Public Preview Version

.NET Memory Dump Analysis Accelerated

Version 4.0

.NET Core and Framework

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Prerequisites

WinDbg Commands

We use these boxes to introduce some WinDbg commands used in practice exercises

Basic .NET programming and debugging

Training Goals

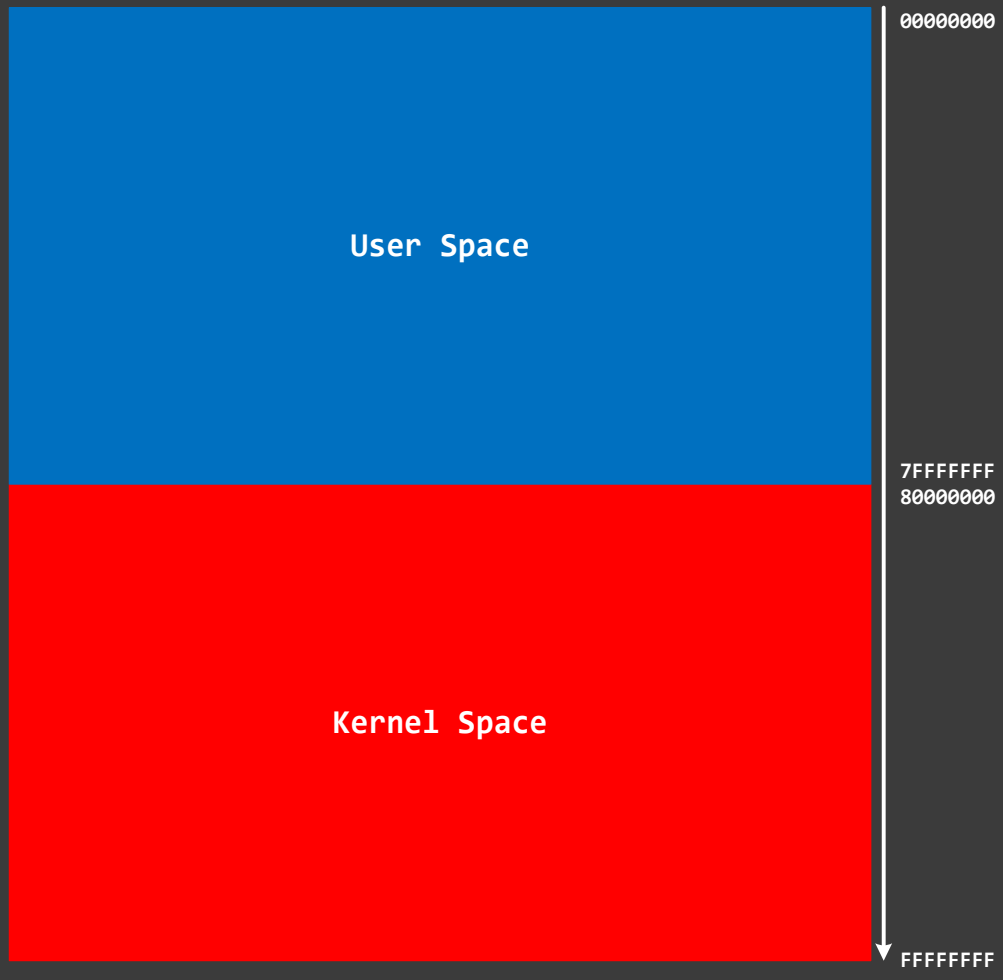
- Review fundamentals
- Learn how to analyze process dumps
- Learn necessary commands in context
- Cover CoreCLR and CLR 4 (x86 and x64)

