Detecting Thread Creation Trampolines

Get-InjectedThreadEx.~~ps1~~cpp

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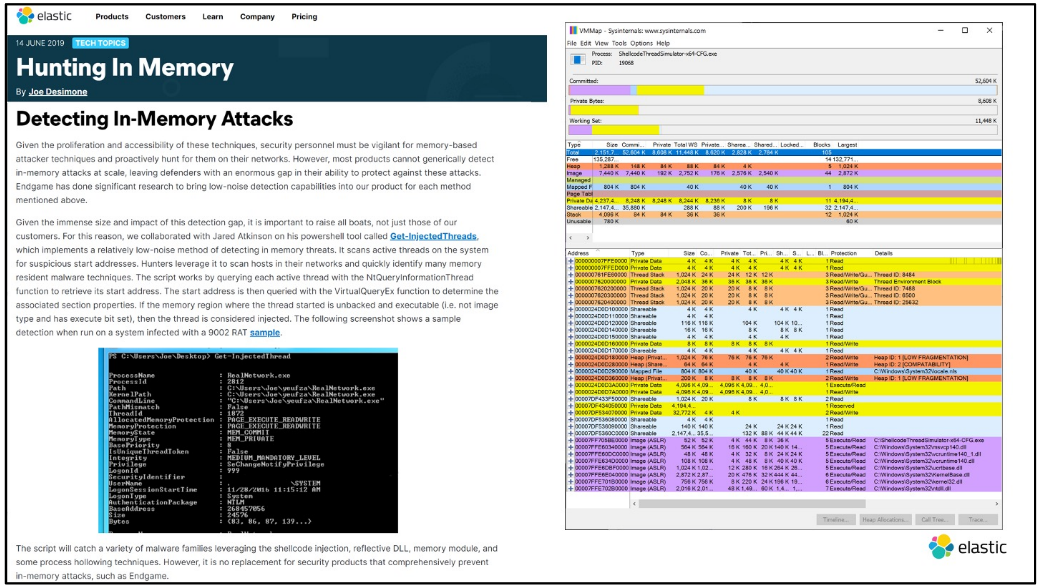

Since its debut at the 2017 SANS Threat Hunting Summit, Get-InjectedThread.ps1 has been a blue team staple for identifying suspicious threads via their start addresses.
At a high level this approach detects threads created with a user start address in unbacked executable memory. Basically, unbacked executable memory is normal in processes that do Just-In-Time compilation – such as .NET or javascript engines.

However, that JIT'd code rarely manages its own threads – usually that is handled by the runtime or engine. Looking at the sysinternal's VirtualMemoryMap picture, Thread Start Addresses should be in 'purple' image memory – not yellow, blue, orange etc.

Docs / Windows / Apps / Win32 / API / Processthreadsapi.h /

CreateThread function (processthreadsapi.h)

Article • 10/13/2021 • 5 minutes to read

Creates a thread to execute within the virtual address space of the calling process.

To create a thread that runs in the virtual address space of another process, use the CreateRemoteThread function.

Syntax

C++

```
HANDLE CreateThread(
  [in, optional]  LPSECURITY_ATTRIBUTES   lpThreadAttributes,
  [in]            SIZE_T                  dwStackSize,
  [in]            LPTHREAD_START_ROUTINE  lpStartAddress,
  [in, optional]  __drv_aliasesMem LPVOID lpParameter,
  [in]            DWORD                   dwCreationFlags,
  [out, optional] LPDWORD                 lpThreadId
);
```

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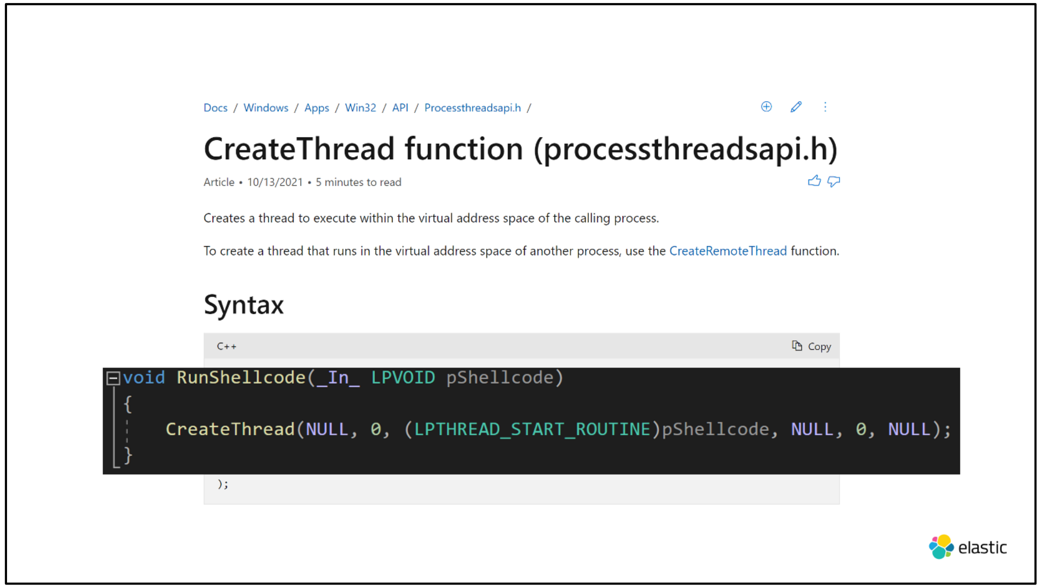
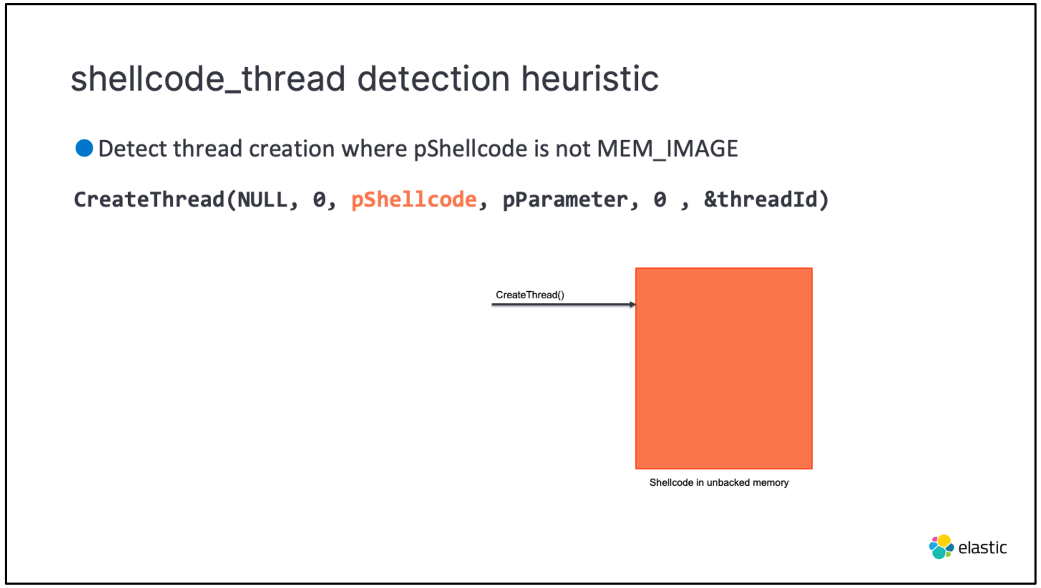
As a quick recap, the CreateThread() API lets you provide a pointer to a desired StartAddress which will be used as the entrypoint of a function that takes exactly one user-provided parameter.



