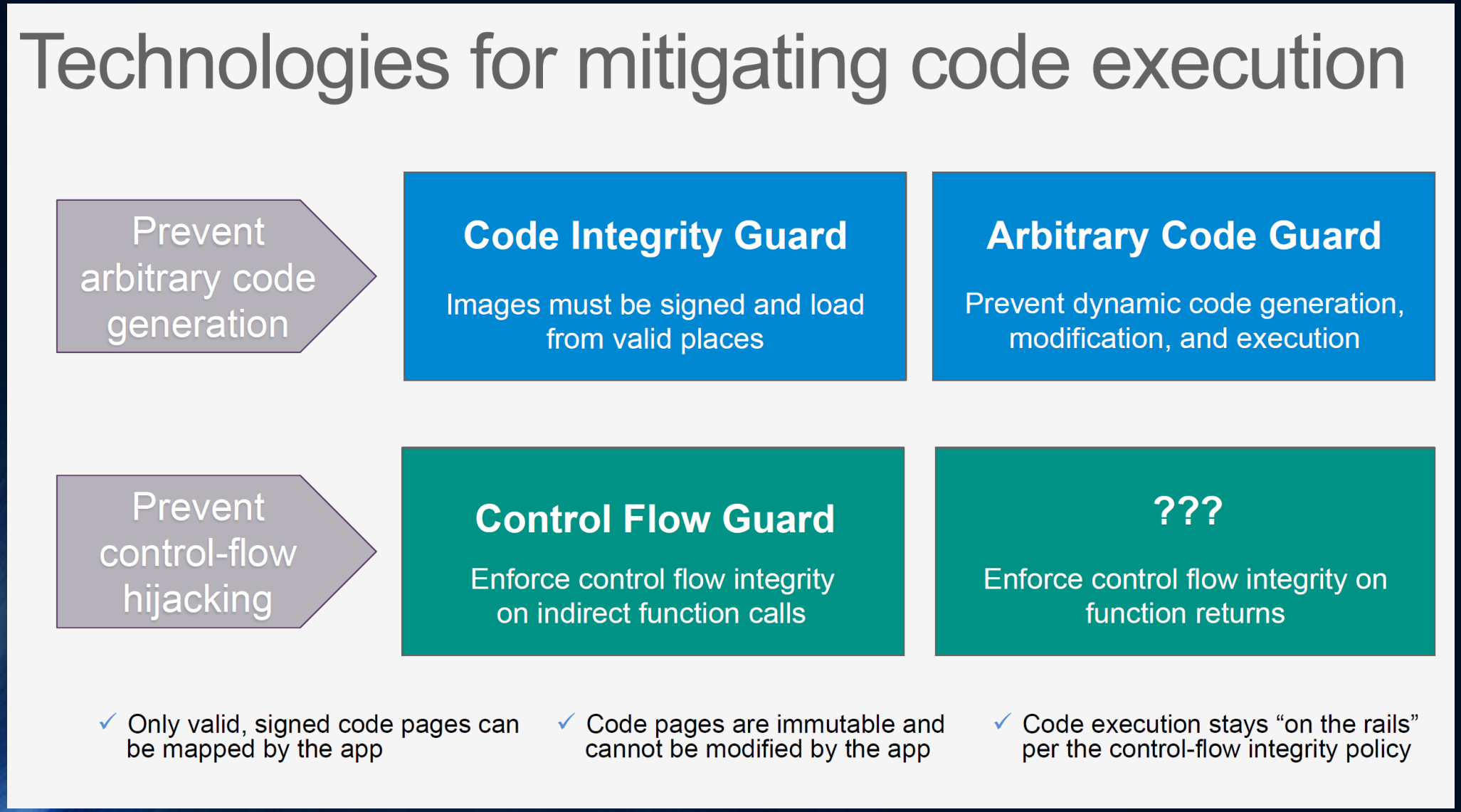
1. An Overview of Microsoft Exploitation Mitigation Features and Bypasses

Paths to Achieve Native Code Execution



From <<Microsoft's strategy and technology improvements for mitigating native remote code execution>> - Matt Miller, David Weston

Microsoft's Technologies for Mitigating Code Execution



From <<Microsoft's strategy and technology improvements for mitigating native remote code execution>> - Matt Miller, David Weston

ACG (Arbitrary Code Guard)

- ACG prevents a process from generating dynamic code or modifying existing executable code, and is configured via ProcessDynamicCodePolicy
- Two W^X policies:
  - ✓Existing code pages cannot be made writable
  - ✓New, unsigned code pages cannot be created
- Enforced in all kernel functions that deal with memory protection:
  - ✓NtProtectVirtualMemory, NtAllocateVirtualMemory, NtMapViewOfSection, etc.

CIG (Code Integrity Guard)

- CIG prevents a process from loading unsigned images, and is configured via ProcessSignaturePolicy
- Enforced in the kernel function that creates the section object for the image (NtCreateSection)
- In addition to ProcessSignaturePolicy, another mitigation policy ProcessImageLoadPolicy (NoRemoteImages, NoLowMandatoryLabelImages) and a process creation attribute (CHILD_PROCESS_POLICY) are used to prevent loading untrusted images.

CFG (Control Flow Guard)

- CFG prevents an exploit from hijacking the program's control flow, and is configured via ProcessControlFlowGuardPolicy
- The call target check is enforced at each indirect control transfer instruction (call and jmp). The check is performed by routines in ntdll.dll (LdrpValidateUserCallTarget, LdrpDispatchUserCallTarget etc).
- CFG does not protect control transfers via "ret" that are expected to be addressed by a hardware-based solution (such as Intel CET, etc.)

Mitigation Policy and Representation in EPROCESS

```
kd> dt nt!_EPROCESS
   ...
   +0x300 Flags2           : Uint4B
   ...
   +0x300 DisableDynamicCode : Pos 10, 1 Bit
   ...
   +0x304 Flags            : Uint4B
   ...
   +0x304 ControlFlowGuardEnabled : Pos 4, 1 Bit
   ...
   +0x6cc Flags3           : Uint4B
   ...
   +0x6cc ProhibitRemoteImageMap : Pos 11, 1 Bit
   +0x6cc ProhibitLowILImageMap : Pos 12, 1 Bit
   +0x6cc SignatureMitigationOptIn : Pos 13, 1 Bit
   +0x6cc DisableDynamicCodeAllowOptOut : Pos 14, 1 Bit
   ...
   +0x6cc PreferSystem32Images : Pos 17, 1 Bit
   ...
   +0x6cc DisableDynamicCodeAllowRemoteDowngrade : Pos 23, 1 Bit
   ...
   +0x6cc ControlFlowGuardExportSuppressionEnabled : Pos 26, 1 Bit
   ...
   +0x6cc ControlFlowGuardStrict : Pos 29, 1 Bit
   ...
   +0x810 Flags4           : Uint4B
   ...
   +0x810 RestrictSetThreadContext : Pos 1, 1 Bit
```

```
PS C:\Users\bing> Get-ProcessMitigation -Id 1672

ProcessName: MicrosoftEdgeCP
Source     : Running Process
Id         : 1672

DEP:
    Enable                            : on
    Disable ATL                       : off

ASLR:
    BottomUp                          : on
    ForceRelocate                     : on
    HighEntropy                       : on
    DisallowStripped                  : off

StrictHandle:
    RaiseExceptionOnInvalid           : on
    HandleExceptionsPermanently       : on

System Call:
    DisallowWin32kSysCalls            : off

ExtensionPoint:
    DisableExtensionPoints            : off

DynamicCode:
    ProhibitDynamicCode               : on
    AllowThreadOpt                    : on
    AllowRemoteDowngrade              : off

CFG:
    EnableCFG                         : on
    EnableExportSuppression           : off
    StrictMode                        : off

BinarySignature:
    MicrosoftSignedOnly               : off
    StoreSignedOnly                   : on
    MitigationOptIn                   : off

FontDisable:
    DisableNonSystemFonts             : off
    AuditNonSystemFontLoading         : off

ImageLoad:
    NoRemoteImages                    : on
    NoLowMandatoryLabelImages         : off
    PreferSystem32Images              : off
```

