DIVING INTO IE 10’S ENHANCED PROTECTED MODE SANDBOX

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AGENDA

- Introduction
- Sandbox Internals
- Sandbox Limitations / Weaknesses
- Sandbox Escape
- Sandbox Escape Demo
- Conclusion
DIVING INTO IE 10’S ENHANCED PROTECTED MODE SANDBOX

INTRODUCTION
INTRODUCTION

- Purpose: Answer important questions on EPM sandbox implementation and EPM sandbox security
- Research is based on IE 10 (10.0.9200.16540) running on Windows 8 (x64)
- More details can be found in the companion white paper
Diving Into IE 10’s Enhanced Protected Mode Sandbox

Sandbox Internals
EPM is mainly sandboxed via AppContainer

IE’s AppContainer name:
- “windows_ie_ac_<nnn>”

IE’s AppContainer capabilities:
- Default: internetExplorer, internetClient, sharedUserCertificates, (+3 more)
- Additional if “private network access” is on: privateNetworkClientServer, enterpriseAuthentication
AppContainer processes are assigned a Lowbox token

Lowbox token:
- `TOKEN_LOWBOX (0x4000)` set in the token flags
- Low Integrity
- Package/AppContainer SID
- Capability SIDs
- Lowbox Number Entry
  - Links the token with an AppContainer number (also called Lowbox number/ID) which is used in AppContainer restriction/isolation schemes
INTERNALS > RESTRICTIONS > APPCONTAINER > LOWBOX TOKEN > ILLUSTRATION

- IE EPM process tree in Process Explorer

<table>
<thead>
<tr>
<th>Process</th>
<th>PID</th>
<th>Integrity</th>
<th>Image Type</th>
<th>ASLR</th>
<th>DEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>iexplore.exe</td>
<td>2592</td>
<td>Medium</td>
<td>64-bit ASLR</td>
<td>DEP (permanent)</td>
<td></td>
</tr>
<tr>
<td>iexplore.exe</td>
<td>2852</td>
<td>AppContainer</td>
<td>64-bit ASLR</td>
<td>DEP (permanent)</td>
<td></td>
</tr>
</tbody>
</table>

- IE EPM AppContainer and Capabilities

![IE EPM AppContainer and Capabilities](image-url)
Secureable objects need to have an additional ACE for any of the following to allow AppContainer process access:

- The AppContainer
- **ALL APPLICATION PACKAGES**
- Capability that matches one of the AppContainer’s capabilities

Prevents access to personal user files (e.g.):

- `C:\Users\<UserName>\Documents, Pictures, Videos`
AppContainer-specific locations are available for data storage

File System:
- `%UserProfile%\AppData\Local\Packages\<AppContainer Name>\AC`

Registry:
- `HKCU\Software\Classes\Local Settings\Software\Microsoft\Windows\CurrentVersion\AppContainer\Storage\<AppContainer Name>`
INTERNALS > RESTRICTIONS > APPCONTAINER > SECURABLE OBJECTS > APPCONTAINER & ALL APP. PACKAGES ACE
Access to browser-related data located outside the AppContainer-specific locations is possible via the `internetExplorer` capability (S-1-15-3-4096) ACE.

Examples:
- `%UserProfile%\AppData\Local\Microsoft\Feeds` (R)
- `%UserProfile%\Favorites` (R/W)
- Few subkeys of `HKCU\Software\Microsoft\Internet Explorer` (R and R/W)
INTERNALS > RESTRICTIONS > APPCONTAINER > SECURABLE OBJECTS > INTERNETEXPLORER CAPABILITY ACE
Created named objects will be inserted into a separate AppContainer-specific object directory:
- \Sessions\<Session>\AppContainerNamedObjects\<AppContainer SID>

- Prevents named object squatting
INTERNALS > RESTRICTIONS > GLOBAL ATOM TABLE

Restrictions

- Querying and deleting global atoms are limited to atoms created or referenced by processes running in the same AppContainer
  - AppContainer references are tracked using AppContainer numbers