In other words, it’s a simple shellcode runner.

And its sibling function CreateRemoteThread() is effectively remote process injection.

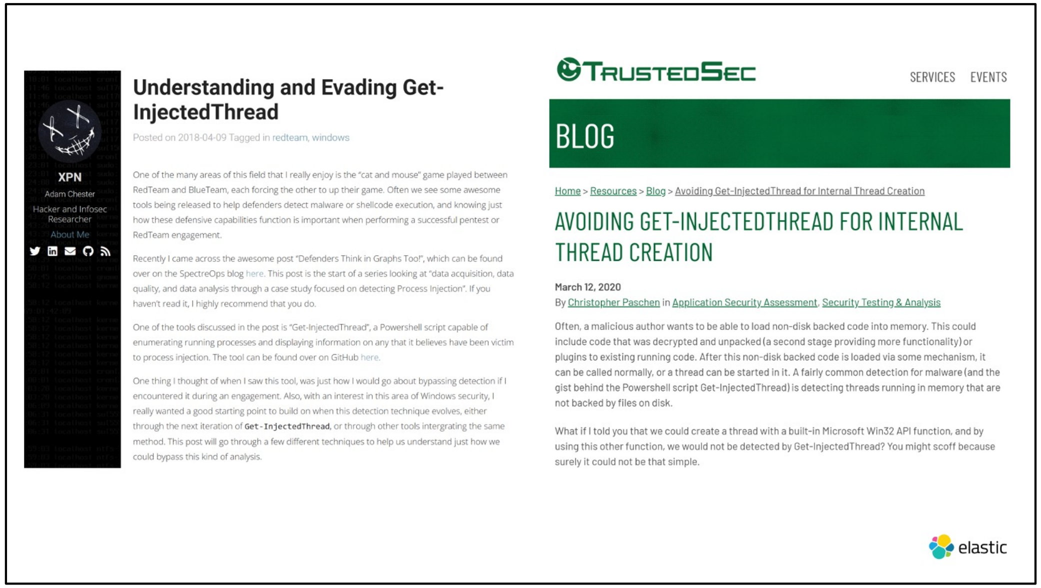


The original detection was based off inspection of the StartAddress parameter being passed to a CreateThread() function – and then determining whether it was backed by a PE file on disk, or not.

While this particular script was an after-the-fact point-in-time scan implementation based on asking the kernel for the value of the Win32StartAddress stored in the relevant ETHREAD structure, the same information is available inline during create thread notify kernel callbacks.

All good EDR products should be providing telemetry of suspicious thread creations.
And all good EPP products should be denying suspicious thread creations by default – with a mechanism to add allowlist entries for legitimate software exhibiting this behaviour.

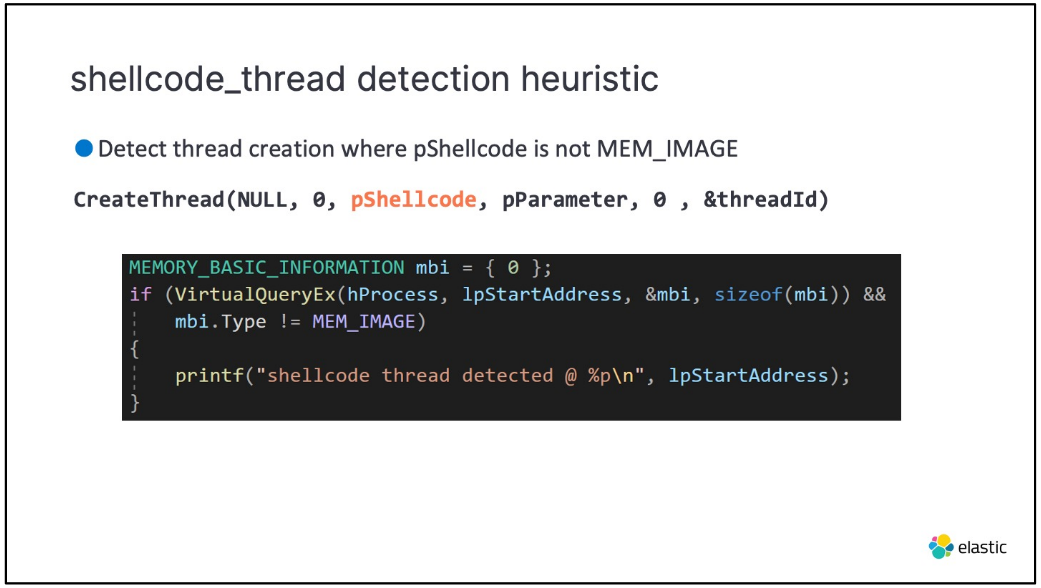
You'll see such behaviour from other security products (!!), older copy-protection software, anti-cheat software and some Unix software which has been shimmed to run on Windows – like Java. Even with this finite set of exceptions to handle, this detection and/or prevention approach remains highly relevant and successful.



However, a number of bypasses have been demonstrated and published.

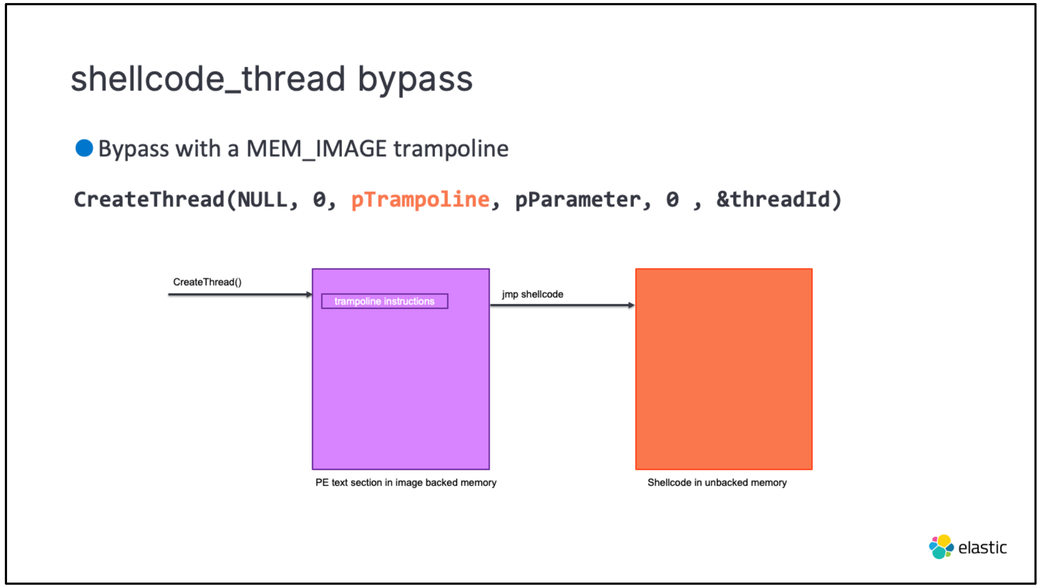
Most notably these two excellent blogs –
Understanding and Evading Get-InjectedThread by Adam Chester.
Avoiding Get-InjectedThread for Internal Thread Creation by Christopher Paschen.