Achieving Arbitrary Code Execution With ACG+CIG+CFG All in Place

- ACG and CIG together ensure only trusted code can be executed. They are enforced in kernel mode, so instead of attacking them directly, we choose to circumvent them.
- CFG does a good job in stopping most code-reuse attacks through control-flow hijacking (ROP etc.). However, because CFG is a coarse-grained CFI implementation and the check itself is primarily enforced in user mode, it is subjected to various bypasses.
- Once CFG is breached, we have two options to achieve arbitrary code execution:
  - ROP only
  - Interactive runtime (such as a script engine) + minimal ROP (if needed)

Option I: ROP Only

- Constructing the second-stage exploit or the final payload with ROP-only shellcode is possible, but could be very painful
- Example: The first ROP-Only, Sandbox-Escaping PDF Exploit (CVE-2013-0641).
- Pros:
  - ✓ The native code has direct access to the memory space and system APIs
- Cons:
  - ✓ It is not always possible to find suitable ROP gadgets
  - ✓ It is difficult to implement complex logic
  - ✓ The code is platform and version specific, thus not easy to maintain

Option II: Interactive Runtime + Minimal ROP

- By leveraging and extending the capability of scripting with interactive runtime, we can create a script-based exploit/payload that can achieve almost anything that its native code counterpart can do
- Pros:
  - ✓ It is convenient to implement complex logic with a high-level language
  - ✓ The script-based code is human readable and portable
- Cons:
  - ✓ The data type and execution mechanism of script language are not compatible with that of native code
  - ✓ The script language has some restrictions that are imposed by its script engine
  - ✓ The script language is, by design, not granted the full access to the underlying operating system

2. A JavaScript-Based Browser Exploitation Framework (Microsoft Edge)

Leveraging Chakra JS Engine in Edge to Achieve Arbitrary Code Execution

- The Chakra JS engine in Edge provides a strong scripting environment that allows us to implement complex logic with JavaScript
- However, to achieve arbitrary code execution (go beyond the JS VM), there are some challenges to overcome:
  - ✓ Limited data type
  - ✓ Call system APIs (JS -> native code)
  - ✓ Multithreading and thread communication
  - ✓ Callback mechanism (native code -> JS)

Limited Data Type

- JavaScript has no true 64-bit integer
  - ✓ Max safe value is 2^{53}-1, bitwise operators deal only with 2^{32} integer values
  - ✓ long.js
- JavaScript does not have the concept of pointer and & operator
  - ✓ Modern exploits can convert a memory vulnerability to the primitives of AAR/AAW and addressOf (leaking the address of any JS object)
  - ✓ Mitigation bounty toolkit by @mxatone (Thomas Garnier)
- JavaScript does not support complex byte structure (such as C-style)
  - ✓ Not a big problem if working with AAR/AAW and addressOf primitives
  - ✓ jsStruct

Calling System APIs

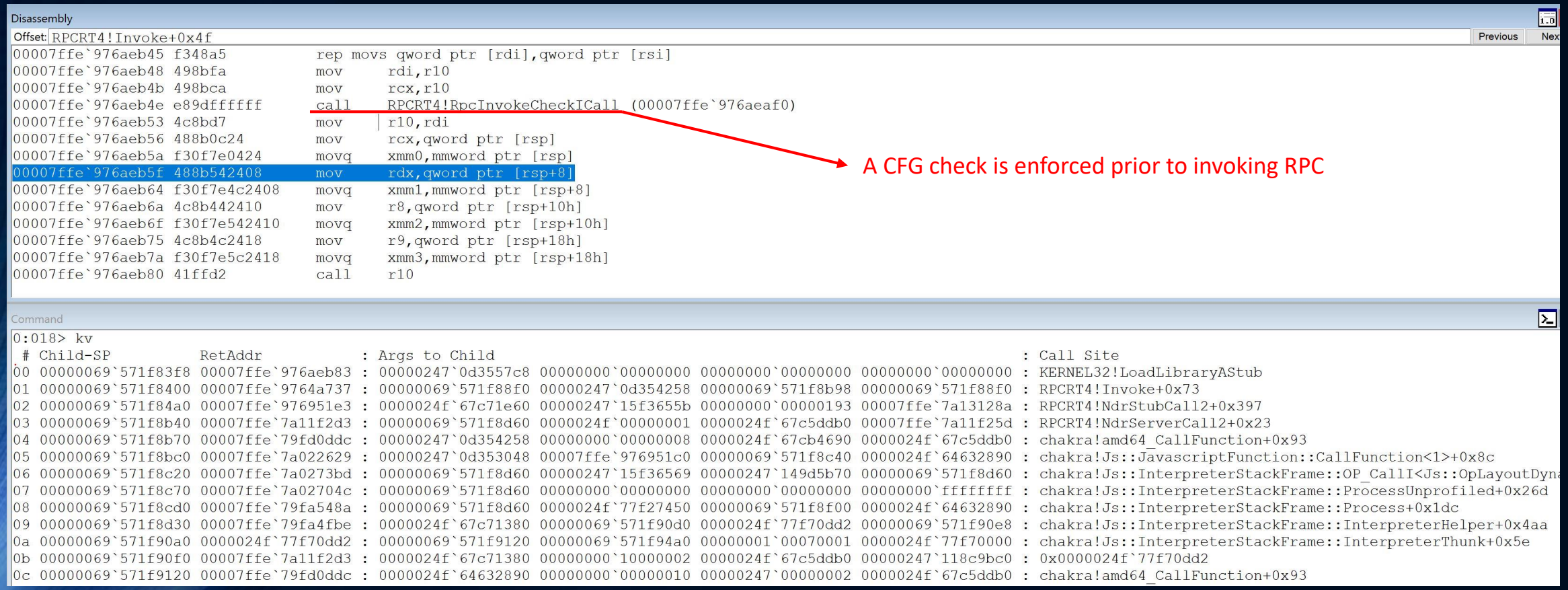
- Call function from JS layer with the ability of controlling all arguments and obtaining the return value
  - ✓ << Mitigation bounty—From read-write anywhere to controllable calls >>
  - ✓ The target function needs to be a valid CFG target
- If CFG is bypassed, the same goal can be accomplished using the code-reuse technique
  - ✓ An ROP gadget chain sets up arguments, transfers control to the target function, and retrieves the return value
  - ✓ Certain existing functions can complete the above operation (such as Js::JavascriptFunction::CallAsmJsFunction<int> in WIP 17101)

Js::JavascriptFunction::CallAsmJsFunction<int>

```
.text:0000000180280AC0 __int64___fastcall_Js__JavascriptFunction__CallAsmJsFunction_int__Js__this_ proc near
.text:0000000180280AC0                                         ; CODE XREF: j_Js__JavascriptFunction__CallAsmJsFunction↑j
.text:0000000180280AC0                                         ; j_Js__JavascriptFunction__CallAsmJsFunction_0↑j ...
.text:0000000180280AC0
.text:0000000180280AC0 var_s0          = qword ptr  0
.text:0000000180280AC0 arg_0           = qword ptr  20h
.text:0000000180280AC0 arg_8           = qword ptr  28h
.text:0000000180280AC0 arg_10          = qword ptr  30h
.text:0000000180280AC0 arg_18          = qword ptr  38h
.text:0000000180280AC0 arg_20          = qword ptr  40h
.text:0000000180280AC0
.text:0000000180280AC0                 mov     [rsp-18h+arg_0], rcx
.text:0000000180280AC5                 mov     [rsp-18h+arg_8], rdx
.text:0000000180280ACA                 mov     [rsp-18h+arg_10], r8
.text:0000000180280ACF                 mov     [rsp-18h+arg_18], r9
.text:0000000180280AD4                 push    rsi
.text:0000000180280AD5                 push    rdi
.text:0000000180280AD6                 push    rbp
.text:0000000180280AD7                 mov     rbp, rsp
.text:0000000180280ADA                 and     rsp, 0FFFFFFFFFFFFFFF0h
.text:0000000180280ADE                 lea     rax, [r9+10h]
.text:0000000180280AE2                 cmp     rax, 2000h
.text:0000000180280AE8                 jl      short loc_180280AEF
.text:0000000180280AEA                 call    __alloca_probe
.text:0000000180280AEF
.text:0000000180280AEF loc_180280AEF:                          ; CODE XREF: __int64___fastcall_Js__JavascriptFunction__CallAsmJsFunction_int__Js__this_+28↑j
.text:0000000180280AEF                 sub     rsp, rax
.text:0000000180280AF2                 mov     [r8], rcx
.text:0000000180280AF5                 mov     rcx, rax
.text:0000000180280AF8                 shr     rcx, 3
.text:0000000180280AFC                 mov     rsi, r8
.text:0000000180280AFF                 mov     rdi, rsp
.text:0000000180280B02                 rep movsq
.text:0000000180280B05                 mov     rax, rdx
.text:0000000180280B08                 mov     rcx, [rsp+var_s0]
.text:0000000180280B0C                 mov     r10, [rbp+arg_20]
.text:0000000180280B10                 mov     rdx, [r10]
.text:0000000180280B13                 movaps  xmm1, xmmword ptr [r10]
.text:0000000180280B17                 mov     r8, [r10+10h]
.text:0000000180280B1B                 movaps  xmm2, xmmword ptr [r10+10h]
.text:0000000180280B20                 mov     r9, [r10+20h]
.text:0000000180280B24                 movaps  xmm3, xmmword ptr [r10+20h]
.text:0000000180280B29                 call    cs:__guard_dispatch_icall_fptr
.text:0000000180280B2F                 lea     rsp, [rbp+0]
.text:0000000180280B33                 pop     rbp
```