- Query restriction is lifted if ATOM_FLAG_GLOBAL flag is set in the atom

- More information can be found in Tarjei Mandt’s presentation "Smashing the Atom: Extraordinary String Based Attacks"
INTERNALS > RESTRICTIONS > APPCONTAINER > UIPI ENHANCEMENTS

- UIPI was introduced in Windows Vista to mitigate shatter attacks

- UIPI prevents lower-integrity processes from sending write-type window messages and installing hooks in higher-integrity processes

- In Windows 8, Win32k additionally blocks write-type messages across AppContainers
  - Done by comparing AppContainer numbers
  - AppContainer number 0 is given to non-AppContainer processes
INTERNALS > RESTRICTIONS > APPCONTAINER > NETWORK ISOLATION

- AppContainers require certain capabilities for network access:
  - `internetClient,.internetClientServer`: Connect to and receive connections from Internet and public network endpoints
  - `privateNetworkClientServer`: Connect to and receive connections from private (trusted intranet) network endpoints

- By default, IE’s AppContainer only has the `internetClient` capability
  - Access to trusted home and corporate intranets are blocked
Unapplied restriction / isolation mechanisms:
- Restricted Tokens
- Job Object Restrictions
- Desktop and Window Station Isolation

Makes some forms of attacks still possible
- Mostly relating to disclosure of some types of potentially sensitive or personal information
- Discussed later in Sandbox Limitations / Weaknesses
INTERNALS > RESTRICTIONS > UNAPPLIED RESTRICTION /
ISOLATION MECHANISMS > ILLUSTRATION

- IE EPM job object (in Process Explorer)

```
<table>
<thead>
<tr>
<th>Limit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakaway OK</td>
<td>True</td>
</tr>
</tbody>
</table>
```

- IE EPM open handles to the default desktop and the default window station (in Process Explorer)

```
<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Handle</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desktop</td>
<td>Default</td>
<td>0x40</td>
<td>0x000F00FF</td>
</tr>
<tr>
<td>WindowStation</td>
<td>\Sessions\1\Windows\WindowStations\WinSta0</td>
<td>0x3C</td>
<td>0x00020327</td>
</tr>
</tbody>
</table>
```
**INTERNALS > IE SHIMS (COMPATIBILITY LAYER)**

- Used for running binary extensions in a low-privileged environment
- Used for supporting certain functionalities that need broker assistance
- Used for applying elevation policies to launch-type APIs (*WinExec, CreateProcess, CoCreateInstance, ...*)
- Done via API hooking (Import Address Table patching)
INTERNALS > IE SHIMS (COMPATIBILITY LAYER) > ILLUSTRATION

Frame Process (Broker)
(iexplore.exe)

COM Objects
- Known Broker Objects
- User Broker Object

COM IPC
- COM Object Calls

Operating System

API Call

IE Shims

Tab Process (Sandboxed)
(iexplore.exe)
[Sandboxed: Low Integrity or AppContainer]
INTERNALS > ELEVATION POLICIES

- Determines how processes / COM servers will be launched:
  - 0: Prevent launch
  - 1: Launch in Low/AppContainer
  - 2: Launch in Medium with prompt
  - 3: Launch in Medium without prompt

- Stored in `HKLM\Software\Microsoft\Internet Explorer\Low Rights\ElevationPolicy\<GUID>`

- Consulted by IE Shims (sandboxed context) and User Broker Object (broker context)
Frame Process (Broker)
(iexplore.exe)

User Broker Object

COM IPC
- COM Object Calls

Elevation Policies

IE Shims

Tab Process (Sandboxed)
(iexplore.exe)
[Sandboxed: Low Integrity or AppContainer]