In today’s talk we’ll go through each major bypass class and the forensic traces they leave in detail.



The original Get-InjectedThread detection was implemented by using the VirtualQueryEx API to ask the kernel for information about the start address's memory region. That information includes a flag indicating whether the memory is a PE image, a mapped file or simply private memory. If it's not image and it's a thread start address – it's suspicious.

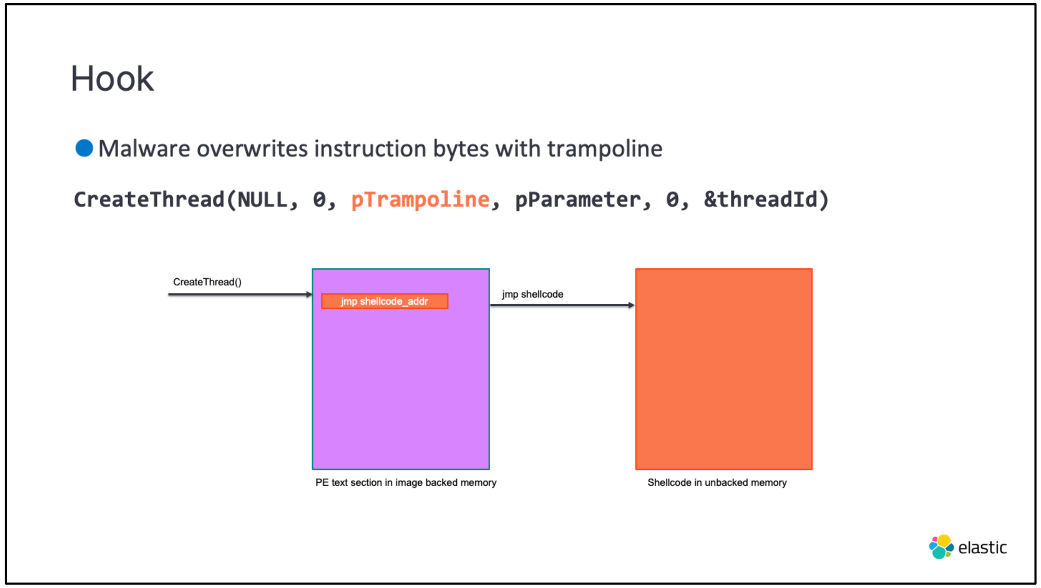
Simple. Quick. And deterministic FPs for certain software.



So how to bypass? We need the Win32StartAddress that is provided to the the kernel to be an image-backed location – and we need that address to point to instructions that pass execution to the ultimate shellcode address.

So, one way this detection can be bypassed by passing in a thread start address which is an image-backed location, but which contains instructions which will transfer execution to the unbacked memory. This is known as a trampoline – as you are quickly catapulted somewhere else.

There are four broad classes of trampolines – you can build your own trampoline from scratch, you can use an illusionary trampoline, you can repurpose something else a a trampoline, or you can find an existing trampoline. Aka hooking, spoofing, gadgets and wrapper functions.



#1 – bring your own trampoline
The simplest trampoline is a small hook. You just write the needed jump instruction into existing image-backed memory.

These bytes can even be restored to their original values straight after thread creation. This helps with avoiding retrospective detection – but recall that your endpoint security product should be doing **inline** detection and will be able to see hooked thread entrypoint at execution time.

Hook

- Malware overwrites instruction bytes with trampoline

```
CreateThread(NULL, 0, pTrampoline, pParameter, 0 , &threadId)
```

```
char hook[] =
{
    0x48, 0xb8, 0x11,0x22,0x33,0x44,0x55,0x66,0x77,0x88, // movabs rax,<placeholder>
    0xff, 0xe0                                          // jmp rax
};
*(ULONG_PTR*)(hook + 2) = (ULONG_PTR)pShellcode;

auto pHookedFunc = GetProcAddress(GetModuleHandleW(L"ntdll.dll"), "DbgUiRemoteBreakin");
WriteProcessMemory(GetCurrentProcess(), pHookedFunc, hook, sizeof(hook), NULL);

CreateThread(NULL, 0, (LPTHREAD_START_ROUTINE)pHookedFunc, NULL, 0, NULL);
```

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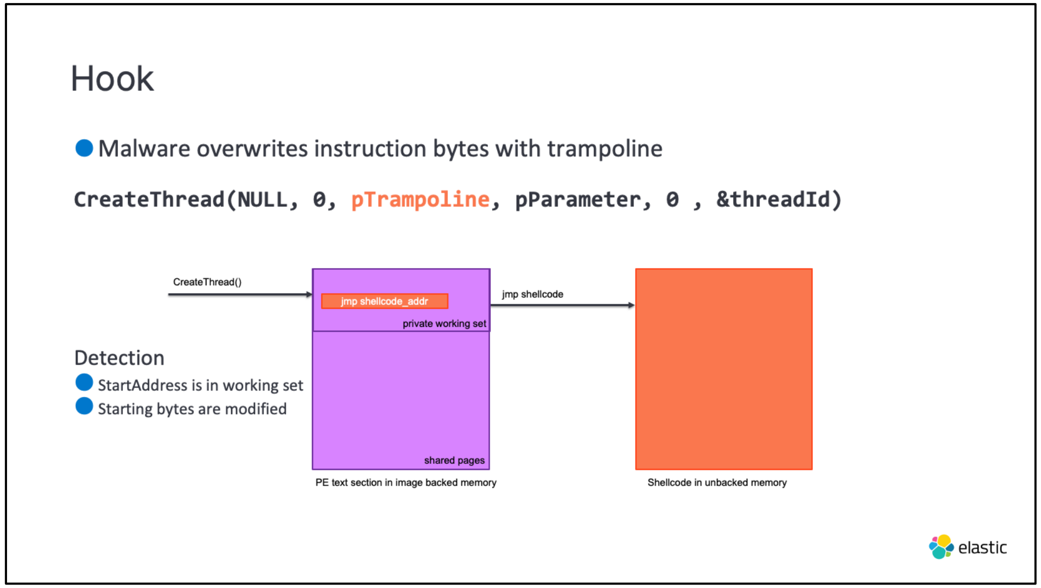
Here’s an example.