Prepare arguments and call the AsmJs function

Calling Function From JS Layer via RPC Mechanism



Calling Arbitrary System APIs

- Because a CFG check (RPCRT4!InvokeCheckICall) is enforced in the RPCRT4!Invoke function, mxatone's method can call only a CFG-friendly function
- When the CFG check in RPC runtime module (RPCRT4.dll) is completely disarmed, we can call an arbitrary function through RPC
  - ✓ RPCRT4!__guard_check_icall_fptr -> ret
  - ✓ RPCRT4!__guard_dispatch_icall_fptr -> jmp rax
- The fptr of the CFG check routine is in IAT that is write protected, but most CFG bypasses can be exploited to make read-only memory writable (calling VirtualProtect)

Calling Arbitrary Function via RPC Mechanism

Disassembly

Offset: 7ffa`08f67d44 Previous Next

```
00007ffa`08f67d2b 498bca          mov     rcx,r10
00007ffa`08f67d2e e89dffffff      call    RPCRT4!RpcInvokeCheckICall (00007ffa`08f67cd0)
00007ffa`08f67d33 4c8bd7          mov     r10,rdi
00007ffa`08f67d36 488b0c24        mov     rcx,qword ptr [rsp]
00007ffa`08f67d3a f30f7e0424      movq    xmm0,mmword ptr [rsp]
00007ffa`08f67d3f 488b542408      mov     rdx,qword ptr [rsp+8]
00007ffa`08f67d44 f30f7e4c2408    movq    xmm1,mmword ptr [rsp+8]
00007ffa`08f67d4a 4c8b442410      mov     r8,qword ptr [rsp+10h]
00007ffa`08f67d4f f30f7e542410    movq    xmm2,mmword ptr [rsp+10h]
00007ffa`08f67d55 4c8b4c2418      mov     r9,qword ptr [rsp+18h]
00007ffa`08f67d5a f30f7e5c2418    movq    xmm3,mmword ptr [rsp+18h]
00007ffa`08f67d60 41ffd2          call    r10
00007ffa`08f67d63 488b7528        mov     rsi,qword ptr [rbp+28h]
```

Command

```
0:023> u RPCRT4!RpcInvokeCheckICall L2
RPCRT4!RpcInvokeCheckICall:
00007ffa`08f67cd0 4883ec28        sub     rsp,28h
00007ffa`08f67cd4 ff15e6470700    call    qword ptr [RPCRT4!_guard_check_icall_fptr (00007ffa`08fdc4c0)]
0:023> u poi(RPCRT4!_guard_check_icall_fptr) L1
ntdll!LdrQueryModuleInfoLocalLoaderLock32:
00007ffa`096c3c00 c20000          ret     0
0:023> kv
 # Child-SP          RetAddr           : Args to Child                                                   : Call Site
00 000000c0`f2c9c278 00007ffa`08f67d63 : 00000000`001fffff 00000000`00000000 f160c000`00000dcc 00000000`00000000 : KERNELBASE!OpenThread
01 000000c0`f2c9c280 00007ffa`08f2450f : 000000c0`f2c9c480 000000c0`f2c9c770 000002a4`18513258 000000c0`f2c9ca18 : RPCRT4!Invoke+0x73
02 000000c0`f2c9c320 00007ffa`08f2739a : 000000c0`f2c9c9f0 00000000`00000000 000000c0`f2c9ca18 00007ff9`ee6d349a : RPCRT4!NdrStubCall2+0x38f
03 000000c0`f2c9c9c0 00007ff9`ee6d1393 : 000002ac`6921cb90 00007ff9`00000001 000002a4`21d002b0 00007ff9`ee6d131d : RPCRT4!NdrServerCall2+0x1a
04 000000c0`f2c9c9f0 00007ff9`ee59d873 : 000002a4`18513258 00000000`00000008 00000000`00000000 00007ff9`ee460000 : chakra!amd64_CallFunction+0x93
05 000000c0`f2c9ca40 00007ff9`ee5a0490 : 000002a4`18512048 00007ffa`08f27380 000000c0`f2c9cac0 000002ac`3f48d470 : chakra!Js::JavascriptFunction::CallFunction<1>+0x83
06 000000c0`f2c9caa0 00007ff9`ee5a4f35 : 000000c0`f2c9cc10 000002ac`693e7ce7 000002ac`21d00310 000000c0`f2c9cc10 : chakra!Js::InterpreterStackFrame::OP_CallI<Js::OpLayoutDynamicProfil
07 000000c0`f2c9caf0 00007ff9`ee5a4b07 : 000000c0`f2c9cc10 00000000`00000000 00000000`00000000 00000000`00000000 : chakra!Js::InterpreterStackFrame::ProcessUnprofiled+0x315
08 000000c0`f2c9cb80 00007ff9`ee5a8b5e : 000000c0`f2c9cc10 000002ac`693a6be0 000000c0`f2c9cdc0 000000c0`f2c9cf00 : chakra!Js::InterpreterStackFrame::Process+0x1a7
09 000000c0`f2c9cbe0 00007ff9`ee5aa265 : 000002ac`69231440 000000c0`f2c9cf90 000002ac`69410dd2 000000c0`f2c9cfa8 : chakra!Js::InterpreterStackFrame::InterpreterHelper+0x48e
0a 000000c0`f2c9cf60 000002ac`69410dd2 : 000000c0`f2c9cfe0 000000c0`f2c9d380 000002ac`69230a20 000002ac`69410000 : chakra!Js::InterpreterStackFrame::InterpreterThunk+0x55
0b 000000c0`f2c9cfb0 00007ff9`ee6d1393 : 000002ac`69231440 00000000`10000002 000002ac`6921cb90 000002a4`28491260 : 0x000002ac`69410dd2
0c 000000c0`f2c9cfe0 00007ff9`ee59d873 : 000002ac`3f48d470 00000000`00000010 00000000`00000080 00007ff9`ee460000 : chakra!amd64_CallFunction+0x93
```

The CFG check on RPCRT4.dll is disabled

Microsoft Made Great Efforts to Improve CFG

Mitigation	In scope	Out of scope
Control Flow Guard(CFG)	Techniques that make it possible to gain control of the instruction pointer through an indirect call in a process that has enabled CFG.	• Hijacking control flow viare turn address corruption • Bypasses related to limitations of coarse-grained CFI (e.g. calling functions out of context) • Leveraging non-CFG images • Bypasses that rely on modifying or corrupting read-only memory • Bypasses that rely on CONTEXT record corruption • Bypasses that rely on race conditions or exception handling • Bypasses that rely on thread suspension • Instances of missing CFG instrumentation prior to an indirect call

