SELA

SELA|DEVELOPER|PRACTICE

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ClrMD Workshop

Agenda

- Logistics
- Introduction to ClrMD
- Loading a memory dump
- ClrHeap, addresses and types
- Marshaling data from instance and static fields
- Make it simpler with C# *dynamic*
- Writing a WinDBG extension leveraging ClrMD

Logistics

- Schedule
- Requirements:
  - Windows computer with Visual Studio and WinDBG installed
  - Internet connection

- First steps
  - Download procdump from SysInternals web site
  - Download IlSpy or prepare your favorite decompiler
  - Install WinDBG

Questions

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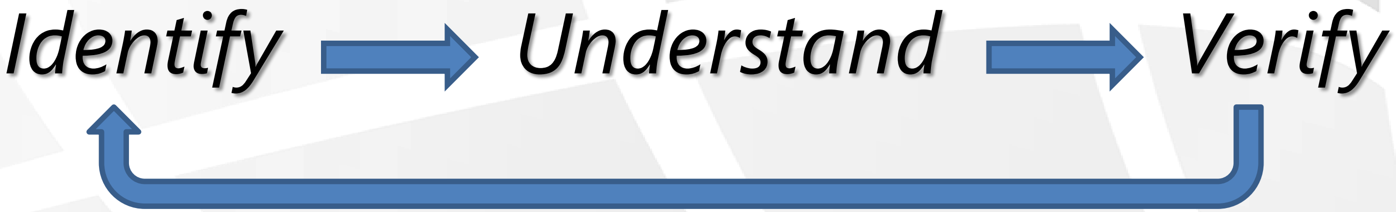
Introduction: pick the right tool

- Investigation =



Identify

Understand

Verify

- Memory issues
  - Memory profiler (Visual Studio, dotMemory/dotTrace, Perfview)

- Performance issues
  - CPU profiler (Visuals Studio, dotTrace, Perfview)

- ...and post mortem investigations
  - Procdump+WinDBG+SOS (not sure you want to go there...)

Introduction

- ClrMD helps you automate .NET application analysis in C#
- Work on running process or memory dump
- Sky is the limit!

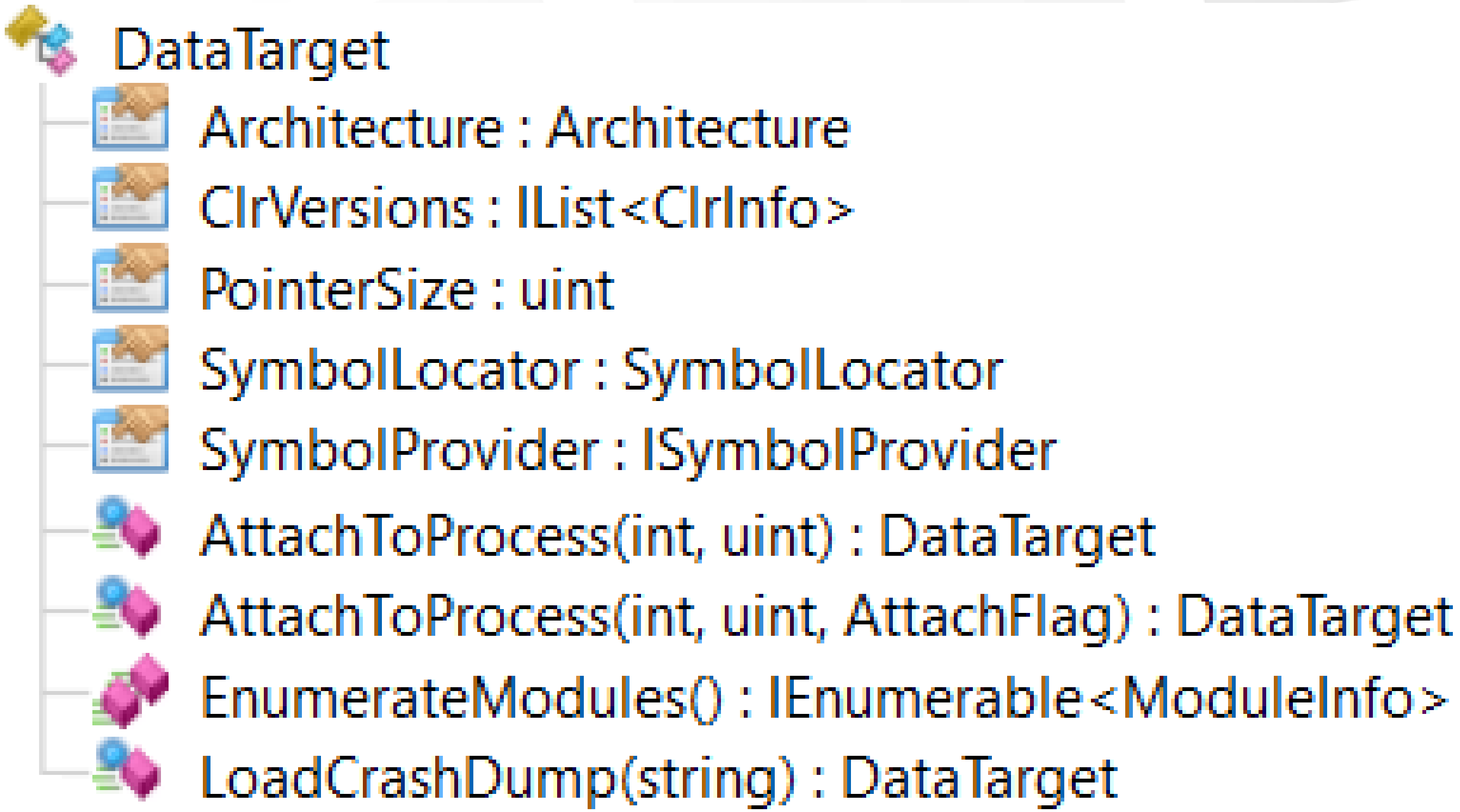
Why ClrMD?