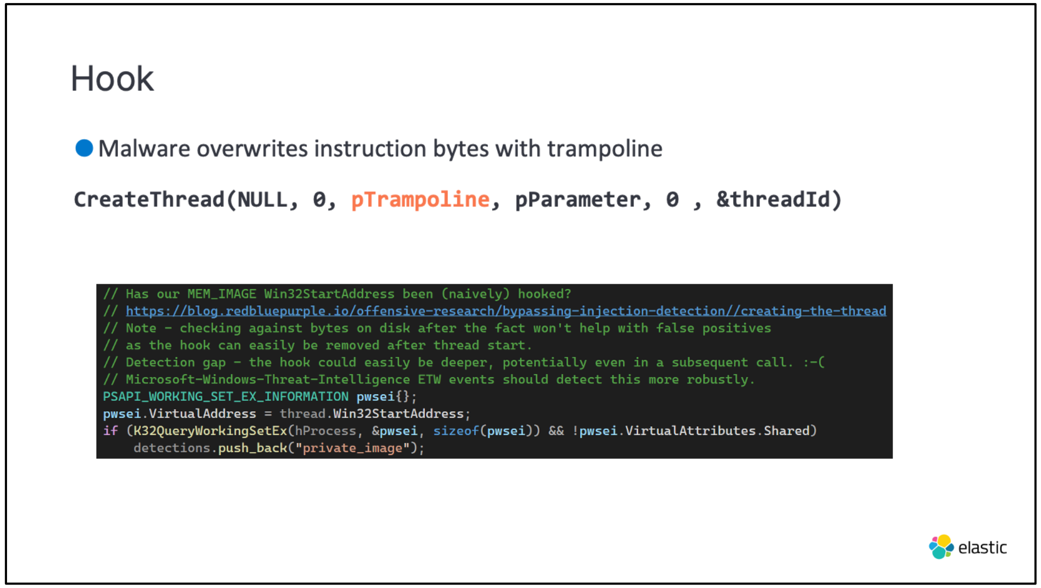
ntdll!DbgUiRemoteBreakin is my favourite function to trampoline via.
It’s a legitimate, but rarely used in production, remote thread start address.

Note the use of WriteProcessMemory() instead of a simple memcpy().
MEM_IMAGE pages are typically read only, and the former handles toggles the page protections to writable and back for us.



Now, we can detect hooked start addresses fairly easily.

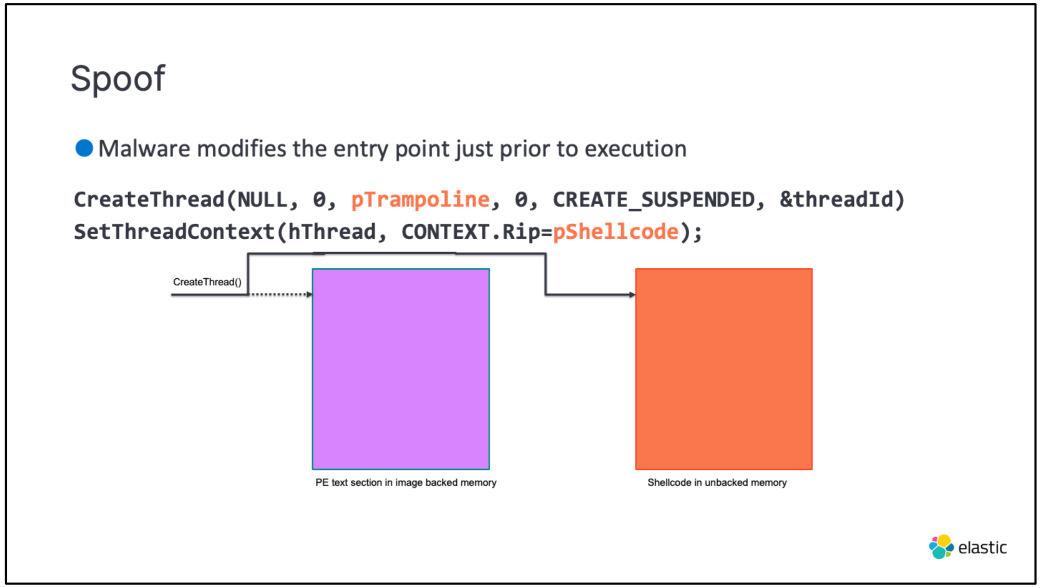
To save memory, Windows ensures that the virtual memory for shared libraries uses the same backing physical memory pages and that virtual memory is tagged as COPY_ON_WRITE in each process's address space. So as soon as the hook is inserted, the whole page can no longer be shared. Instead, a copy is created in the private working set of the process.



We can query the kernel memory manager and ask whether the page containing the start address is shared or is in a private working set.
So now we know that something on the page was modified (which is uncommon) – but not yet if our address was hooked.

This could be a false positive if there is a “legitimate” hook or other modification (or a hook on the executable image which is typically not shared) on the same page.
In particular, most security products like to hook ntdll and there are also a plethora of software products out there that extend functionality of other products via hooks, as well as some older copy protection libraries that just unpack their code at runtime etc.

So, if that 4KB page is private, then an inline detection would additionally compare the start address bytes to an original pristine copy and only alert if they differ.
And, to deploy at scale, it would also need to maintain an allow list for those rare legitimate uses.



#2 – shifting the mat

I mentioned earlier that security products can do inline prevention at the time of the thread notification callback. That's true – but it's also not the whole story.

The thread notify routine is called before the thread starts and it turns out that you can modify the thread's state after the callback but before the thread is executed.

In particular, Microsoft does not provide security vendors with a mechanism to determine whether a thread was created suspended or not. And, on x64 Windows, Microsoft does not allow security vendors to do our own kernel hooking – so we can't easily check the parameters either.

So, malware authors quickly realised that they could create a SUSPENDED thread which triggers the thread callback, then after passing that initial inspection, they can modify the thread's register state with SetThreadContext (or alternatively queue an EarlyBird APC) and then resume the thread.

Again, this is not the whole story - effective security products can still detect this inline too. But that's a topic for another day.

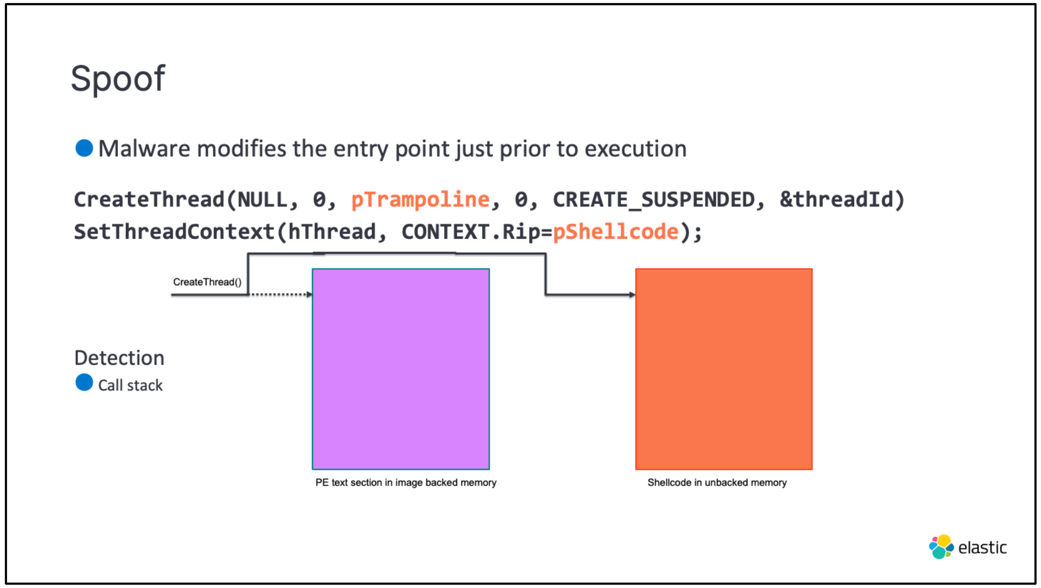
What about retrospective detection via our scanning tool?

The problem with creating the illusion of a legitimate entrypoint like this is that it doesn’t hold up to any kind of rigorous inspection.