CFG Bypasses Still Effective on RS3/RS4

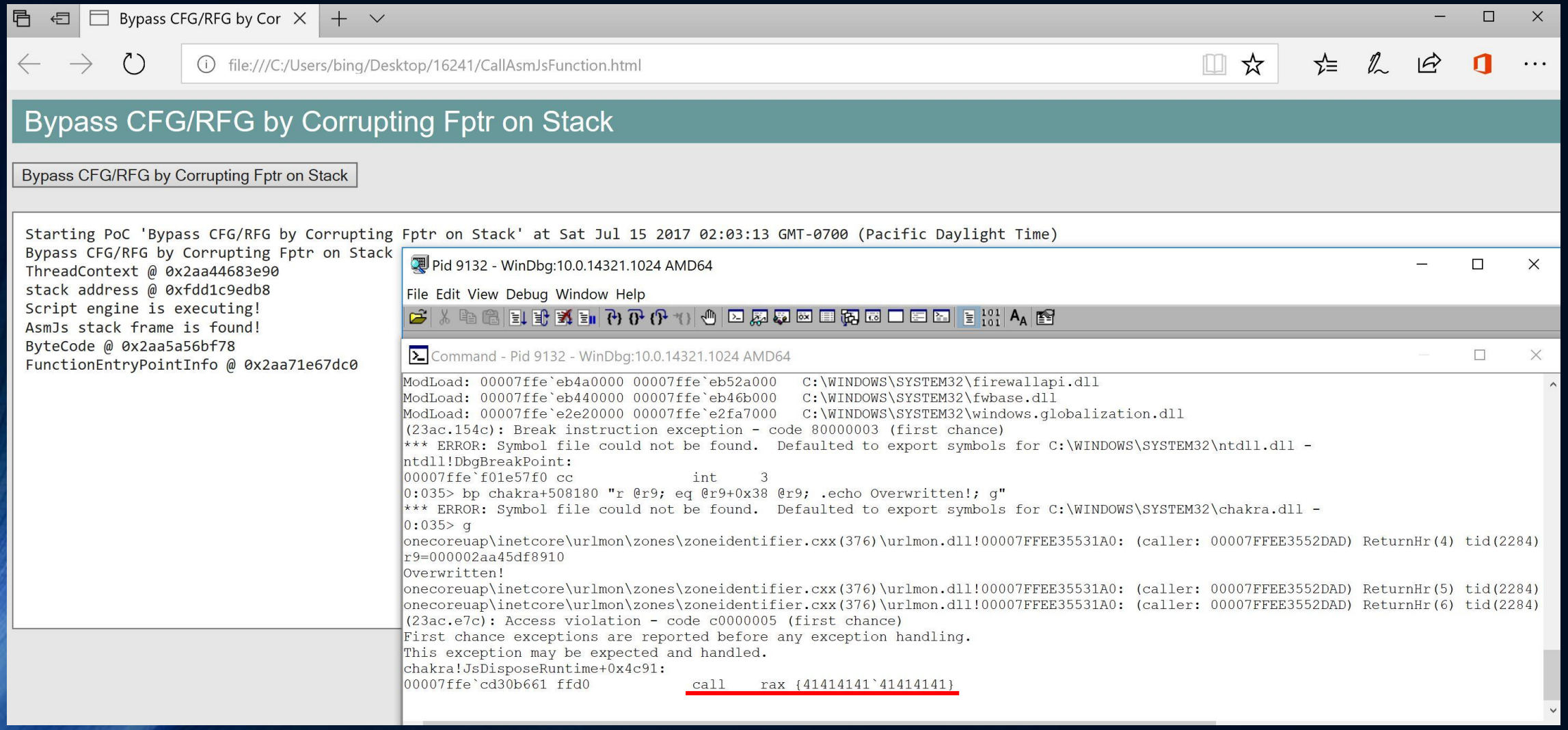
- Attacking mutable read-only memory
  - ✓ Making arbitrary read-only memory writable via loader work mechanism (HITB 2017)
  - ✓ Unlocking .mrdata of ntdll.dll through thread suspension (KCon 2017)
  - ✓ Unlocking .mrdata of ntdll.dll/eShims.dll through fault injection (KCon 2017)
  - ✓ Unlocking .mrdata of eShims.dll through race condition (TSec 2017)
- Corrupting thread's context record
  - ✓ Corrupting thread context in ntdll!LdrInitializeThunk through thread suspension and stack address leaking techniques (XCon 2017)
- Hijacking function pointer
  - ✓ Hijacking AsmJs entryPoint in Js::JavascriptFunction::CallAsmJsFunction<int> through race condition (fixed in RS4)
  - ✓ Hijacking exception/unwind handlers through race condition

A Race Condition Issue in CallAsmJsFunction

```
.text:000000018028B560 __int64 __fastcall Js::JavascriptFunction::CallAsmJsFunction<int>(Js *this)
...
.text:000000018028B58A                  mov     rcx, rdx // the AsmJs function entryPoint (FunctionEntryPointInfo->jsMethod)
.text:000000018028B58D                  push    rdx
.text:000000018028B58E                  push    r8
.text:000000018028B590                  push    r9
.text:000000018028B592                  call    amd64_CheckICall // check whether the entryPoint is a valid call target
                                                     //amd64_CheckICall is a wrapper function of "call cs:__guard_check_icall_fptr"
.text:000000018028B597                  pop     r9
.text:000000018028B599                  pop     r8
.text:000000018028B59B                  pop     rdx
.text:000000018028B59C                  mov     rax, rcx // rax holds the address of call target
.text:000000018028B59F                  mov     rcx, rdi
.text:000000018028B5A2                  xor     r10d, r10d
.text:000000018028B5A5                  mov     rsi, r9
.text:000000018028B5A8                  add     rsi, 8
.text:000000018028B5AC                  push    rax  // push the call target to stack
.text:000000018028B5AD                  push    rcx
.text:000000018028B5AE                  sub     rsp, 20h
.text:000000018028B5B2                  call    ?GetArgsSizesArray@Js@@YAPEAIPEAVScriptFunction@1@@Z
.text:000000018028B5B7                  mov     r12, rax
.text:000000018028B5BA                  add     rsp, 20h
.text:000000018028B5BE                  pop     rcx
.text:000000018028B5BF                  pop     rax  // pop the call target from stack
.text:000000018028B5C0                  push    rax  // push it to stack again
.text:000000018028B5C1                  push    rcx
.text:000000018028B5C2                  sub     rsp, 20h
.text:000000018028B5C6                  call    ?GetStackSizeForAsmJsUnboxing@Js@@YAHPEAVScriptFunction@1@@Z
.text:000000018028B5CB                  mov     r13, rax
.text:000000018028B5CE                  add     rsp, 20h
.text:000000018028B5D2                  pop     rcx
.text:000000018028B5D3                  pop     rax  // pop the call target from stack again
.text:000000018028B5D4                  sub     rsp, r13
...
.text:000000018028B661                  call    rax      // ultimately, issue the AsmJs function call
...
.text:000000018028B66F sub_18028B560    endp
```

The time window for the race condition attack

CFG Bypass by Hijacking Function Entry Point in CallAsmJsFunction



Multithread and Thread Communication

- Web worker is a simple means for running scripts in a background thread separate from the main JS thread
  - ✓ var worker = new Worker('worker.js')
- The native thread communication:
  - ✓ Worker.postMessage()
  - ✓ SharedArrayBuffer with Atomics (disabled in Edge due to Meltdown/Spectre attack)