Demo

ClrMD Basics

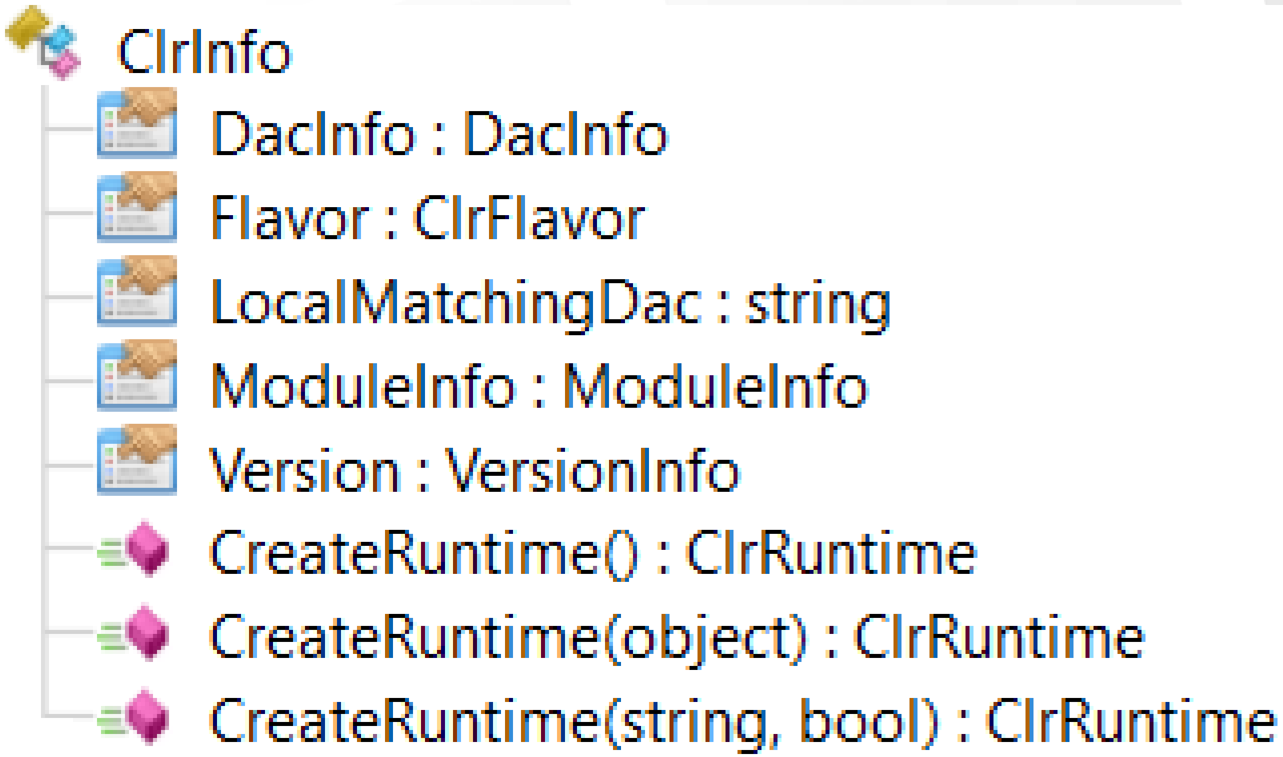
- ClrMD = Microsoft.Diagnostics.Runtime Nuget package
- The source code is available on GitHub
- Take a look at the samples and the implementation