In a normal thread, the user mode start address is typically the third function call in the thread’s stack – after ntdll!RtlUserThreadStart and kernel32!BaseThreadInitThunk. So, when the thread has been hijacked, this is going to be obvious in the call stack.

For context manipulation, the first (or third) frame will belong to the injected code.

For “early bird” APC injection, the base of the call stack will be ntdll!LdrInitializeThunk, ntdll!NtTestAlert, ntdll!KiUserApcDispatcher and then the injected code.

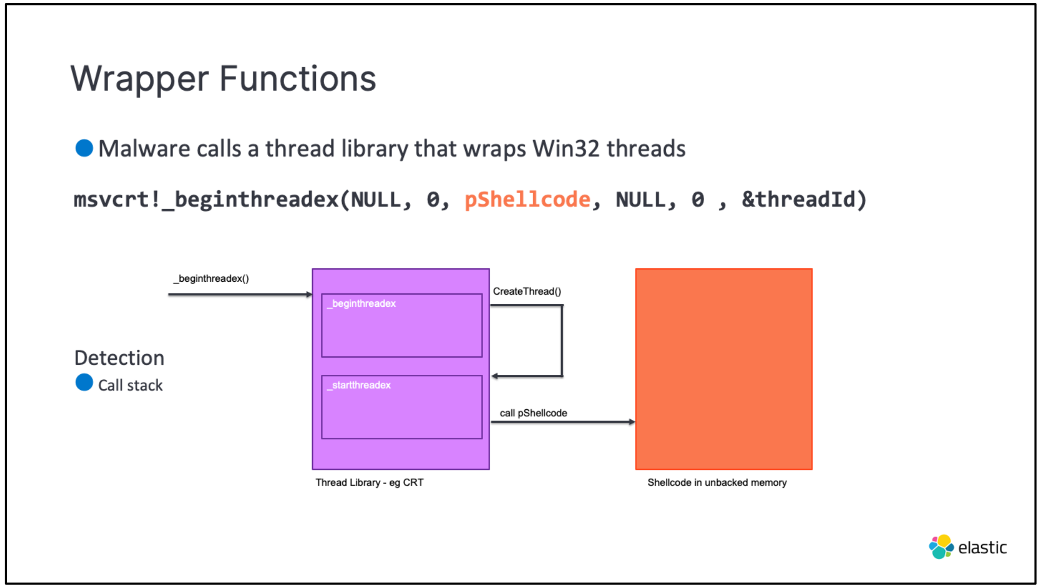


I eschewed the traditional easy walk down the stack using the StackWalk64() API and decided to attempt to manually climb up the stack and look for candidate return addresses.

These can be further validated by disassembling the preceding bytes to a candidate return address looking for a preceding call insttrurciton, and by using unwind information present in PE files to determine if the candidate stack frame was the correct size.

Alas, I sometimes encountered the dreaded SET_FPREG unwind opcode. The presence of a frame pointer means the function can legally use _alloca() for a dynamic stack allocation. And, since I wasn't walking down the stack in the correct fashion, I couldn't emulate execution to determine the frame pointer's exact value at time of unwind. So, I didn't have the stack frame's size – just a lower bound for it.

This improved call stack climbing has accurately identified the initial stack frames in all of the (limited :-p) testing that I have done so far.



The third bypass category is to find a function that does exactly what we want. There are multiple of these. For example, Microsoft's C Runtime is an API layer that sits above Win32 – and it includes thread creation APIs. These APIs perform some extra CRT bookkeeping on thread creation/destruction by passing a CRT thread entrypoint to CreateThread and passing the user entrypoint to for the CRT thread start function to then call as part of the structure pointed to by the CreateThread parameter.

So, in this case, the Win32StartAddress observed will be the non-exported msvcrt!_startthread[ex]. The shellcode address will be at a specific offset from the thread parameter during thread creation (Microsoft CRT source is available) and, after the fact, the shellcode will be the next frame on the callstack after the CRT. Note – without additional tricks this can only be used to create in-process threads and there is no CreateRemoteThread() equivalent in the CRT. Those additional tricks exist though, so you should also not expect this module as a start address in remote threads.

Unfortunately, there is no operating system bookkeeping that will tell you if a thread was created remotely after the fact. So, we can't scan for this – but the inline callbacks used by security products can make this distinction and be more aggressive in blocking anomalous remote thread creations.

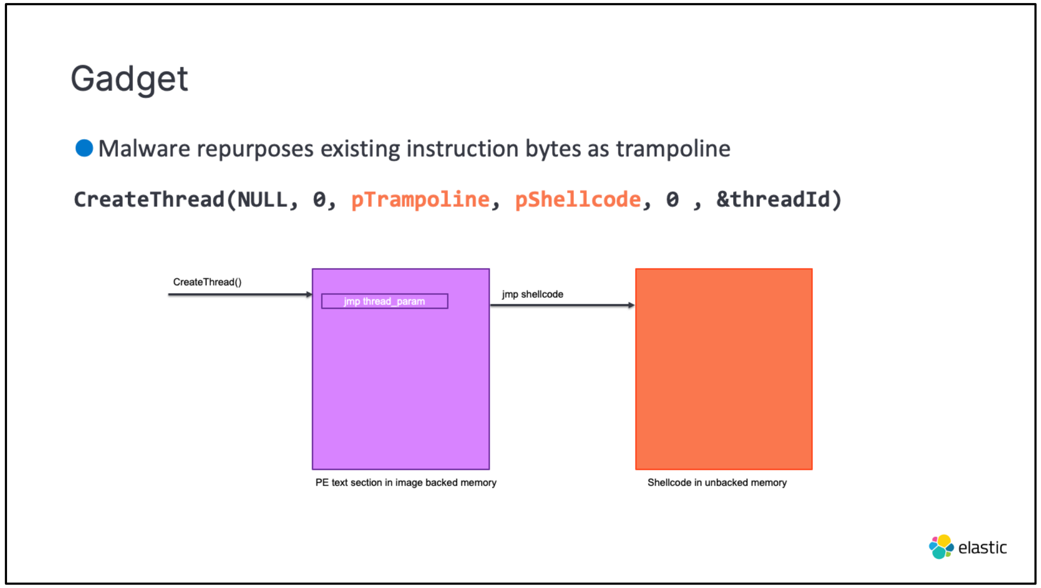
On the retrospective detection front, we just need to collect an an extra stack frame during our reconstruction of the initial stack frames – and look for a private return address in the fourth frame from the bottom. Theoretically, this could false positive on JIT or (legitimate) packed code, but I've yet to encounter a sample of this.

