

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

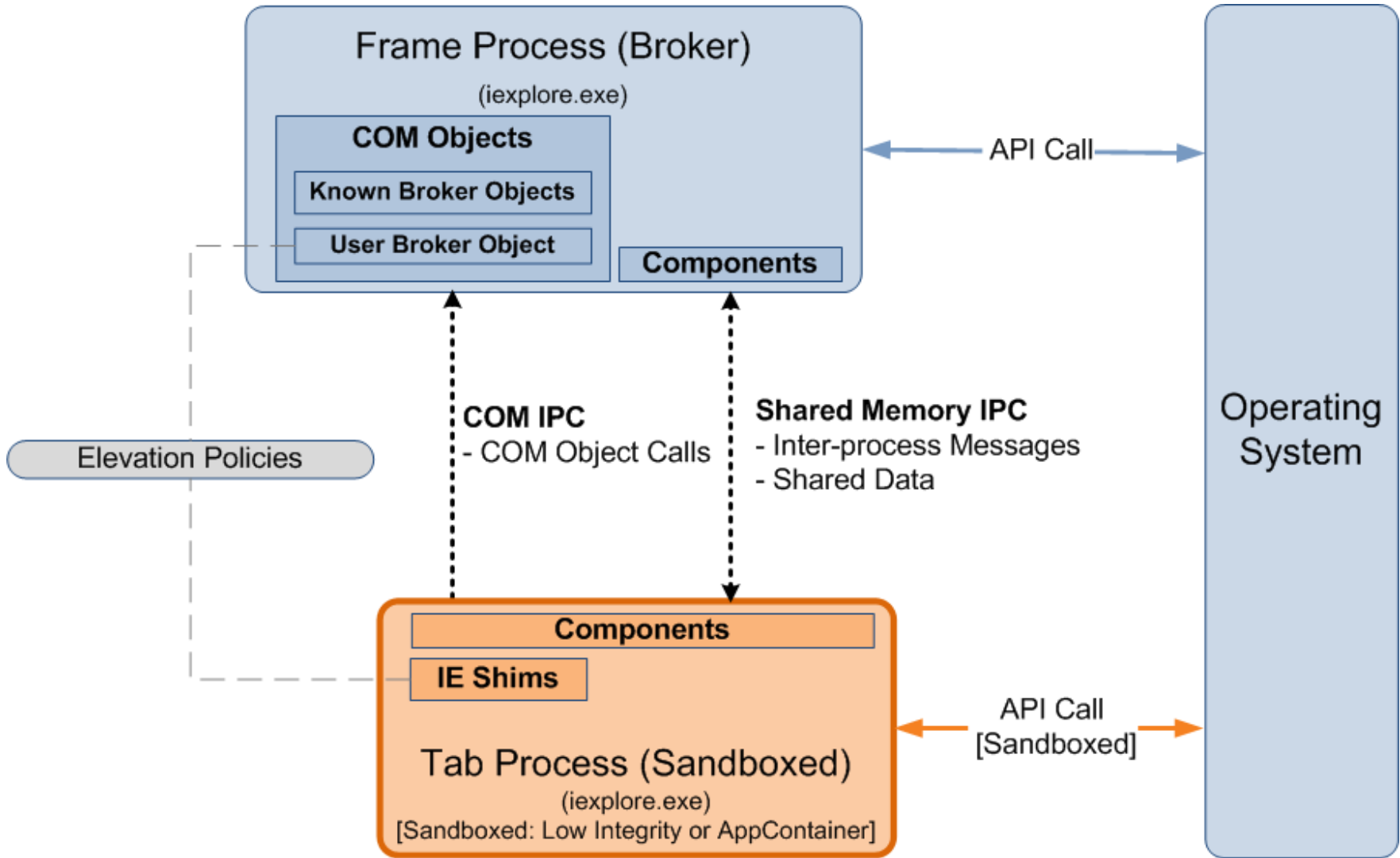
INTRODUCTION

- 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

INTERNALS > ARCHITECTURE



INTERNALS > RESTRICTIONS > APPCONTAINER

- 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*

INTERNALS > RESTRICTIONS > APPCONTAINER > LOWBOX TOKEN

- 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

Process	PID	Integrity	Image Type	ASLR	DEP
ieexplore.exe	2592	Medium	64-bit	ASLR	DEP (permanent)
ieexplore.exe	2852	AppContainer	64-bit	ASLR	DEP (permanent)

■ IE EPM AppContainer and Capabilities

ieexplore.exe:2852 Properties

User: win8-x64\user
 SID: S-1-5-21-70163908-2334023655-2539964353-1001
 Session: 1 Logon Session: 1be37
 Virtualized: No

Group	Flags
S-1-15-2-1430448594-2639229838-973813799-439329657-1197984...	AppContainer
APPLICATION PACKAGE AUTHORITY\Software and hardware c...	Capability
APPLICATION PACKAGE AUTHORITY\Your Internet connection	Capability
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
BUILTIN\Administrators	Deny
Mandatory Label\Low Mandatory Level	Integrity

INTERNALS > RESTRICTIONS > APPCONTAINER > SECURABLE OBJECTS

- Securable objects need to have an additional ACE for any of 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*

INTERNALS > RESTRICTIONS > APPCONTAINER > SECURABLE OBJECTS > APPCONTAINER-SPECIFIC LOCATIONS

- 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

AC Properties

General | Sharing | **Security** | Customize

Object name: C:\Users\user\AppData\Local\Packages>window:

Group or user names:

- Account Unknown(S-1-15-2-1430448594-2639229838-973...**
- SYSTEM
- user (win8-x64\user)
- Administrators (win8-x64\Administrators)

To change permissions, click Edit. Edit...

Permissions for Account Unknown(S-1-15-2-1430448594-2

	Allow	Deny
Full control	✓	
Modify	✓	
Read & execute	✓	
List folder contents	✓	
Read	✓	
Write	✓	

For special permissions or advanced settings, click Advanced. Advanced

[Learn about access control and permissions](#)

OK Cancel Apply

Windows Properties

General | Sharing | **Security**

Object name: C:\Windows

Group or user names:

- ALL APPLICATION PACKAGES**
- CREATOR OWNER
- SYSTEM
- Administrators (win8-x64\Administrators)

To change permissions, click Edit. Edit...