Cloning a SharedArrayBuffer to a Web Worker Thread

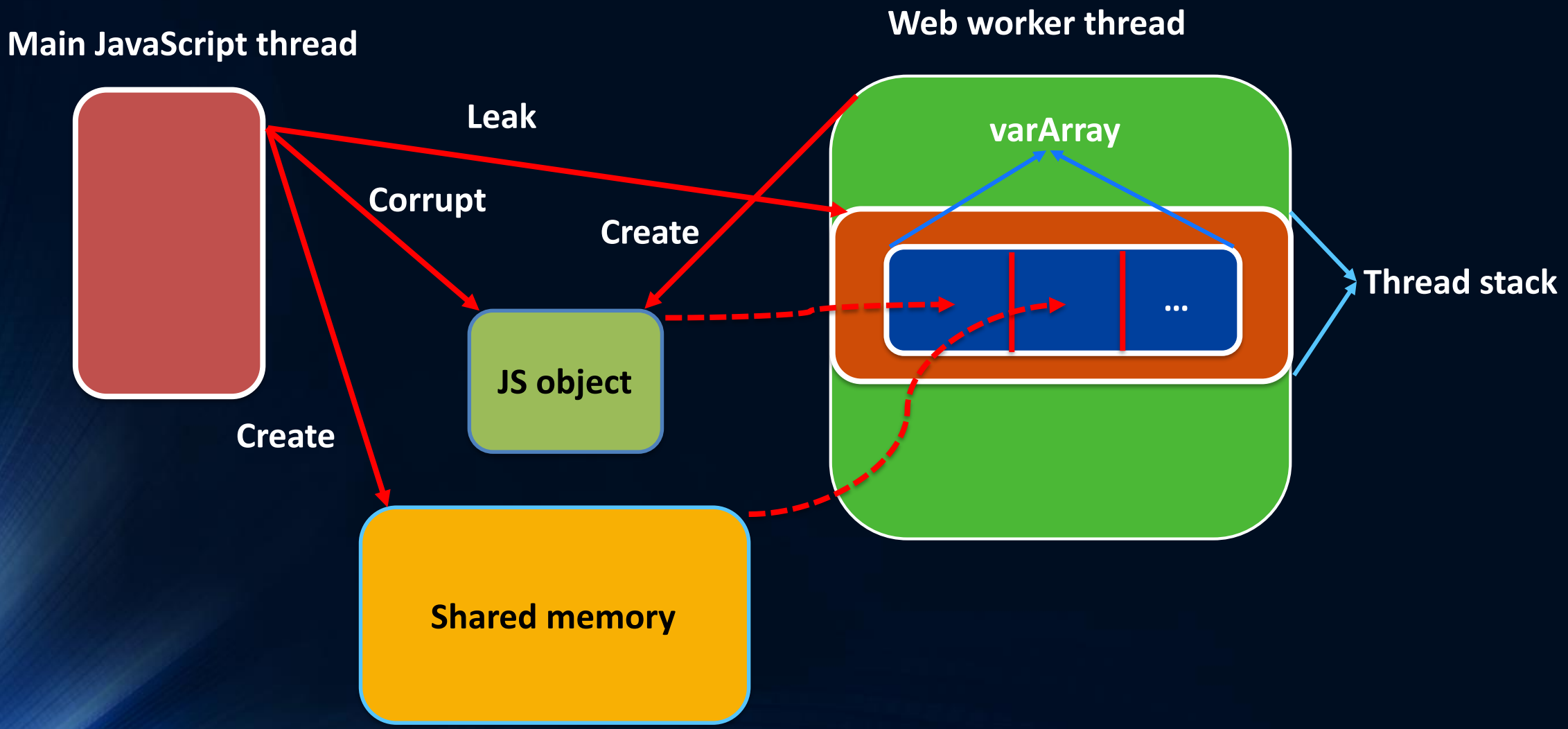
```
0:045> kv
 # Child-SP          RetAddr           : Args to Child                                                           : Call Site
00 0000008e`2033e9e8 00007ffc`abf44f9f : 000001d2`7bc2a720 00000000`00000030 00000000`00000000 000001d2`62eed920 : chakra!Js::SharedArrayBuffer::SharedArrayBuffer
01 0000008e`2033e9f0 00007ffc`abcaaab5 : 0000008e`2033ed20 0000008e`00000052 000001d2`00000004 0000008e`2033eb48 : chakra!Js::DeserializationCloner<Js::StreamReader>::TryCloneObjec
02 0000008e`2033eac0 00007ffc`abcaab5d : 0000008e`2033ec98 0000008e`00000024 0000008e`2033eb48 0000008e`2033ed20 : chakra!Js::SCAEngine<unsigned int,void * __ptr64,Js::Deserializat
03 0000008e`2033eb10 00007ffc`abcaac2e : 0000008e`2033ed20 0000008e`2033eba0 0000008e`2033ed20 0000008e`2033f3f8 : chakra!Js::DeserializationCloner<Js::StreamReader>::ReadObjectPro
04 0000008e`2033eb70 00007ffc`abcaaaf4 : 0000008e`2033ed20 0000008e`0000001b 0000008e`1361c8a0 000001ca`13611120 : chakra!Js::DeserializationCloner<Js::StreamReader>::ClonePropertie
05 0000008e`2033ec20 00007ffc`abcaa7e1 : 0000008e`2033ec98 00000000`00000004 0000008e`2033ec90 000001d2`7bc2a720 : chakra!Js::SCAEngine<unsigned int,void * __ptr64,Js::Deserializat
06 0000008e`2033ec70 00007ffc`abcaa71a : 0000008e`00000004 0000008e`2033ed20 000001d2`62e5f440 00000000`00000000 : chakra!Js::SCAEngine<unsigned int,void * __ptr64,Js::Deserializat
07 0000008e`2033ece0 00007ffc`abcacd2a : 000001d2`7a1848a8 000001ca`62c9faa0 0000008e`2033ee90 000001d2`62e5f440 : chakra!Js::SCADeserializationEngine::Deserialize+0x9a
08 0000008e`2033ed70 00007ffc`acbbe746 : 000001d2`62ee1b00 000001ca`62c9faa0 000001d2`7a1d4b40 00000000`00000000 : chakra!ScriptEngineBase::Deserialize+0x1ca
09 0000008e`2033f300 00007ffc`acbbdadb : 000001d2`62ee1b00 00000000`00000000 000001d2`7a1d4b40 0000008e`2033f3b8 : edgehtml!CSCADeserializationContext::CloneVarFromStream+0xbe
0a 0000008e`2033f380 00007ffc`acbbdd7b : 00000000`000000b8 000001d2`7a210c00 000001d2`7a1b0680 00000000`00000000 : edgehtml!CMessagePort::SetMessageEventData+0x8b
0b 0000008e`2033f3e0 00007ffc`acbbd4c4 : 000001d2`63f0cf50 000001d2`7a1b0680 000001d2`7a1b8800 00000000`00000000 : edgehtml!CMessagePort::HandlePostMessage+0xa3
0c 0000008e`2033f460 00007ffc`acbbd3dd : 000001d2`63f0cf50 00007ffc`acf5e9d2 00000000`00000000 000001d2`7a18fcb0 : edgehtml!CMessagePort::HandleNotification+0x34
0d 0000008e`2033f4a0 00007ffc`acf4550b : 000001d2`7a1d4c90 0000008e`2033f579 000001d2`7882dec0 00000000`0268f309 : edgehtml!CMessageDispatcher::ProcessNotification+0x9d
0e 0000008e`2033f4e0 00007ffc`acdbe328 : 0000001a`b14109e8 00000000`002b43e0 00000000`000f4240 00000000`00000000 : edgehtml!GWndAsyncTask::Run+0x1b
0f 0000008e`2033f510 00007ffc`acf27c93 : 0000001a`b14109e8 000001ca`60cfedd0 000001d2`63f0cf50 00000000`00000001 : edgehtml!HTML5TaskScheduler::RunReadiedTask+0x208
10 0000008e`2033f5e0 00007ffc`acdfc643 : 000001d2`7a18fcf0 00000000`00000001 000001d2`7a18fd08 00000000`00000000 : edgehtml!HTML5TaskScheduler::RunReadiedTasks+0xe3
11 0000008e`2033f640 00007ffc`acdfc521 : 000001d2`7882de00 00000009`69f55da3 000001ca`62c26400 00000000`00000000 : edgehtml!HTML5EventLoopDriver::DriveLowPriorityTaskExecution+0x11
12 0000008e`2033f680 00007ffc`acdbcf89 : 00000000`00000003 000001ca`62c26400 000001d2`00000000 00000000`00000000 : edgehtml!GlobalWndOnPaintPriorityMethodCall+0x71
13 0000008e`2033f6b0 00007ffc`ce8fb85d : 00000000`001d0624 00000000`00000001 00000000`00000002 00000000`00000000 : edgehtml!GlobalWndProc+0x129
14 0000008e`2033f710 00007ffc`ce8fb54c : 00000000`00000008 00007ffc`acdbce60 00000000`001d0624 00000000`80000000 : user32!UserCallWinProcCheckWow+0x2ad
15 0000008e`2033f880 00007ffc`ce9119c3 : 00000000`00000000 00000000`00000000 00000000`00000000 00000000`00000000 : user32!DispatchClientMessage+0x9c
16 0000008e`2033f8e0 00007ffc`d14c3b14 : 00000000`00000000 00007ffc`acbbb380 00007ffc`cb630440 00007ffc`acbbd7bb : user32!_fnDWORD+0x33
17 0000008e`2033f940 00007ffc`cd9f1744 : 00007ffc`ce8fb272 000001ca`612d7760 0000008e`2033fa18 00000000`0014092c : ntdll!KiUserCallbackDispatcherContinue (TrapFrame @ 0000008e`2033
18 0000008e`2033f9c8 00007ffc`ce8fb272 : 000001ca`612d7760 0000008e`2033fa18 00000000`0014092c 000001ca`612d7760 : win32u!NtUserDispatchMessage+0x14
19 0000008e`2033f9d0 00007ffc`acd0c682 : 0000008e`2033fa70 000001d2`66cdaab0 000001d2`7a1b8800 00000000`00000000 : user32!DispatchMessageWorker+0x222
1a 0000008e`2033fa50 00007ffc`acd0c60a : 0000008e`2033fb90 00000000`00000000 00000000`00000000 00007ffc`acd13198 : edgehtml!WorkerGlobalScopeThread::RunMessageLoopForSTA+0x36
1b 0000008e`2033fab0 00007ffc`acd0c58b : 000001d2`66cdaab0 000001d2`66cdaab0 00000000`00000000 00000000`00000000 : edgehtml!WorkerGlobalScopeThread::RunMessageLoop+0x2e
1c 0000008e`2033fb10 00007ffc`acd0c4da : 000001d2`7a1b8800 000001d2`66cdaab0 00000000`00000000 00000000`00000000 : edgehtml!WorkerGlobalScopeThread::RunWorkerGlobalScope+0x7b
1d 0000008e`2033fb60 00007ffc`acd0c45e : 00000000`00000000 00000000`00000000 00000000`00000000 00000000`00000000 : edgehtml!WorkerGlobalScopeThread::RunThread+0x5e
1e 0000008e`2033fbc0 00007ffc`ceaa1fe4 : 00000000`00000000 00000000`00000000 00000000`00000000 00000000`00000000 : edgehtml!WorkerGlobalScopeThread::ThreadProc+0xe
1f 0000008e`2033fbf0 00007ffc`d148ef91 : 00000000`00000000 00000000`00000000 00000000`00000000 00000000`00000000 : KERNEL32!BaseThreadInitThunk+0x14
20 0000008e`2033fc20 00000000`00000000 : 00000000`00000000 00000000`00000000 00000000`00000000 00000000`00000000 : ntdll!RtlUserThreadStart+0x21
```