Red Team – Yes, you can bypass my stack climbing scan by writing some fake call stack in the slack space left by stack randomization. But -

a) endpoint security products are likely doing to be stack walking properly rather than my stack climbing approach.

b) security products can easily store the size of that randomization during thread creation and check for shenanigans later

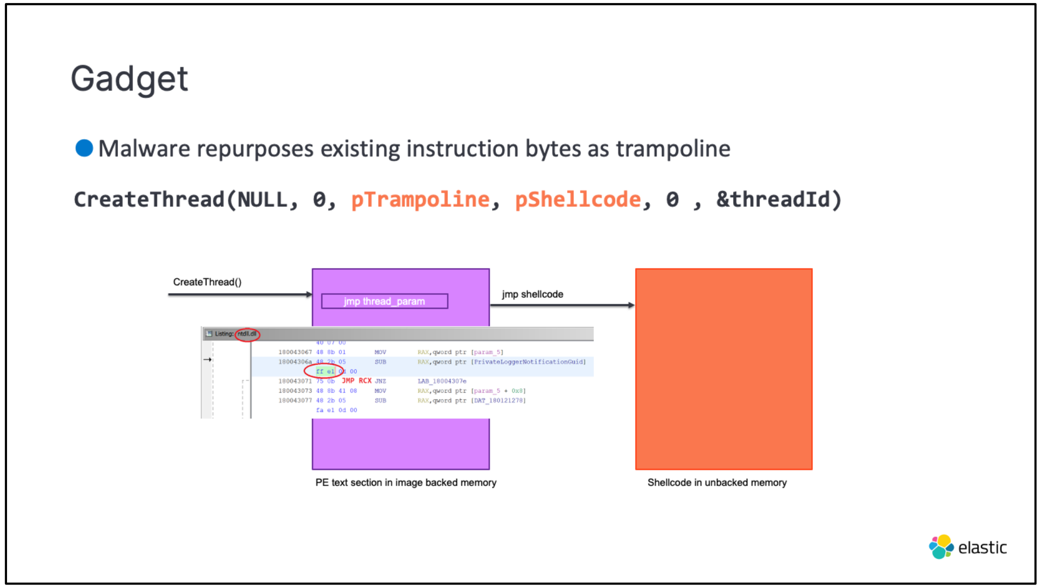
c) I can just climb the stack a little higher…



#4 – we repurpose something to do something else that the original author did not intend.
Basically, we attempt to find a suitable gadget within image backed memory so that no code modification is necessary.

Our earlier 64-bit hook was 12 bytes and finding an exact 12-byte gadget is unlikely in practice.
However, on x64 Windows, functions use a four-register fast-call calling convention by default. So, when the OS calls our gadget, we will have control over the RCX register which will contain the parameter we passed into CreateThread().

So, the simplest x64 gadget is the two-byte “jmp rcx” instruction ‘ffe1’ – which it turns out is fairly trivial to find.

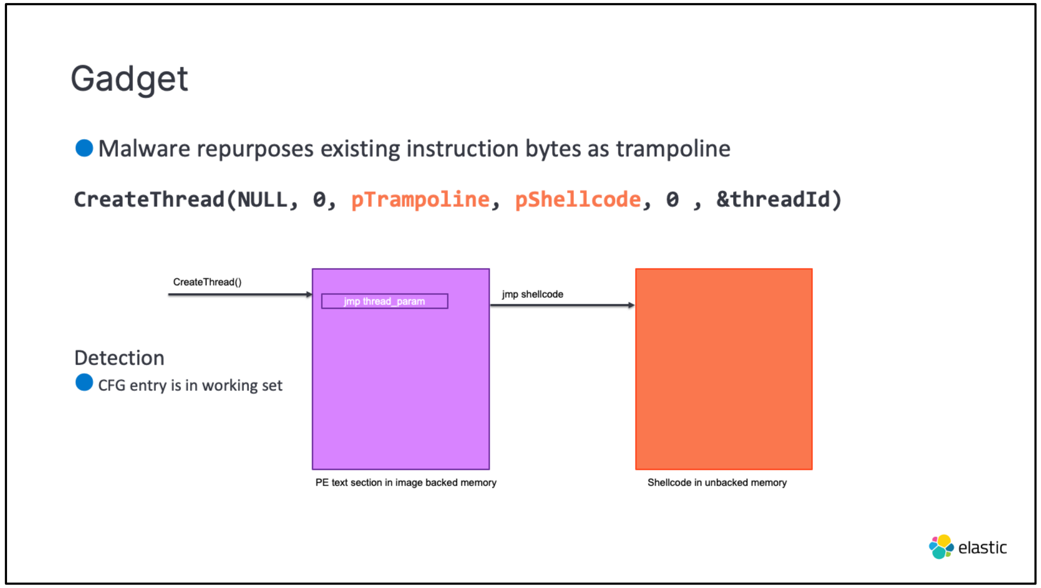


Gadgets don't even need to have originally been instructions per se – they could be within operands or other data within the code section.
For example, this "ff e1" gadget in ntdll.dll was part of the relative address of a GUID.

We could potentially come up with a list of possible RCX-RIP pivot gadgets and detect those…
But we can actually detect unknown gadgets too. Because it doesn't actually work...yet. ;-)

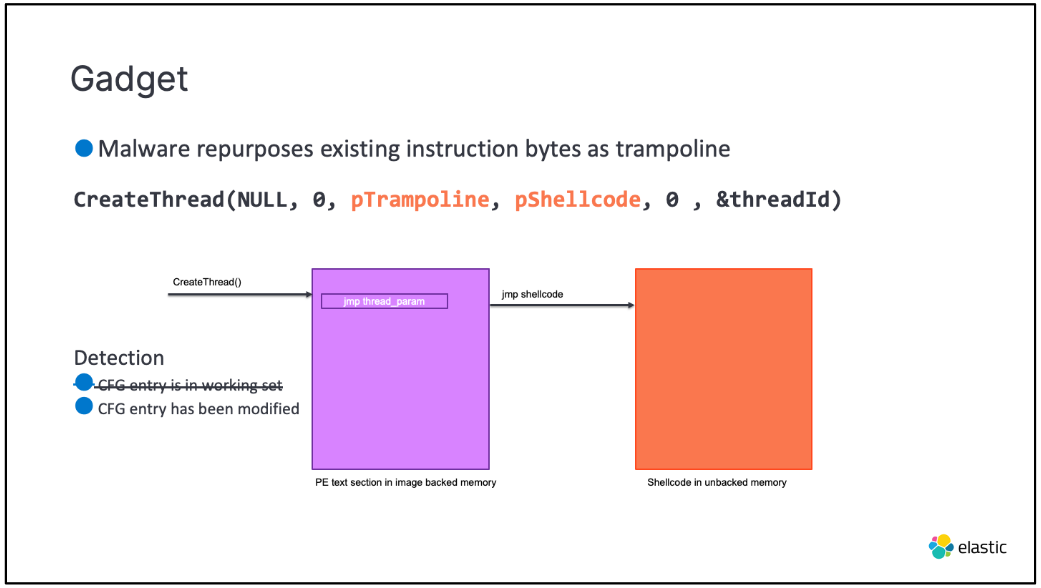
In all modern Windows software, thread start address are protected by Control Flow Guard (CFG) which has a bitmap of valid indirect call targets computed at compile time.
So, to use this gadget, the malware must typically first call the SetProcessValidCallTargets() function to ask the kernel to dynamically set the bit corresponding to this gadget in the CFG bitmap.

(This is not a CFG bypass. It is a CFG feature to support legitimate software doing weird things. Remember that CFG is an exploit protection – and being able to call SetProcessCallTargets in order to call CreateThread is a chicken and egg problem for exploit writers.)



Like before, to save memory, the CFG bitmap pages for DLLs are also shared between processes.
So, this time we can detect whether the start address's CFG bitmap entry is on a shared page or in a private working set. And alert if it is private.