Permissions for ALL APPLICATION PACKAGES

	Allow	Deny
Full control		
Modify		
Read & execute	✓	
List folder contents	✓	
Read	✓	
Write		

For special permissions or advanced settings, click Advanced. Advanced

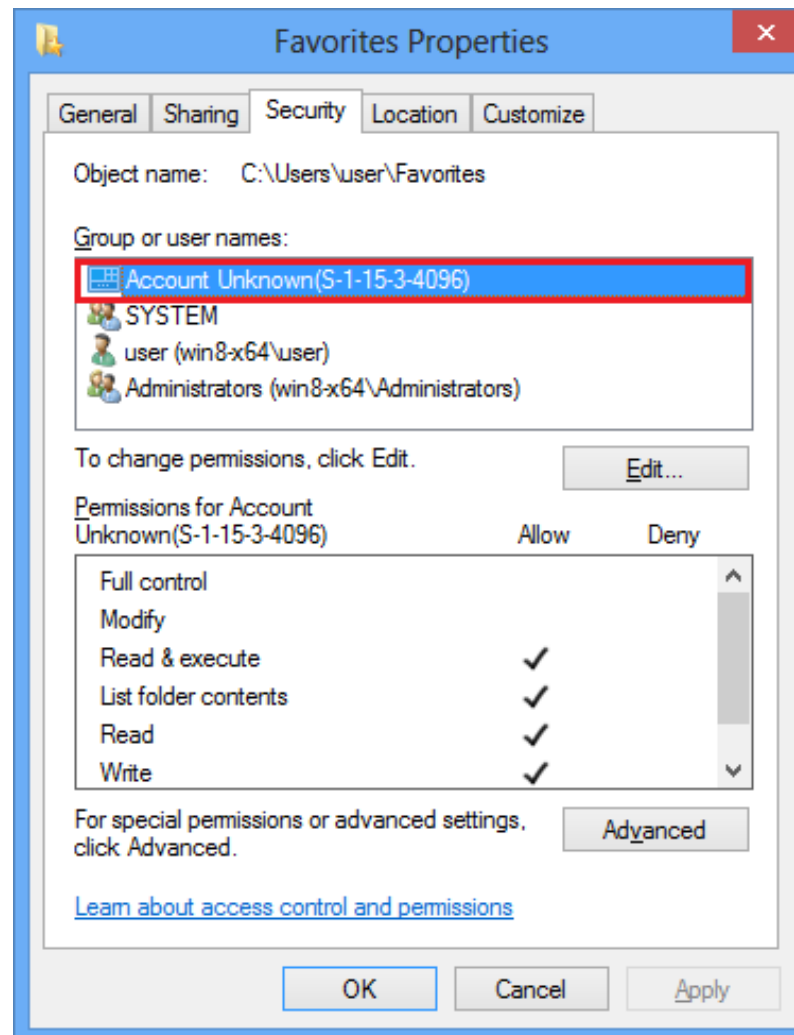
[Learn about access control and permissions](#)

OK Cancel Apply

INTERNALS > RESTRICTIONS > APPCONTAINER > SECURABLE OBJECTS > OTHER IE-ACCESSIBLE LOCATIONS

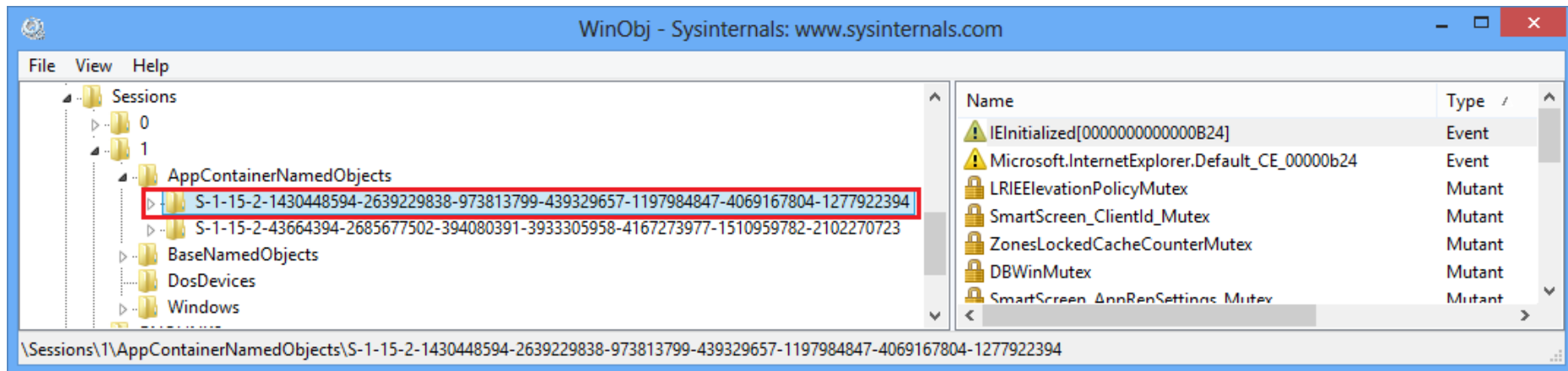
- Access to browser-related data located outside the AppContainer-specific locations is possible via the *internetExplorer* capability (S-1-15-3-4096) ACE
- Examples:
 - *%UserProfile%\AppData\Local\Microsoft\Feeds* (R)
 - *%UserProfile%\Favorites* (R/W)
 - Few subkeys of *HKCU\Software\Microsoft\Internet Explorer* (R and R/W)

INTERNALS > RESTRICTIONS > APPCONTAINER > SECURABLE OBJECTS > INTERNETEXPLORER CAPABILITY ACE



INTERNALS > RESTRICTIONS > APPCONTAINER > OBJECT NAMESPACE ISOLATION

- 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

INTERNALS > RESTRICTIONS > UNAPPLIED RESTRICTION / ISOLATION MECHANISMS

- 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)

Job Limits:

Limit	Value
Breakaway OK	True

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

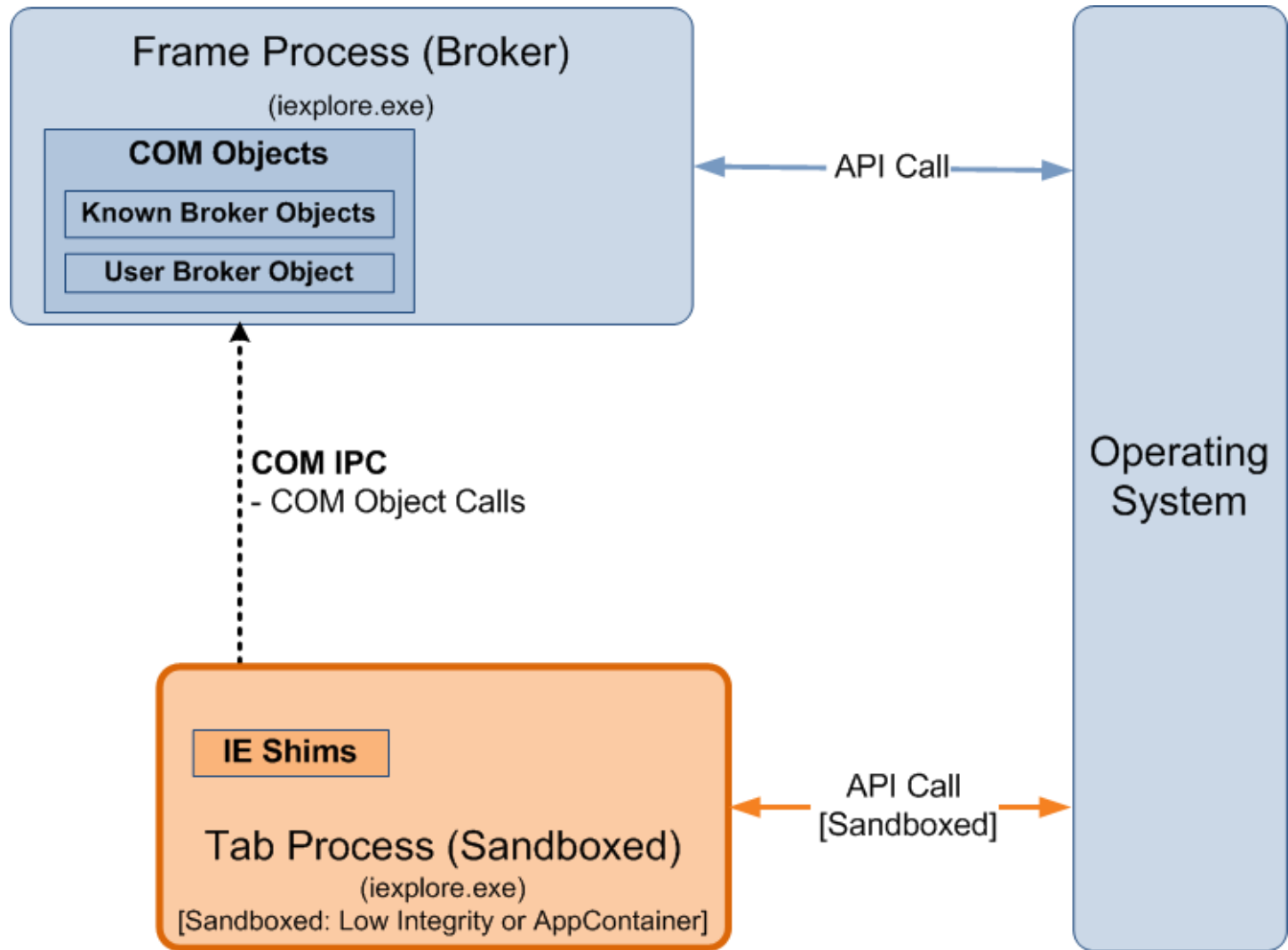
Type	Name	Handle	Access
Desktop	\Default	0x40	0x000F00FF