DataTarget to bootstrap them all



- DataTarget
  - Architecture : Architecture
  - ClrVersions : IList<ClrInfo>
  - PointerSize : uint
  - SymbolLocator : SymbolLocator
  - SymbolProvider : ISymbolProvider
  - AttachToProcess(int, uint) : DataTarget
  - AttachToProcess(int, uint, AttachFlag) : DataTarget
  - EnumerateModules() : IEnumerable<ModuleInfo>
  - LoadCrashDump(string) : DataTarget

ClrInfo and a little bit of black magic



ClrInfo

- DacInfo : DacInfo
- Flavor : ClrFlavor
- LocalMatchingDac : string
- ModuleInfo : ModuleInfo
- Version : VersionInfo
- CreateRuntime() : ClrRuntime
- CreateRuntime(object) : ClrRuntime
- CreateRuntime(string, bool) : ClrRuntime

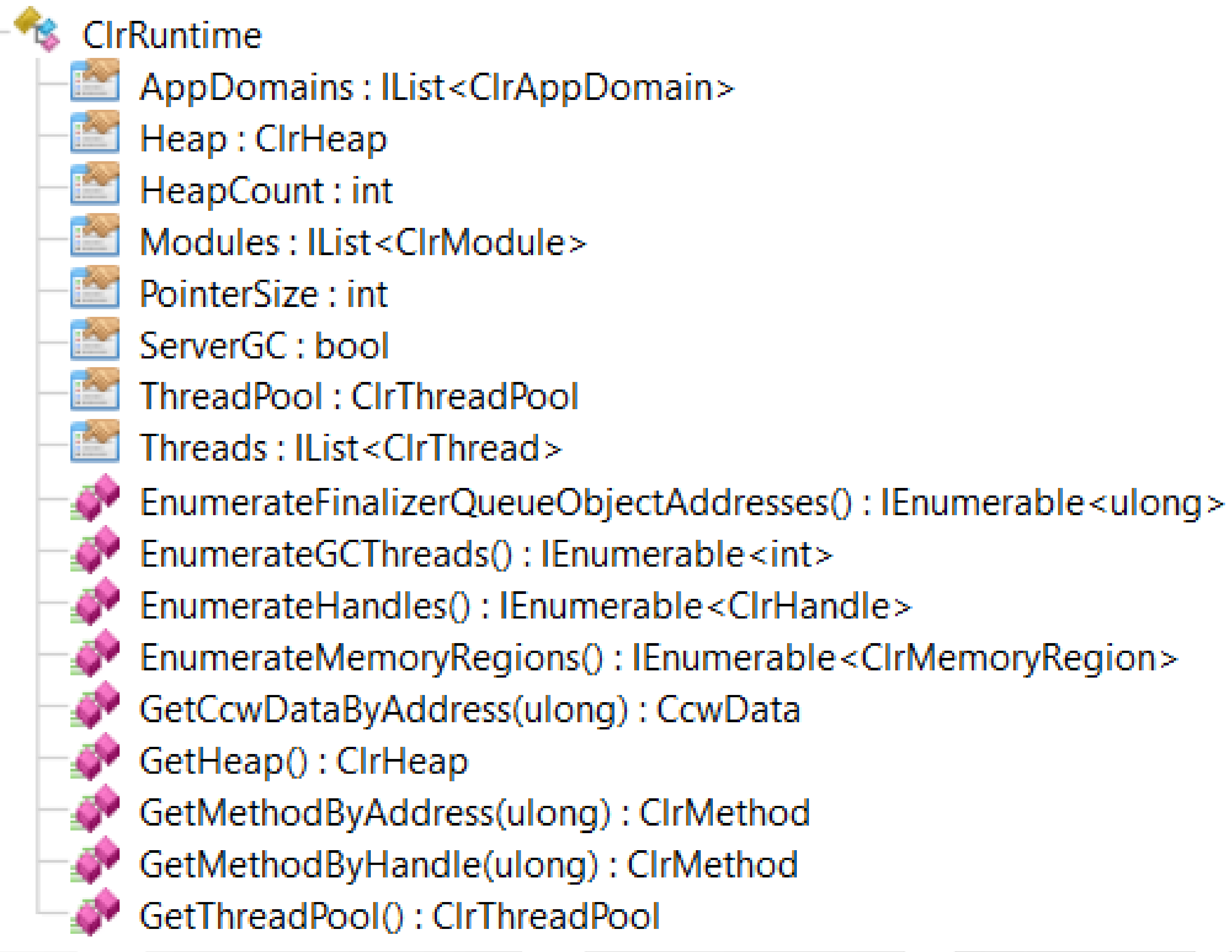
- Use DataTarget.SymbolLocator to setup symbols/dll locations