Operating System

API Call

API Call [Sandboxed]
INTERNALS > IPC

- Used by the sandboxed and the broker process to communicate

- Two types of IPC mechanism used:
  - Shared Memory IPC
    - Inter-process messages
    - Data Sharing
  - COM IPC
    - Broker COM Object calls
Used for inter-process messages and sharing data

3 shared memory sections are used for communication:
- `IsoSpaceV2_Scope<Trusted,LILNAC,Untrusted>`
- Shared memory sections are internally called “Spaces”
- Data communicated/shared are called “Artifacts”

Broker and sandboxed process are notified of message availability via messaging events
INTERNALS > IPC > SHARED MEMORY IPC > SPACES, CONTAINERS AND ARTIFACTS (ILLUSTRATION)
**INTERNALS > IPC > COM IPC**

- Used for broker COM object calls
  - Calls to User Broker Object
  - Calls to Known Broker Objects

- Bootstrapped using the Shared Memory IPC
  - Marshaled *IEUserBroker* interface of the User Broker Object is stored by broker in an *Artifact*
  - *Artifact* ID is passed to the sandboxed process via the “*CREADAT*” switch
INTERNALS > SERVICES

- Services exposed by the broker process to the sandboxed process
  - Privileged operations
  - Operations that need to run in the context of the broker/frame process
- Detailed list of services are in the companion white paper
INTERNALS > SERVICES > USER BROKER OBJECT

- Services for launching elevated processes / COM servers and instantiating Known Broker Objects

  *iertutil!CoCreateUserBroker* are used for retrieving the IEUserBroker interface

- Example Interfaces and Methods:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>IID_IEUserBroker {1AC7516E-E6BB-4A69-B63F-E841904DC5A6}</td>
<td>WinExec()</td>
<td>Invoke WinExec() in the context of the broker</td>
</tr>
<tr>
<td>IID_IEAxInstallBroker {B2103BDB-B79E-4474-8424-4363161118D5}</td>
<td>BrokerGetAxInstallBroker()</td>
<td>Instantiate “Internet Explorer Add-on Installer” COM object</td>
</tr>
</tbody>
</table>
INTERNALS > SERVICES > KNOWN BROKER OBJECTS

- Additional services exposed by the broker
- Instantiated via `IEUserBroker->CreateKnownBrokerObject()`

Example CLSIDs and Interfaces:

<table>
<thead>
<tr>
<th>CLSID</th>
<th>Interface</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLSID_ShdocvwBroker {9C7A1728-B694-427A-94A2-A1B2C60F0360}</td>
<td>IID_IShdocvwBroker {A9968B49-EAF5-4B73-AA93-A25042FCD67A}</td>
<td>Large number of services. E.g. handles forwarded <code>kernel32!CreateFileW()</code>, displaying the Internet Options dialog box, etc.</td>
</tr>
<tr>
<td>CLSID_CProtectedModeAPI {ED72F0D2-B701-4C53-ADC3-F2FB59946DD8}</td>
<td>IID_IProtectedModeAPI {3853EAB3-ADB3-4BE8-9C96-C883B98E76AD}</td>
<td>Handles the following Protected Mode API: <code>IEShowSaveFileDialog()</code>, <code>IESaveFile()</code>, ...</td>
</tr>
</tbody>
</table>
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(iexplore.exe)

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COM IPC
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Components
- IE Shims

Tab Process (Sandboxed)
(iexplore.exe)
[Sandboxed: Low Integrity or AppContainer]

Operating System

API Call

API Call [Sandboxed]
Broker code that handles IPC messages from the sandboxed process

Reachable/callable via the Shared Memory IPC

Example handlers:
- `ieframe!CBrowserFrame::_Handle*()`
- `ieframe!CDownloadManager::HandleDownloadMessage()`

Directly/indirectly calls `iertutil!IsoGetMessageBufferAddress()` to retrieve the IPC message
Frame Process (Broker)

(iexplore.exe)

Components

API Call

Shared Memory IPC
- Inter-process Messages
- Shared Data

Operating System

API Call
[Sandboxed]