Type	Name	Handle	Access
WindowStation	\Sessions\1\Windows\WindowStations\WinSta0	0x3C	0x00020327

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)

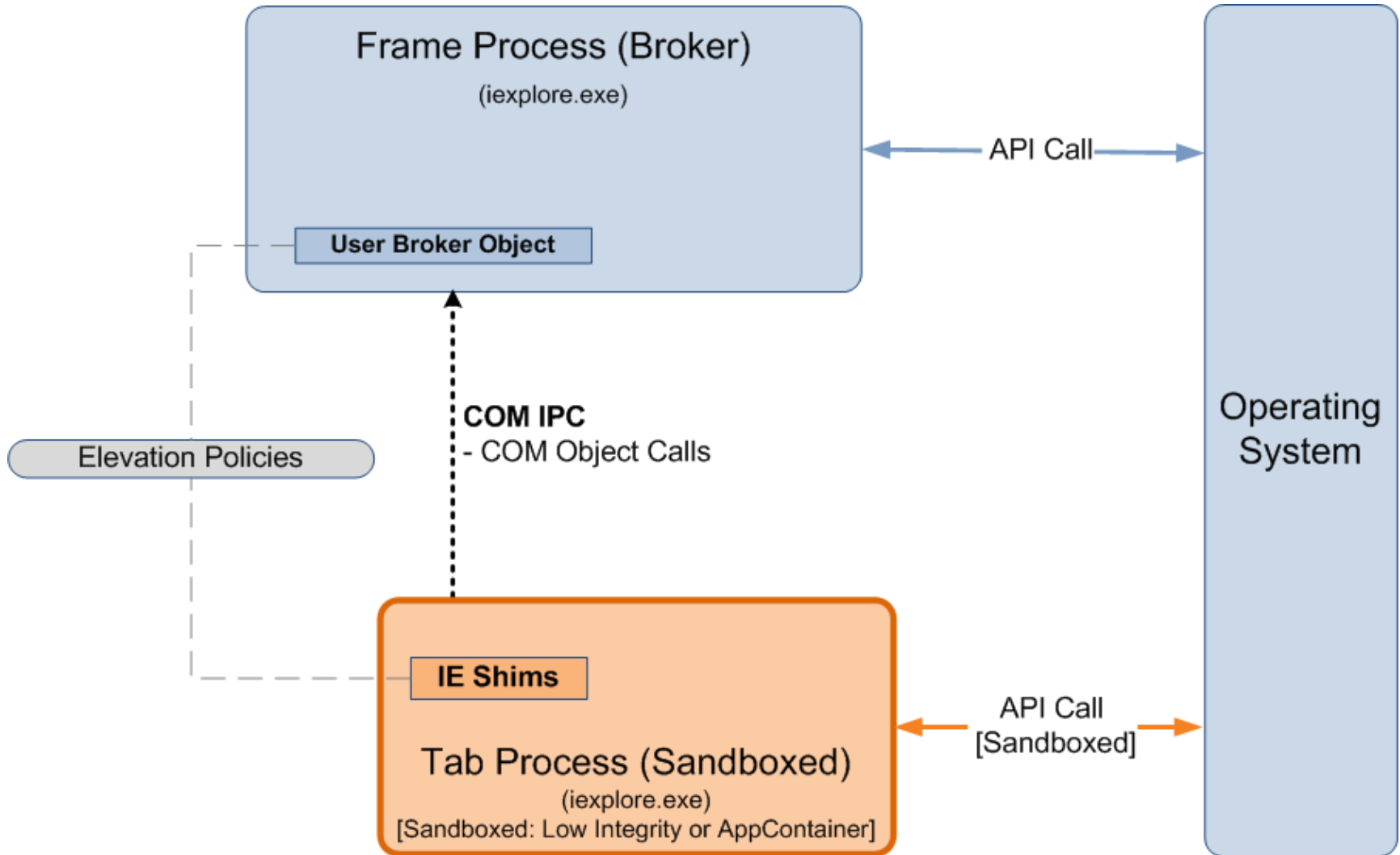
INTERNALS > IE SHIMS (COMPATIBILITY LAYER) > ILLUSTRATION



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)