- worker.postMessage({sharedBuffer}, [sharedBuffer]); // transfer
- worker.postMessage({sharedBuffer}); // clone

Sharing Objects Between Multiple JS Threads

- With AAR/AAW, it is possible to directly share certain type of JS objects between multiple JS threads:
  1. Web worker thread creates a varArray (JavascriptArray) on its stack and stores one certain JS object (such as an ArrayBuffer) in the varArray
  2. Main JS thread creates a shared memory (such as an Uint32Array)
  3. Main JS thread leaks the stack of the web worker thread and searches the varArray
  4. Main JS thread writes the object of shared memory into the leaked varArray, and reads out the object exposed by web worker
  5. Main JS thread helps to corrupt that object to grant the worker thread the ability of AAR/AAW
  6. Web worker thread acquires the AAR/AAW and the shared memory to communicate with Main JS thread

Diagram of Sharing Objects Between JS Threads



Callback Mechanism

- Under some scenarios, the ability to allow native code callback into JS is required (API hook, WindowProc etc.)
- Due to the difference in execution mechanism, it is almost impossible to let the native code call a JS function in a natural fashion
  - ✓ Interpreter mode, no true function address
  - ✓ JIT mode, the JITed function requires context info of the JS engine
- It is a good idea to use another thread to help in arguments preparation and context switching
- amd64_CallFunction can be used as a pivot to reach the target JS function

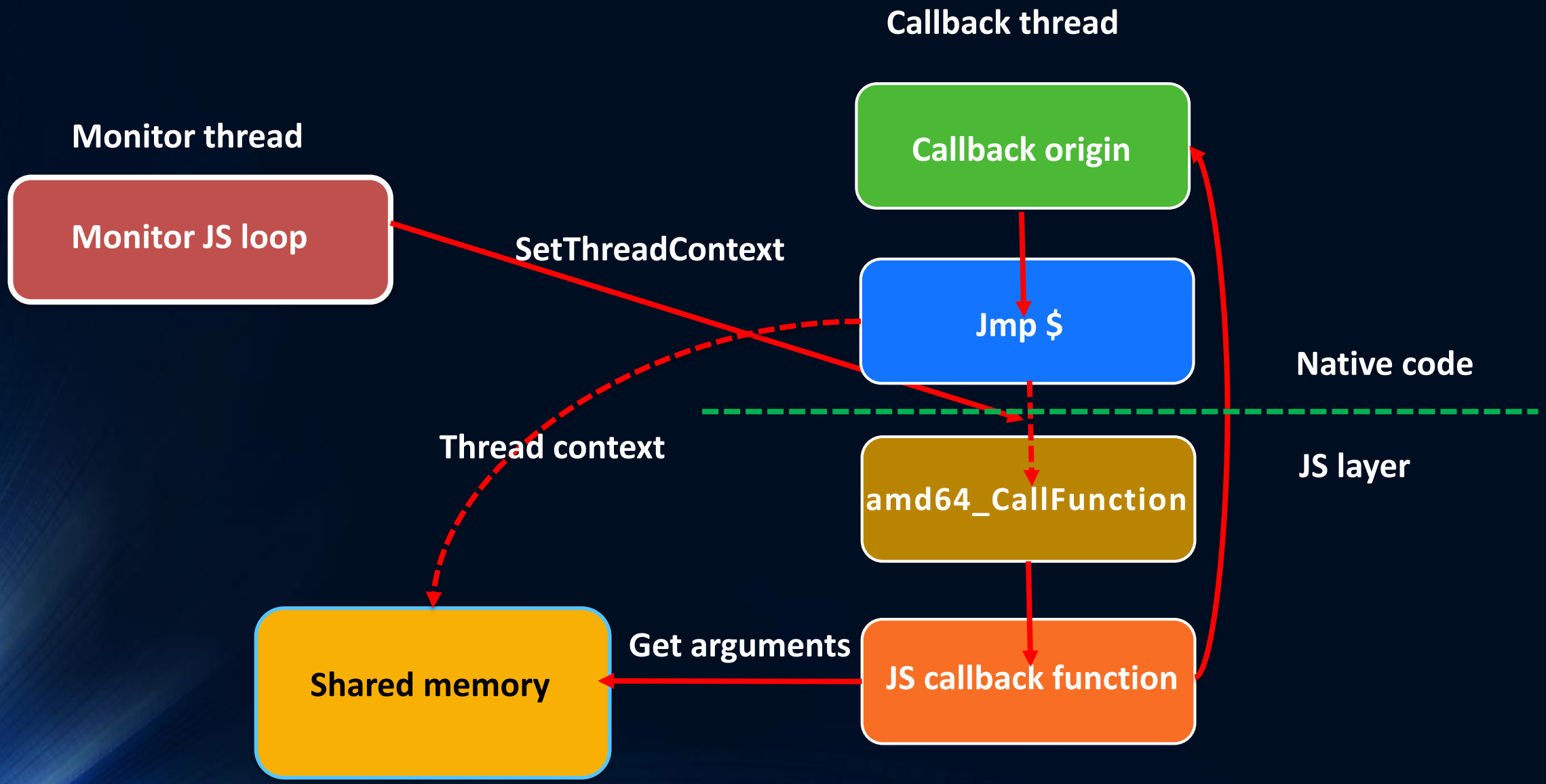
Prototype of chakra!amd64_CallFunction

- var amd64_CallFunction(RecyclableObject *function, JavascriptMethod entryPoint, CallInfo callInfo, uint argc, Var *argv);
  1. function: the JavascriptFunction object of the target JS function
  2. entryPoint: the address of the target JS function ((function + 0x08) -> (Type + 0x18) -> entryPoint)
  3. callInfo: (unused:32 + Flags:8 + Count:24)
  4. argc: the number of arguments
  5. argv: the array of arguments