Tab Process (Sandboxed)

(iexplore.exe)
[Sandboxed: Low Integrity or AppContainer]
INTERNALS > SUMMARY (PUTTING IT ALL TOGETHER)

Frame Process (Broker)

(iexplore.exe)

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COM IPC
- COM Object Calls

Shared Memory IPC
- Inter-process Messages
- Shared Data

Elevation Policies

Operating System

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IE Shims

Tab Process (Sandboxed)

(iexplore.exe)

[Sandboxed: Low Integrity or AppContainer]
DIVING INTO IE 10’S ENHANCED PROTECTED MODE SANDBOX

SANDBOX LIMITATIONS/WEAKNESSES
LIMITATIONS

- What can malicious code still do or access once it is inside the EPM sandbox?
- Compatibility and significant development effort are the most likely reasons for some of the limitations/weaknesses
- These are current limitations/weaknesses, future patches or improvements may address some, if not all of them
LIMITATIONS > FILE SYSTEM ACCESS

- Can still read files from system/common folders due to the “ALL APPLICATION PACKAGES” (AAP) ACE:
  - %ProgramFiles%
  - %ProgramFiles(x86)%
  - %SystemRoot%

- AAP ACE is for compatibility with Windows Store Apps

- Implication: List installed applications for future attacks, steal license key files stored in system/common locations, etc.
LIMITATIONS > FILE SYSTEM ACCESS (CONT.)

- Few user-specific folders are still accessible due to the “ALL APPLICATION PACKAGES” and internetExplorer ACE
  - `%UserProfile\Favorites` (R/W via internetExplorer ACE)

- Can also steal EPM cookies and cache files in AppContainer-specific location:
  - `%UserProfile%\AppData\Local\Packages\<AppContainer Name>\AC\InetCache, InetCookies`
LIMITATIONS > Registry Access

- Can still read most system/common keys due to the "ALL APPLICATION PACKAGES" ACE:
  - `HKEY_CLASSES_ROOT, HKEY_LOCAL_MACHINE, ...`

- AAP ACE is for compatibility with Windows Store Apps

- Implication: Retrieve system/general application configuration/data
  - `HKLM\Software\...\Low Rights\ElevationPolicy`
  - `HKLM\Software\...\Windows NT\CurrentVersion (Registered Owner/Org.)`
LIMITATIONS > REGISTRY ACCESS (CONT.)

- Several user-specific keys in HKCU are still accessible due to the “ALL APPLICATION PACKAGES” and the internetExplorer ACE

- Implication: Read potentially sensitive/personal information
  - HKCU\Software\...\Explorer\RunMRU
  - HKCU\Software\...\Explorer\RecentDocs
  - HKCU\Software\...\Internet Explorer\TypedURLs
LIMITATIONS > FILE SYSTEM/REGISTRY ACCESS AND RESTRICTED TOKENS

- EPM could potentially further lockdown access to user-specific locations (*HKCU* and `%UserProfile%`) using a restricted token.

- Lockdown would mean brokering access to locations that the EPM-sandboxed process would normally have direct access to, e.g.:
  - AppContainer-specific locations
  - Those that have an *internetExplorer* capability ACE
LIMITATIONS > CLIPBOARD ACCESS

- Can still read from and write to the clipboard
  - No clipboard restriction in the job object
  - Window station isolation is not implemented

- Caveat: An AppContainer process should be the process that is actively receiving keyboard input in order to access the clipboard

- Implication:
  - Capture potentially sensitive information and a potential sandbox escape vector
Can still send allowed messages (e.g. WM_GETTEXT) to windows owned by other processes
  - No UILIMIT_HANDLES restriction in the job object
  - Desktop isolation is not implemented

Implication: Capture information from controls/windows of other applications

Screen capture is another possible information disclosure attack
LIMITATIONS > NETWORK ACCESS

- Can still connect to Internet and public network endpoints
  - Possible via the `internetClient` capability