INTERNALS > ELEVATION POLICIES > ILLUSTRATION



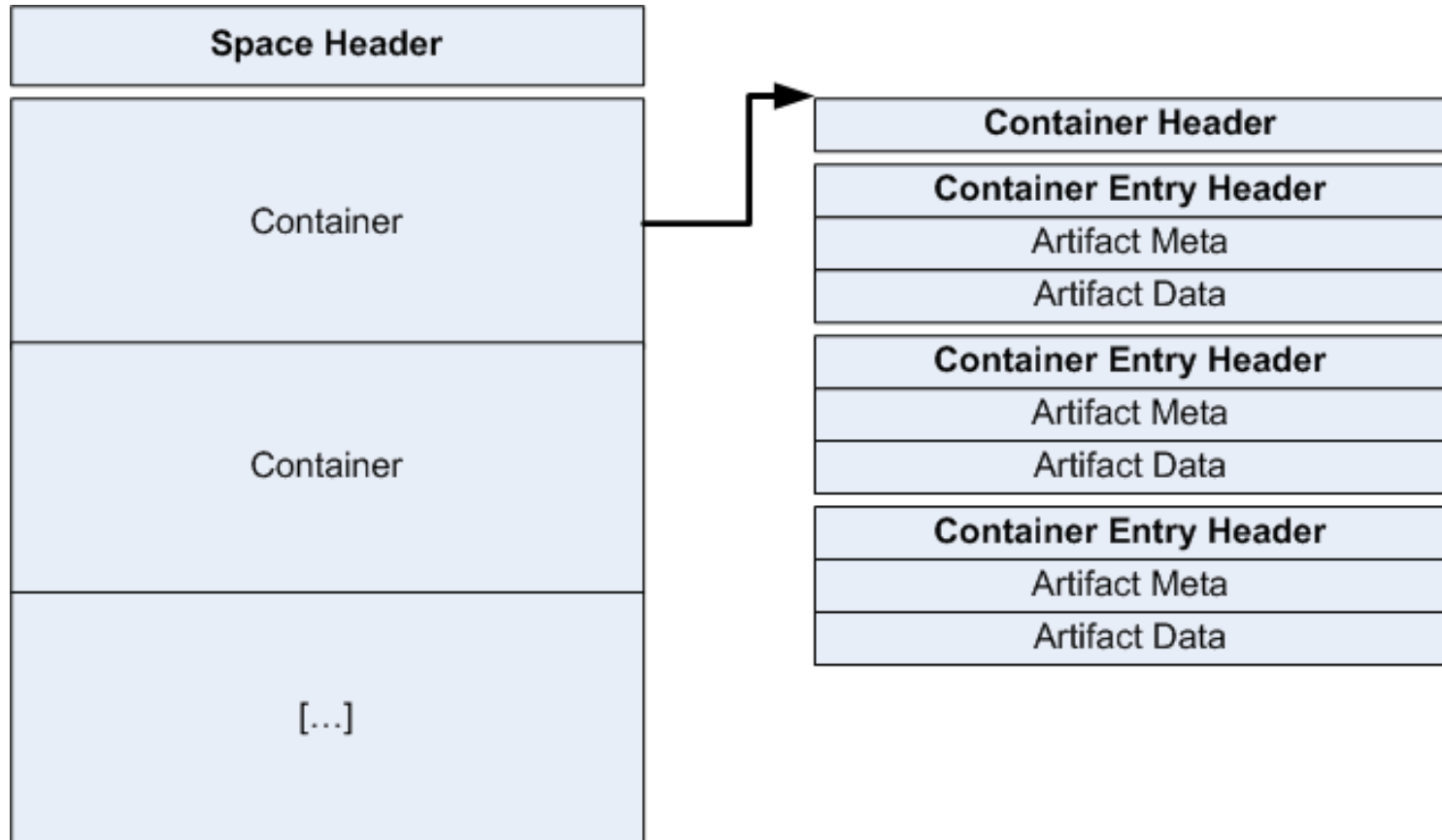
INTERNALS > IPC

- 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

INTERNALS > IPC > SHARED MEMORY IPC

- 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)

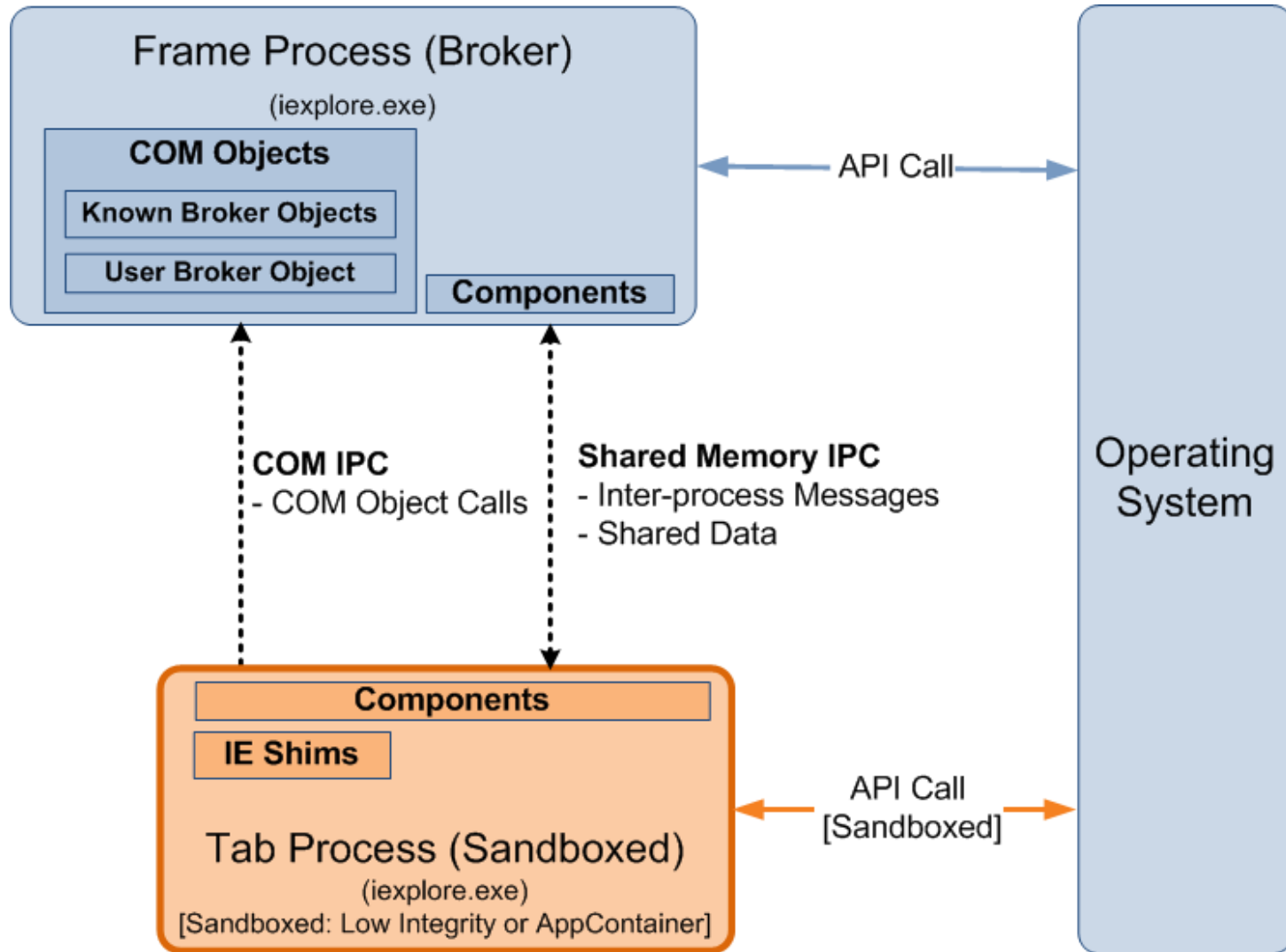


INTERNALS > IPC > COM IPC

- 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 > IPC > ILLUSTRATION



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:

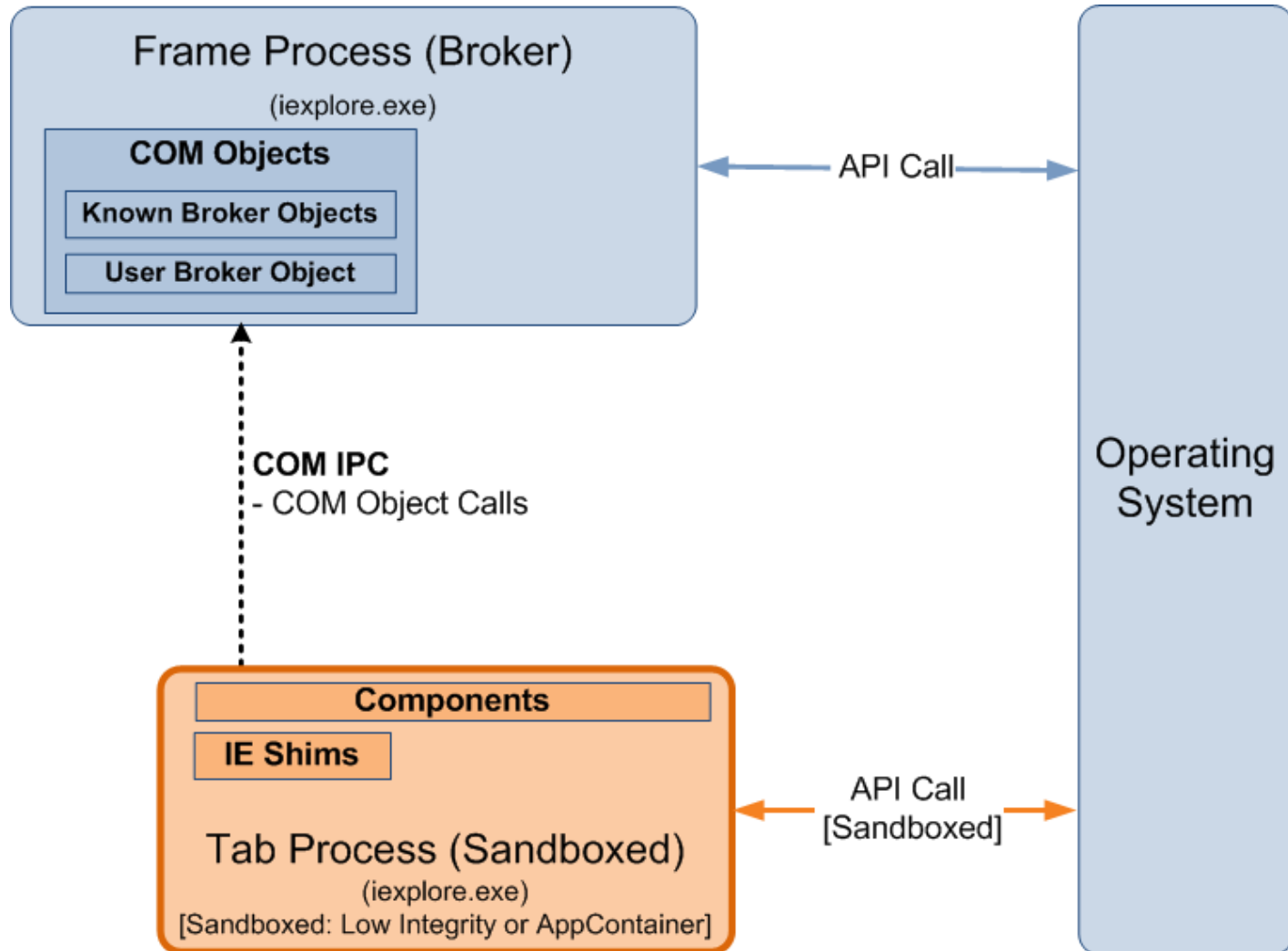
Interface	Method	Notes
IID_IEUserBroker {1AC7516E-E6BB-4A69-B63F-E841904DC5A6}}	WinExec()	Invoke WinExec() in the context of the broker
IID_IEAxInstallBrokerBroker {B2103BDB-B79E-4474-8424-4363161118D5}	BrokerGetAxInstallBroker()	Instantiate “Internet Explorer Add-on Installer” COM object

INTERNALS > SERVICES > KNOWN BROKER OBJECTS

- Additional services exposed by the broker
- Instantiated via *IEUserBroker-> CreateKnownBrokerObject()*
- Example CLSIDs and Interfaces:

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

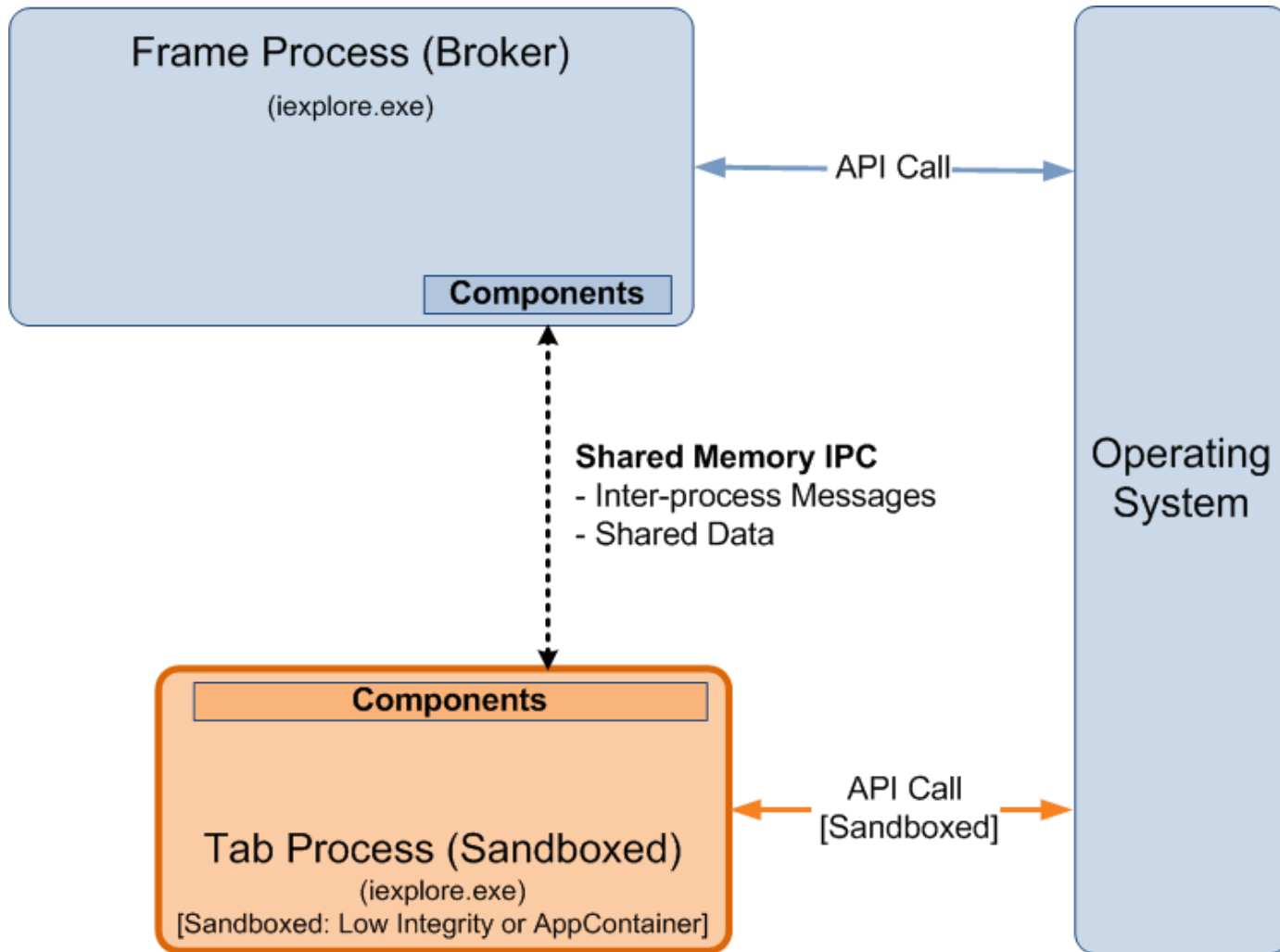
INTERNALS > SERVICES > USER BROKER OBJECT AND KNOWN BROKER OBJECTS > ILLUSTRATION