  srv*c:\symbols*http://msdl.microsoft.com/download/symbols

ClrRuntime

- AppDomains
- Threads
- Thread Pool
- Heap

- More advanced
  - finalizers
  - pinned objects
  - methods



ClrRuntime

AppDomains : IList<ClrAppDomain>

Heap : ClrHeap

HeapCount : int

Modules : IList<ClrModule>

PointerSize : int

ServerGC : bool

ThreadPool : ClrThreadPool

Threads : IList<ClrThread>

EnumerateFinalizerQueueObjectAddresses() : IEnumerable<ulong>

EnumerateGCThreads() : IEnumerable<int>

EnumerateHandles() : IEnumerable<ClrHandle>

EnumerateMemoryRegions() : IEnumerable<ClrMemoryRegion>

GetCcwDataByAddress(ulong) : CcwData

GetHeap() : ClrHeap

GetMethodByAddress(ulong) : ClrMethod

GetMethodByHandle(ulong) : ClrMethod

GetThreadPool() : ClrThreadPool

Getting started with ClrMD

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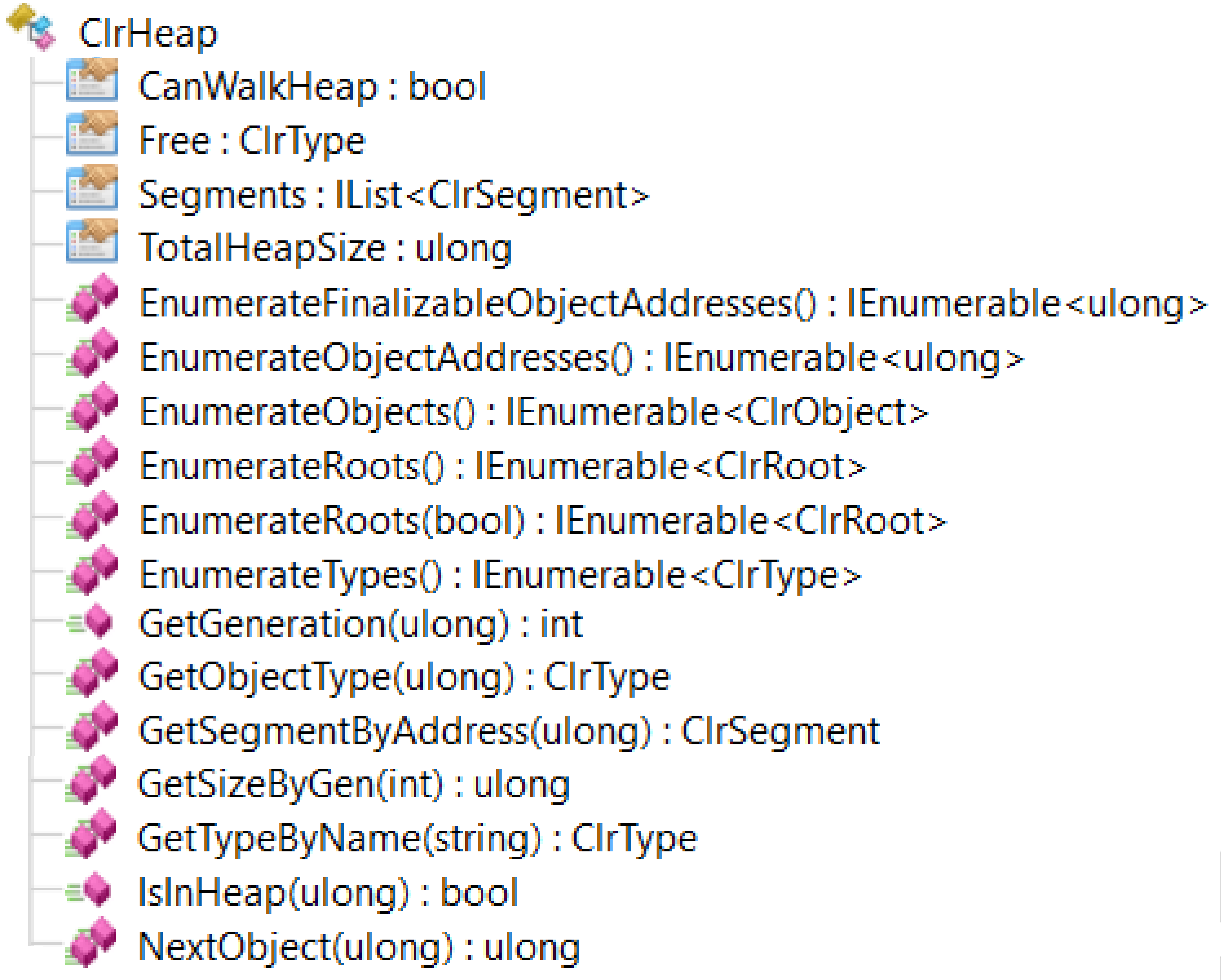
ClrHeap

- CanWalkHeap!
- address != object

- Low level details
  - segments
  - finalizables
  - roots



ClrHeap

- CanWalkHeap : bool
- Free : ClrType
- Segments : IList<ClrSegment>
- TotalHeapSize : ulong
- EnumerateFinalizableObjectAddresses() : IEnumerable<ulong>
- EnumerateObjectAddresses() : IEnumerable<ulong>
- EnumerateObjects() : IEnumerable<ClrObject>
- EnumerateRoots() : IEnumerable<ClrRoot>
- EnumerateRoots(bool) : IEnumerable<ClrRoot>
- EnumerateTypes() : IEnumerable<ClrType>
- GetGeneration(ulong) : int
- GetObjectType(ulong) : ClrType
- GetSegmentByAddress(ulong) : ClrSegment
- GetSizeByGen(int) : ulong
- GetTypeByName(string) : ClrType
- IsInHeap(ulong) : bool
- NextObject(ulong) : ulong

How to browse all objects in the heap

```
foreach (ulong address in heap.EnumerateObjectAddresses())
{
    try
    {
        var objType = heap.GetObjectType(address);
        if (objType == null)
            continue;

        var obj = objType.GetValue(address);

        ...

    }
    catch (Exception x)
    {
        WriteLine(x);
        // some InvalidOperationException might occur sometimes
    }
}
```

Count duplicated strings

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Problem of class instance marshalling

- All addresses are meaningless in the current process

- ClrType.GetValue() automatically marshals basic types
  - Numbers
  - Bool
  - String