Calling the JS Function From Native Code

- With the aid of a monitor thread, the control flow can smoothly transition from native code to JS layer:
  1. When a user callback needs to be registered, the address of the callback function is set to an instruction of dead loop (jmp $, \xEB\xFE)
  2. A dedicated monitor thread is created to watch for the occurrence of a user callback (OpenThread, GetThreadContext)
  3. When the user callback occurs (Context.RIP == jmp $), the monitor thread saves the current thread context in shared memory, loads the context for the JS layer, and redirects the control flow to chakra!amd64_CallFunction (SetThreadContext)
  4. amd64_CallFunction kicks off the usual JS function-calling process in the chakra JS engine
  5. The target JS callback function is called and retrieves the original inbound arguments from shared memory, processing according to its logic
  6. Finally, amd64_CallFunction exits the chakra JS engine and returns to the place where the callback occurred

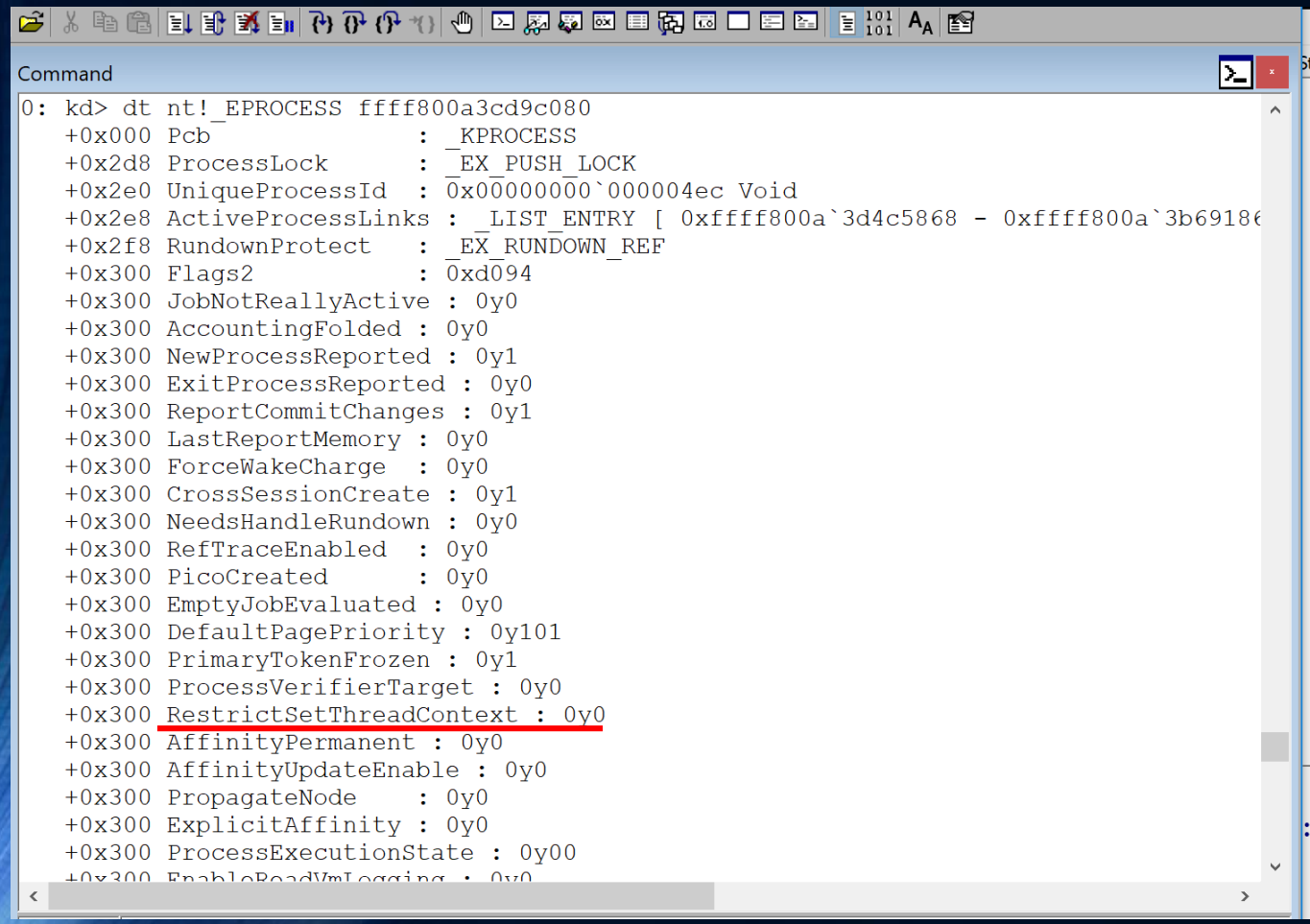
Diagram of Calling JS Function From Native Code