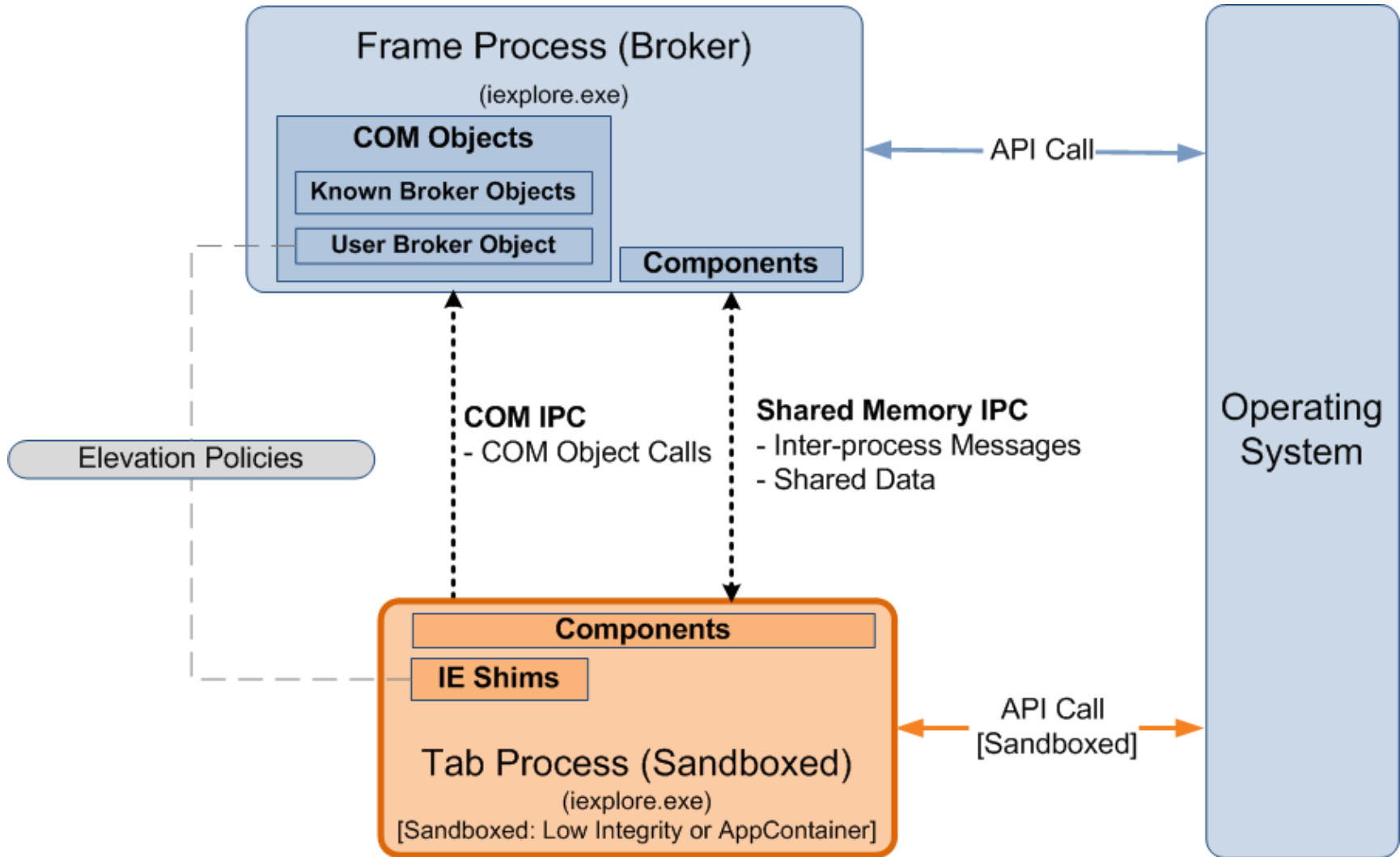
INTERNALS > SERVICES > BROKER COMPONENTS MESSAGE HANDLERS

- 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

INTERNALS > SERVICES > BROKER COMPONENTS MESSAGE HANDLERS > ILLUSTRATION



INTERNALS > SUMMARY (PUTTING IT ALL TOGETHER)



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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 has 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