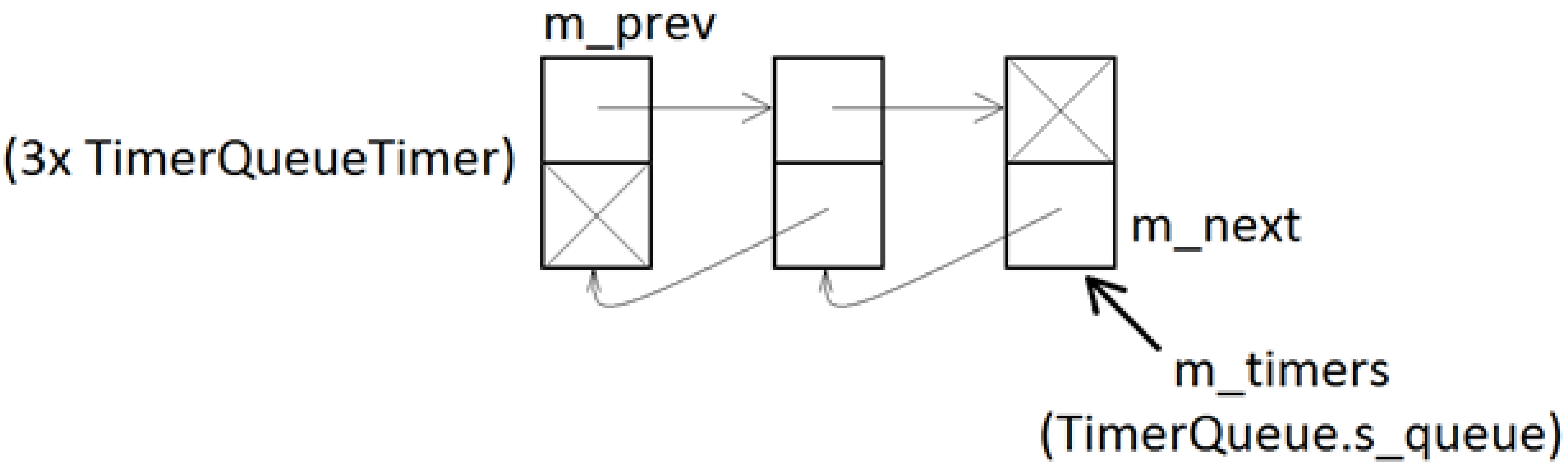
- All reference type instances must be marshalled by hand
  → field by field!

List all timers

Demo

Implementation details of Timer

- A `Timer` stores its details in a `TimerQueueTimer`
- A static `_queue` field of `TimerQueue` points to the list head



How to list all timers?

1. Get a `ClrType` for `TimerQueue`
2. Reaching a static `s_queue` field
3. Reading the static `s_queue` field value to get the list head
4. Reading an instance field to get the next `TimerQueueTimer`
5. Decyphering a callback method name and target

How to access a static field of a class? (1/2)

- Access directly to a specific `ClrType`
  - Look for the defining module
  - Call `ClrModule.GetTypeByName` with the name

```
foreach (ClrModule module in runtime.Modules)
   if (module.AssemblyName.Contains("mscorlib.dll"))
      return module.GetTypeByName("System.Threading.TimerQueue");
```

How to access a static field of a class? (2/2)

- Access a static field via `ClrType.GetStaticFieldByName`
- Each AppDomain has a different value for all statics
  - List all AppDomain
  - Check if the static has a value or not

```
ClrStaticField staticField =
   timerQueueType.GetStaticFieldByName("s_queue");
foreach (ClrAppDomain domain in runtime.AppDomains)
{
    ulong? timerQueue = (ulong?)staticField.GetValue(domain);
    if (!timerQueue.HasValue || timerQueue.Value == 0)
        continue;
```

List all timers – part 1 | get a static field

Lab

How to get instance field value?

- Get the `ClrInstanceField` from `ClrType`
  - Get the type from the instance address
- Call `ClrInstanceField`.`GetValue` with the instance address

```
var type = heap.GetObjectType(address);
ClrInstanceField field = type.GetFieldByName(fieldName);
return field?.GetValue(address);
```

How to decipher a delegate?