Each two CFG bits corresponds to 16 addresses. Two bits is four states.
Specifically, in a pretty awesome optimisation by Microsoft, two states correspond only to the 16-byte aligned address (allowed, and export supressed) and two states correspond to all 16 addresses (allowed and denied). Modern CPUs fetch instructions in 16-byte lines so modern compilers like to align the vast majority of function entry points to 16-bytes. This means that the CFG bitmap can be an eighth of the size without any appreciable increase in the risk of valid gadgets due to an overly permissive bitmap.

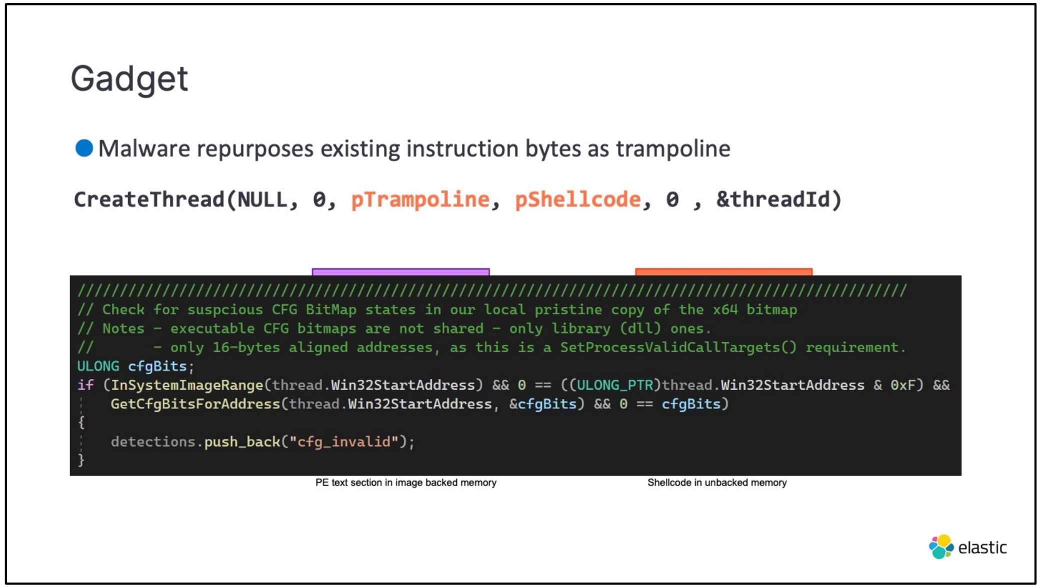


But… if each two bits corresponds to 16 addresses, then a private 4K page of bits corresponds to 256KB of code. That's quite the false positive potential…

So far, I've identified three false positive scenarios -

- The legacy Edge browser would harden its javascript host process by un-setting CFG bits for certain abusable functions.
- user32.dll is too kind to legacy software – and will un-suppress export addresses if they are registered as call back functions.
- Some security products will drop a page of hook trampolines too close to legitimate modules and private executable memory always has private bitmap entries.
  (Actually, they'll often drop this at a different module's preferred system load address – and so force that DLL to be loaded non-shared and waste a few MB of your host's physical memory as well).

So, we need to rule out FPs by comparing against an expected CFG bitmap value. We could read this from the PE file on disk… but the x64 bitmap is already mapped into our process as part of the the shared CFG bitmap!



This only work for DLLs because of their shared nature.
Microsoft's doesn't tell us where the CFG BitMap is – but we can easily find it as various exported functions need to know where it is.
Note – to detect Wow64 variants of this, you would need to run a Wow64 version of the tool.

So, to detect these gadget trampolines, we just need to to calculate the offset into the CFG BitMap for the Win32StartAddress and then read those 2 bits of memory from our own process.

And once we have that it is straight forward to check whether the address is a valid indirect call target.

Another approach to checking Win32StartAddress legitimacy would be comparison against a list of known gadget instructions.
Sure, you could attempt that, but instead of detecting known-bad can we instead create a model for good entry points?

Theoretically x64 prologs should be quite constrained because of the need to describe the prolog via UNWIND_INFO.
In theory, that's great. In practice, there are compiler writers.
It's usually just some pushes and a stack pointer adjustment and maybe a frame pointer.
But there could be some hot patch space, jump tables, optimizations for wrapper functions or early returns…

But that's still a small enough set of cases to handle.

Identifying code that doesn't follow known convention is useful – but it could easily be a rare compiler that I haven't tested against.

Get-InjectedThreadEx

```cpp
// False positives can occur if data was included in a code section. This was common in older compilers...
// ...and also in new compilers that support XFG. In this case, the 8-byte XFG hash is immediately before.
// https://blog.quarkslab.com/how-the-msvc-compiler-generates-xfg-function-prototype-hashes.html
const auto& tailbytesEnd = tailBytes.data() + tailBytes.size();
auto bIsValidTail = tailBytes.size() >= sizeof(UINT64) &&
    IsValidXfgHash(*(UINT64*)(tailbytesEnd - sizeof(UINT64)));

// The byte preceding a function prolog is typically a return, or filler byte.
bIsValidTail |= tailBytes.empty() || '\x00' == tailBytes.back(); // NUL filled.
for (auto i = 1; !bIsValidTail && i <= tailBytes.size(); i++) {
    if (!ZYAN_SUCCESS(ZydisDecoderDecodeInstruction(&decoder, NULL, tailbytesEnd - i, i, &instruction)) ||
        continue;
    switch (instruction.mnemonic) {
        // valid basic block end instructions
    case ZYDIS_MNEMONIC_CALL:
    case ZYDIS_MNEMONIC_JMP:
    case ZYDIS_MNEMONIC_RET:
        // valid alignment filler instructions
    case ZYDIS_MNEMONIC_NOP:
    case ZYDIS_MNEMONIC_INT3:
        bIsValidTail = true;;
```

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Similarly, the bytes before an entry point are usually a filler byte (00, 90 [nop] or cc [int3/breakpoint]), a return or a jump. But again – this is only convention.

And older compilers would regularly place raw data side by side with code in the executable .text section. Based on an analysis of x64 binaries on the Microsoft's symbol server I did in 2018 - this mixing of code and data was normal in Visual Studio 2012, mostly remediated in VS2013 and appears to have been finally fixed in VS2015 Update 2.

So, you might still see false positives with this heuristic – but only for non-Microsoft software.
Or so I though. Until I hit a false positive on a very recently compiled Microsoft binary. Looking closer though, that data had some very interesting cross references… I'd completely forgotten that eXtended Flow Guard litters ~55 bit hashes before any XFG protected indirect call targets. The folks at Quarks Lab reversed the algorithm and found two ~9-bit masks. One for always on. And one for always off. And I could check those.