LIMITATIONS > SCREEN SCRAPING AND SCREEN CAPTURE

- 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

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SANDBOX ESCAPE

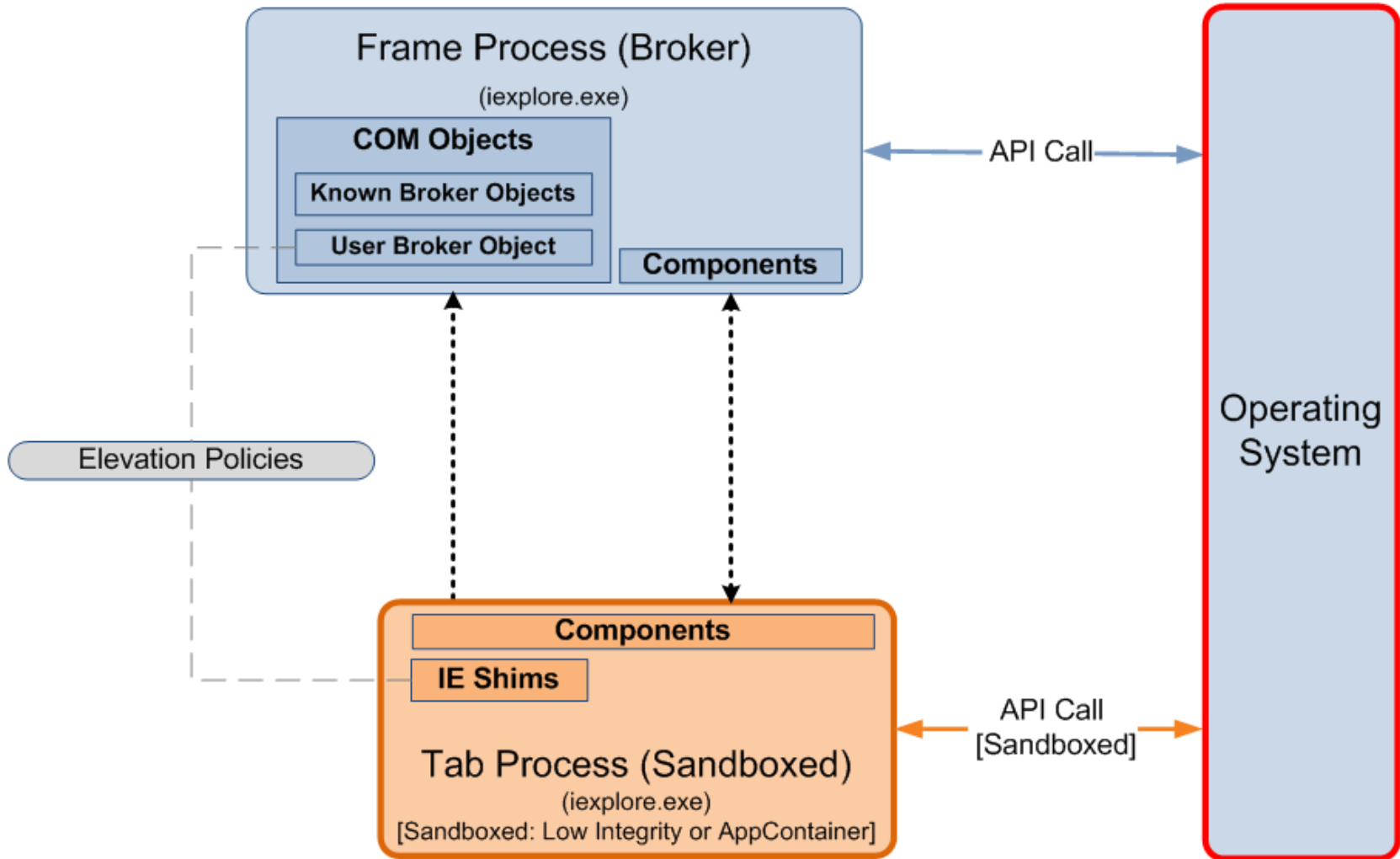
ESCAPE

- 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

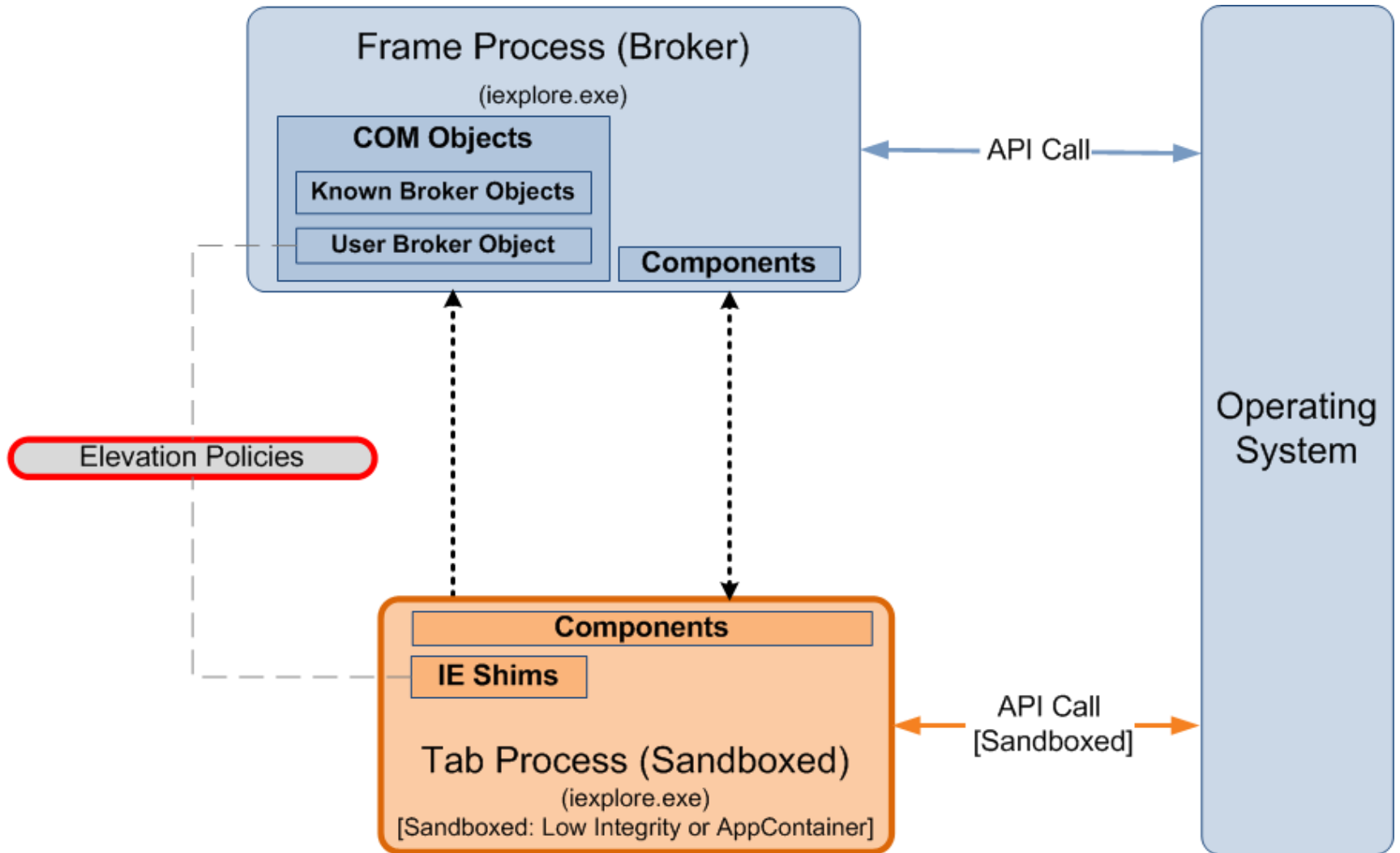
ESCAPE > LOCAL ELEVATION OF PRIVILEGE (EoP) VULNERABILITIES > ILLUSTRATION



ESCAPE > POLICY VULNERABILITIES

- 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

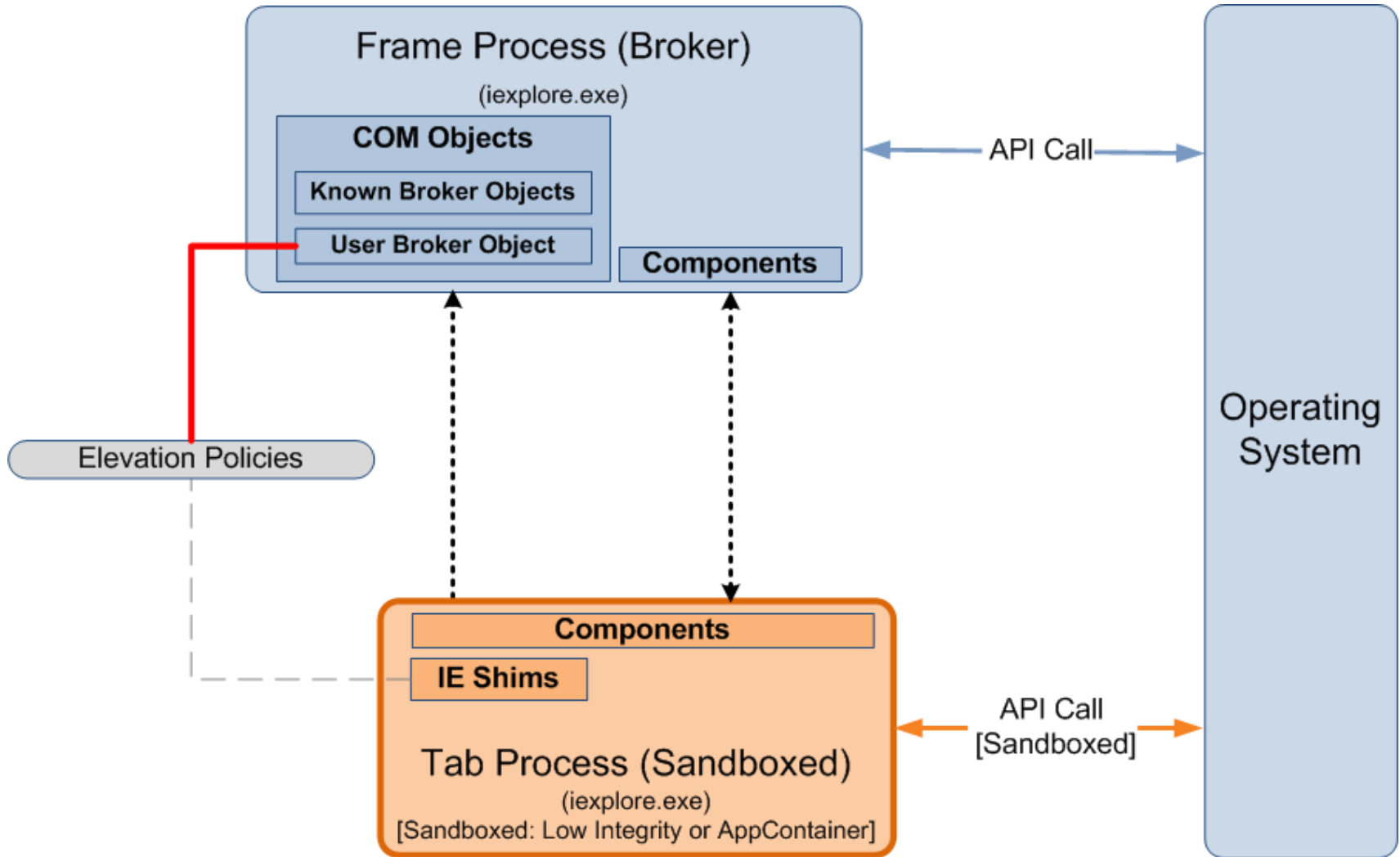