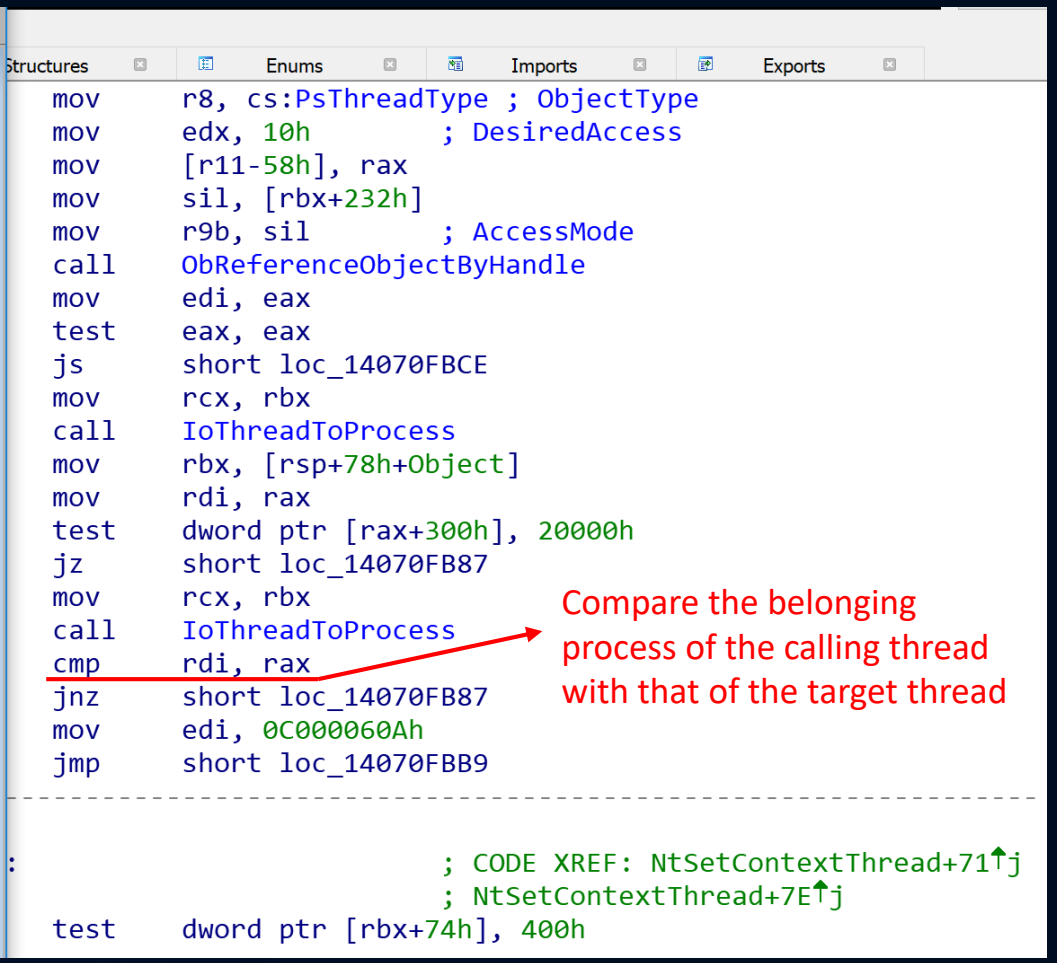


Restricting SetThreadContext

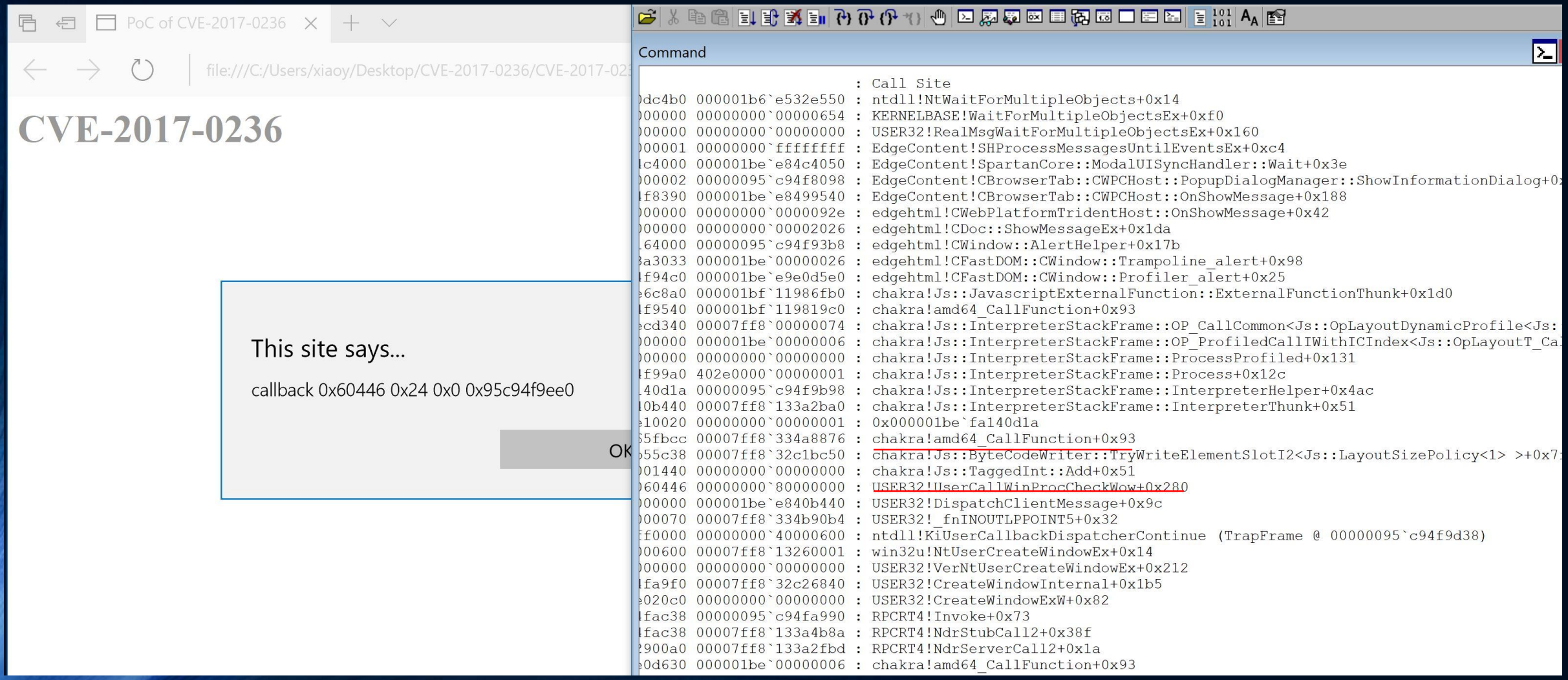
- A flag in EPROCESS (introduced in RS2) prevents setting the context of a thread of the same process
- On Windows 10 RS2/RS3/RS4, this flag is not enabled for Edge
- Without SetThreadContext, we may explore other approaches (such as ROP) to simulate the context change

EPROCESS.Flags2.RestrictSetThreadContext

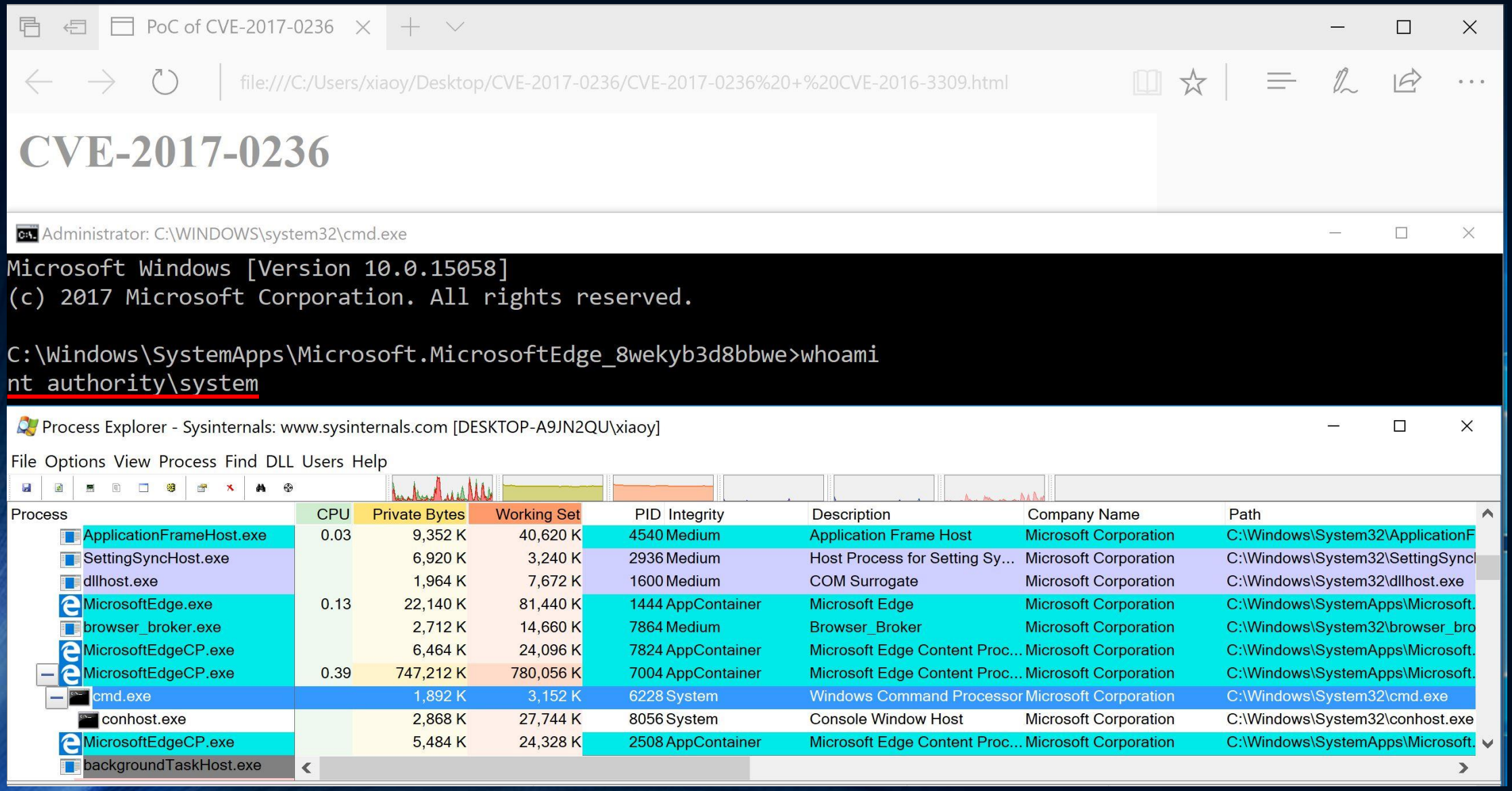




Demo: WindowProc Callback



Demo: CVE-2017-0236 + CVE-2016-3309



Conclusion

- ACG+CIG+CFG raise the bar very high for making reliable exploits
- Compared with ACG and CIG, CFG still appears to be weak
- All mitigation features must work collaboratively to be effective
- The interactive runtime provides strong scripting capability that can be leveraged to create a shellcode-free exploit/payload

Q&A and Acknowledgements

- Send questions to bing_sun@mcafee.com, chong_xu@mcafee.com
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