It would be nice if Microsoft required thread entry points in images to be named exports…

Get-InjectedThreadEx

```cpp
// There are no valid thread entry points (that I know of) in many Win32 modules.
const std::array<std::string, 11> modulesWithoutThreadEntrypoints = {
    "kernel32", "kernelbase", "user32", "advapi32",
    "psapi", "dbghelp", "imagehlp", "powrprof",
    "verifier", "setupapi", "rpcrt4" }; // ...and many more
const auto startModule = std::filesystem::path(mappedPath).stem().string();
for (const auto& module : modulesWithoutThreadEntrypoints)
    if (startModule == module) {
        (void)GetNearestSymbolWithPdb(hProcess, thread.Win32StartAddress, symbol);
        detections.push_back("unexpected(" + startModule + ")");
    }

// kernel32!LoadLibrary
// And, even if there are, LoadLibrary is always a suspicious start address.
static auto hKernel32 = GetModuleHandleW(L"kernel32.dll");
static auto pLoadLibraryW = GetProcAddress(hKernel32, "LoadLibraryW");
static auto pLoadLibraryA = GetProcAddress(hKernel32, "LoadLibraryA");
if (pLoadLibraryA == thread.Win32StartAddress || pLoadLibraryW == thread.Win32StartAddress)
    detections.push_back("unexpected(" + symbol + ")");
```

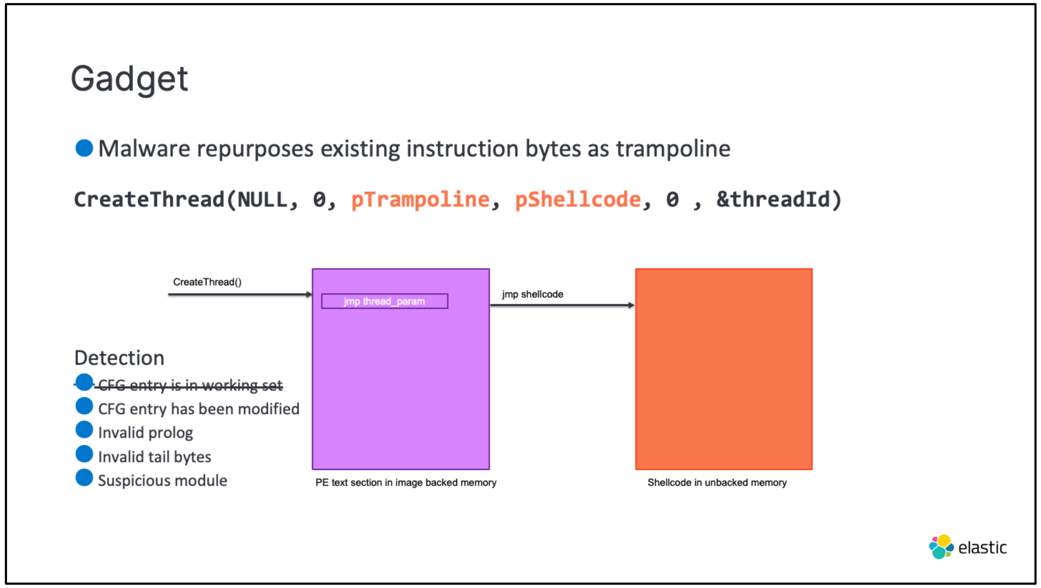
So, modules that are already loaded as typically where you want to find your gadgets.
But many Win32 modules have no valid thread entry points at all – so this is an easy check to make gadget and wrapper function use harder. Though, my list is definitely non-exhaustive.

Kernel32/base is a special case.
LoadLibrary is not technically a valid thread entrypoint – but CreateRemoteThread(kernel32!LoadLibrary, “signed.dll”) is actually how most security products would prefer software to do code injection if it really must.

Get-InjectedThreadEx

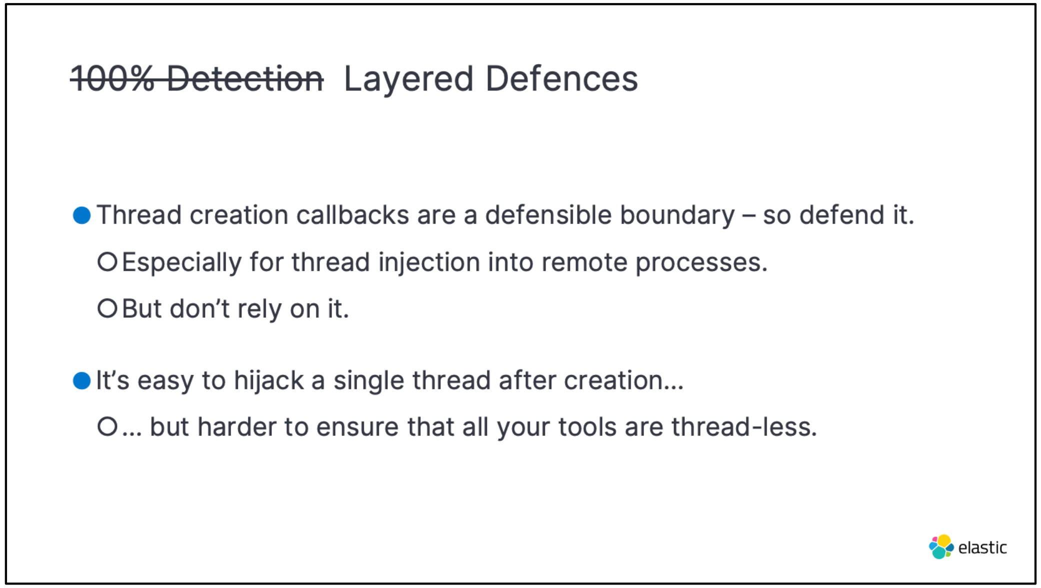
```
// ntdll.dll but not a known entrypoint.
// These are the only valid thread entry points in ntdll that I know of.
static const std::array<PVOID, 4> ntdllThreadEntryPoints = {
    GetSymbolAddress("ntdll!TppWorkerThread"),
    GetSymbolAddress("ntdll!EtwpLogger"),
    GetSymbolAddress("ntdll!DbgUiRemoteBreakin"),
    GetSymbolAddress("ntdll!RtlpQueryProcessDebugInformationRemote")
};

if (mappedPath.ends_with(L"\\System32\\ntdll.dll")) {
    auto bValidNtdllEntry = false;
    for (const auto& address : ntdllThreadEntryPoints)
        bValidNtdllEntry |= address == thread.Win32StartAddress;

    if (!bValidNtdllEntry) {
        detections.push_back("unexpected(" + symbol + ")");
    }
}
```

ntdll – it's loaded everywhere so is often the first choice for a gadget or hook.
There are only four valid ntdll entry points that I know of – so explicitly check for these.



So, in fact, there are quite a few ways to detect suspicious start address gadgets.

The end result – we can now detection the original technique plus all four classes of bypass.



Don't expect 100% detection from suspicious thread creations alone.
You'll want defence-in-depth with memory scanning of unbacked memory and detection when unbacked memory is calling out to suspicious APIs etc.

That said I'd love to hear about thread **creation** bypasses.
It's somewhat easy to hijack a single thread after creation, but ensuring that that all your malware's threads, including any third-party payloads (statically linked libraries, reflective DLLs, BOFs etc) use the right detection bypass for the installed security product(s) is a maintenance cost for the adversary. And mistakes will be made.

References

- https://www.elastic.co/security-labs/hunting-memory
  - https://www.slideshare.net/JoeDesimone4/taking-hunting-to-the-next-level-hunting-in-memory
  - https://gist.github.com/jaredcatkinson/23905d34537ce4b5b1818c3e6405c1d2
- https://blog.xpnsec.com/understanding-and-evading-get-injectedthread/
- https://www.trustedsec.com/blog/avoiding-get-injectedthread-for-internal-thread-creation/

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Links

- @jdu2600
- https://www.elastic.co/security-labs/get-injectedthreadex-detection-thread-creation-trampolines
- https://github.com/jdu2600/Get-InjectedThreadEx