ESCAPE > POLICY CHECK VULNERABILITIES > CVE-2013-4015

- Mislead *ieframe!GetSanitizedParametersFromNonQuotedCmdLine()* 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

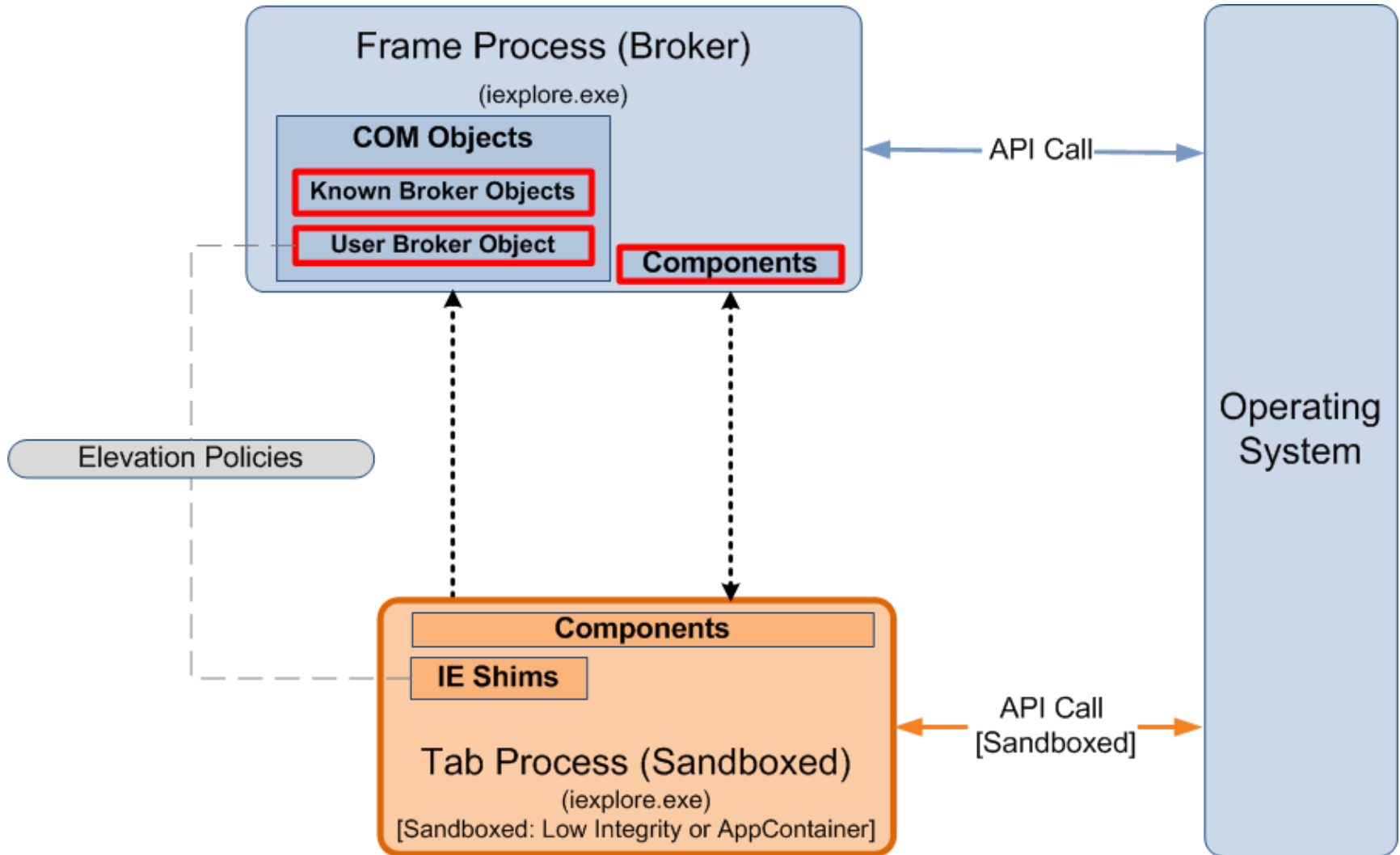
ESCAPE > POLICY CHECK VULNERABILITIES > ILLUSTRATION



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



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

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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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