- Difference between an instance and a static method
  - Look for the value of **`_target`** field
- The callback is stored in the **`_methodPtr`** field
  - Use `ClrRuntime.GetMethodByAddress` to get a `ClrMethod`

```
var methodPtr = GetFieldValue(heap, timerCallbackRef, "_methodPtr");
ClrMethod method = clr.GetMethodByAddress((ulong)(long)methodPtr);
var thisPtr = GetFieldValue(heap, timerCallbackRef, "_target");
if ((thisPtr != null) && ((ulong)thisPtr) != 0)
{
   ...
```

List all timers – part 2 | get field value and method

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ClrMD can be verbose

- ClrMD is powerful but syntax can be tedious to use:

```
var type = heap.GetObjectType(address);
ClrInstanceField field = type.GetFieldByName("value");
return field?.GetValue(address);
```

- What if we could use an easier syntax?

```
return heap.GetProxy(address).value;
```

Problems with ClrMD

- Verbose syntax to get any value
  - Need a `ClrType`
  - Marshal everything explicitly

- Lack of enumeration/array iterator
  - Where are my `for`/`foreach`?

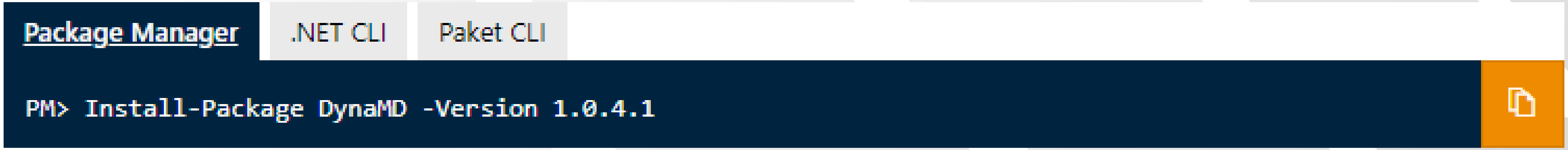
- Missing boilerplate helpers
  - How to get all instances of a type?

Late-binding in C#

- `dynamic` keyword enables the usage of late-binding in C#

- Implement `DynamicObject` and override `TryGetMember`, `TryInvokeMember`, `TryConvert` and `TryGetIndex` as needed

- DynaMD does all that, and a bit more



```
PM> Install-Package DynaMD -Version 1.0.4.1
```

DynaMD or how to access objects with C# syntax

- Wrap remote objects with `DynamicProxy`
  - `var obj = heap.GetProxy(address);`
- Access object fields a-la C#
  - `var buckets = obj.m_tables.m_buckets`
- Allow **`foreach`** on `IEnumerable` and **`for`** on arrays
- Easy to wrap
  - `var queues = heap.GetProxies(concurrentQueueTypeName);`

Look at DynaMD usage

Demo

Look into concurrent data structures

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WinDBG Extension 101

- Extension = .dll exporting commands as native functions
  - Case sensitive
  - Provide long and short command names
  - Even the !help command
- Use UnmanagedExports nuget to export managed methods
  - Decorate your static methods with DllExport attribute

  -
    ```
    MyCmd(IntPtr client, [MarshalAs(UnmanagedType.LPStr)] string args)
    ```
- Copy your extension + dependencies into winext subfolder

Bind ClrMD with WinDBG extension

- Add Common.cs from Github WinDbgExt sample
  - Resolve dependency to ClrMD thanks to `AppDomain.AssemblyResolve`
  - Expose `DebugExtensionInitialize` function for versioning
  - Bind the `Console.Write/WriteLine` output to WinDBG output

- Extend the DebuggerExtensions partial class with your commands
  - Just call `InitApi()` with the received `IDebugClient`

Show ClrMD GitHub common.cs

Demo

String duplicates in WinDBG

Lab

Questions

Resources

- Criteo blog series and source code
  - http://labs.criteo.com/2017/12/clrmd-part-9-deciphering-tasks-thread-pool-items/
  - https://github.com/chrisnas/DebuggingExtensions

- ClrMD on github for source code and samples

  https://github.com/Microsoft/clrmd

- DynaMD on github

  https://github.com/kevingosse/DynaMD