- Implications:
  - Communicate and send stolen information to a remote attacker
  - Use the system to connect to or attack other Internet and public network endpoints
LIMITATIONS > SUMMARY

- Some types of potentially sensitive or personal information can still be stolen
  - Because of the access control list of certain folders and registry keys
  - Because of unapplied or unimplemented restriction and isolation mechanisms
DIVING INTO IE 10’S ENHANCED PROTECTED MODE SANDBOX

SANDBOX ESCAPE
What are the potential vectors for escaping the EPM sandbox?
ESCAPE > LOCAL ELEVATION OF PRIVILEGE (EoP) VULNERABILITIES

- Particularly those that result in kernel-mode code execution
- Multiple kernel attack vectors are available
- Example (Win32k): CVE-2013-1300
  - Discovered by Jon Butler and Nils
  - Used to escape Google Chrome’s sandbox in Pwn2Own 2013
ESCAPE > LOCAL ELEVATION OF PRIVILEGE (EoP) VULNERABILITIES > ILLUSTRATION
Permissive policies that can cause the execution of arbitrary code in a privileged context

Example (IE): CVE-2013-3186
- Discovered by Fermin Serna
- Default elevation policy allows the execution of msdt.exe in medium without prompt
- msdt.exe can be used to execute arbitrary scripts
ESCAPE > POLICY VULNERABILITIES > ILLUSTRATION
ESCAPE > POLICY CHECK VULNERABILITIES

- Issues that can cause a policy check bypass
- Example (IE): CVE-2013-4015 (MS13-055)
  - Bug I discovered in a function used by the User Broker Object: ieframe!GetSanitizedParametersFromNonQuotedCmdLine()
  - Return value of the vulnerable function is eventually used in an elevation policy check
Mislead `ieframe!GetSanitizedParameters FromNonQuotedCmdLine()` by using a tab instead of a space to delimit app name and arguments:

```
C:\Windows\System32\cmd.exe\t..\notepad.exe /c calc.exe
```

- Returns “`C:\Windows\system32\notepad.exe`” as application name

- `C:\Windows\system32\notepad.exe` has a default medium without prompt elevation policy

- But `kernel32!WinExec()` will execute `cmd.exe` instead
Escape > Service Vulnerabilities

- Services exposed by higher-privileged processes are a large attack surface for sandbox escape

- Example (Reader): CVE-2013-0641
  - Used in the first in-the-wild Reader sandbox escape exploit
  - Buffer overflow in a broker service due to an incorrect output buffer size passed to an API
ESCAPE > SERVICE VULNERABILITIES > ILLUSTRATION

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(iexplore.exe)

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API Call

Elevation Policies

Operating System

Frame Process (Sandboxed)
(iexplore.exe)

[Container: Low Integrity or AppContainer]

IE Shims

Components

API Call

[Sandboxed]
ESCAPE > SUMMARY

- Involves exploiting a weakness in a higher-privileged code (kernel, other applications, or the broker)
- Permissive policies and improper handling of untrusted data are prime examples of weaknesses that can lead to a sandbox escape
- Vulnerabilities in the sandbox mechanisms are potential vectors for sandbox escape
  - Policy issues, policy checking and broker service vulnerabilities
DIVING INTO IE 10’S ENHANCED PROTECTED MODE SANDBOX

SANDBOX ESCAPE DEMO

CVE-2013-4015 (MS13-055)
DIVING INTO IE 10’S ENHANCED PROTECTED MODE SANDBOX

CONCLUSION
CONCLUSION

- EPM certainly helps in preventing theft of personal files and corporate assets from the network
- However, some types of potentially sensitive or personal information can still be stolen
- EPM can be further improved by combining AppContainer with other restriction/isolation mechanisms
- AppContainer is an interesting security feature to further look at
MAJOR REFERENCES (COMPLETE REFERENCE LIST IS IN THE COMPANION WHITE PAPER)


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Thank You!

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