Training Principles

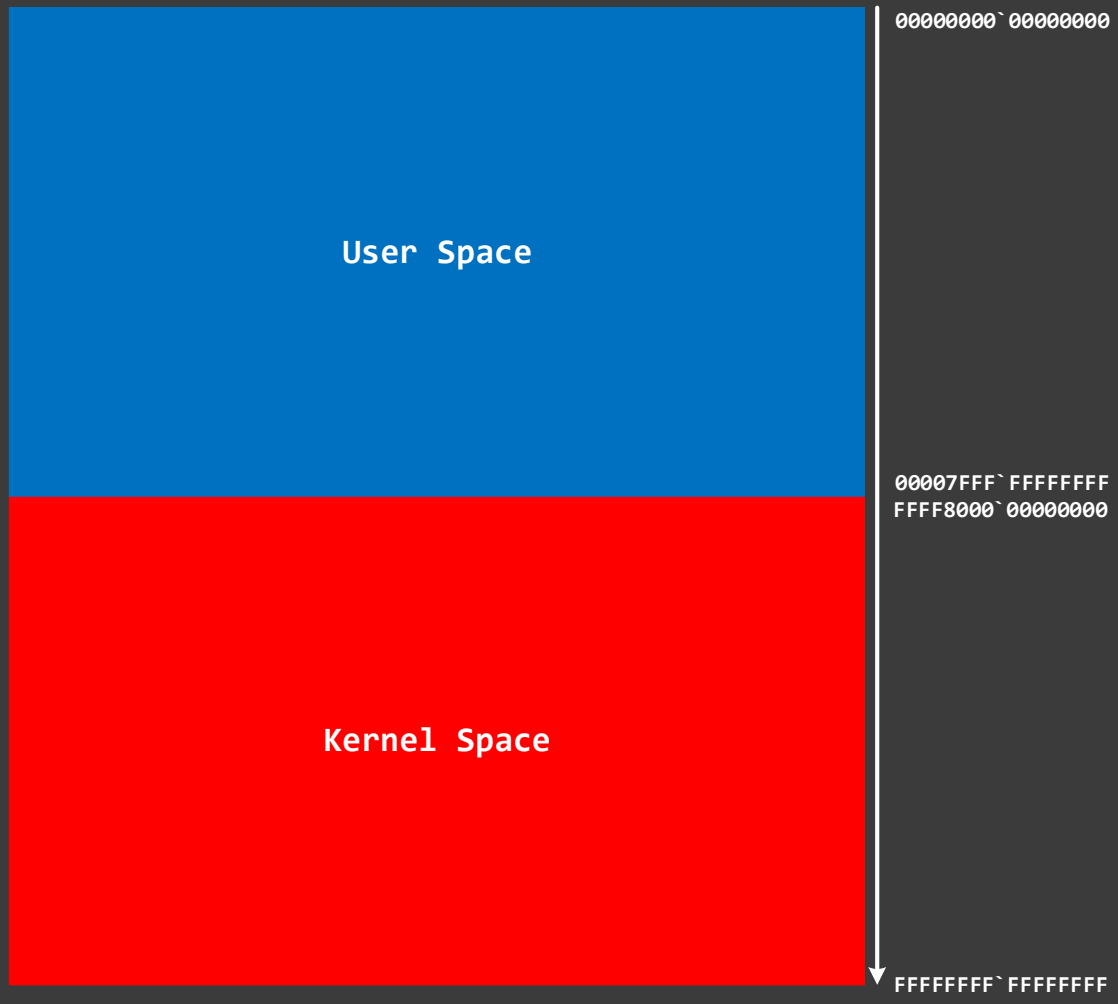
- Talk only about what I can show
- Lots of pictures
- Lots of examples
- Original content and examples

Part 1: Fundamentals

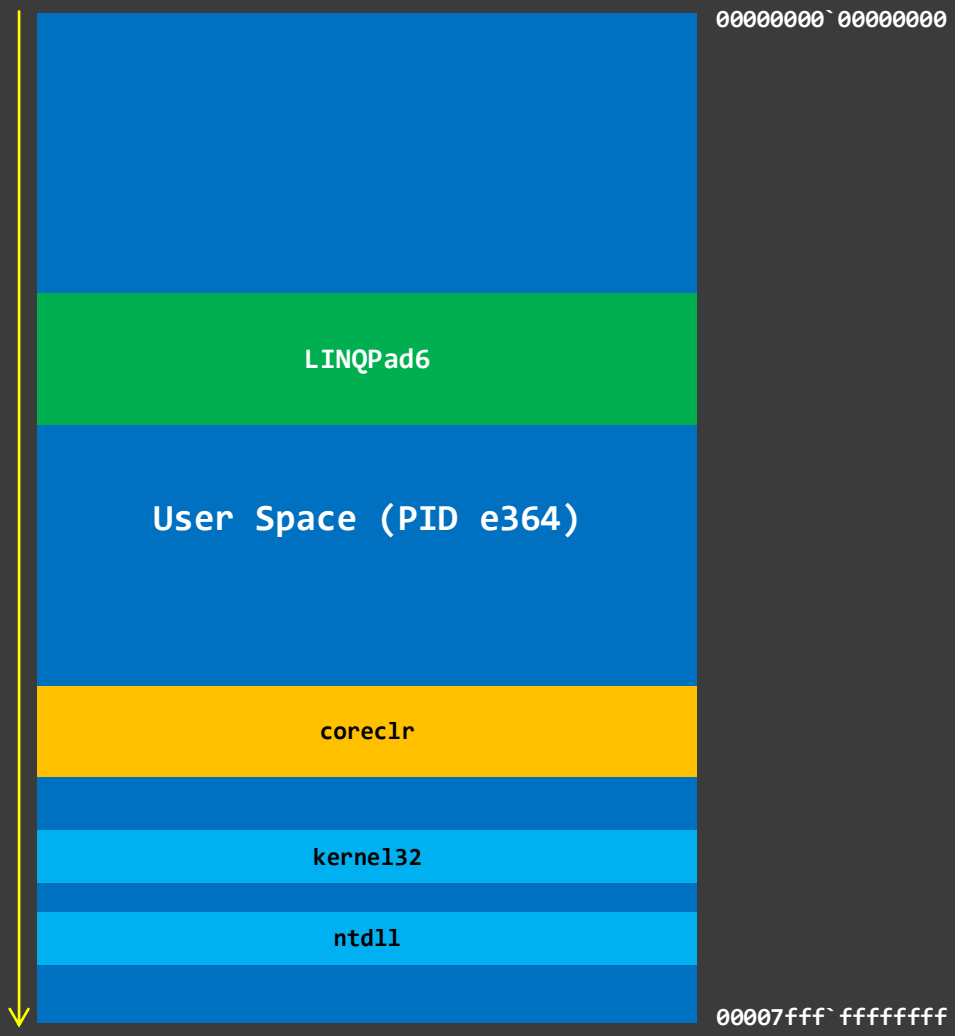
Memory Space (x86)



Memory Space (x64)



User / Managed Space



WinDbg Commands

lmv command lists all loaded modules (EXE and DLLs)

Types/Assemblies/Modules

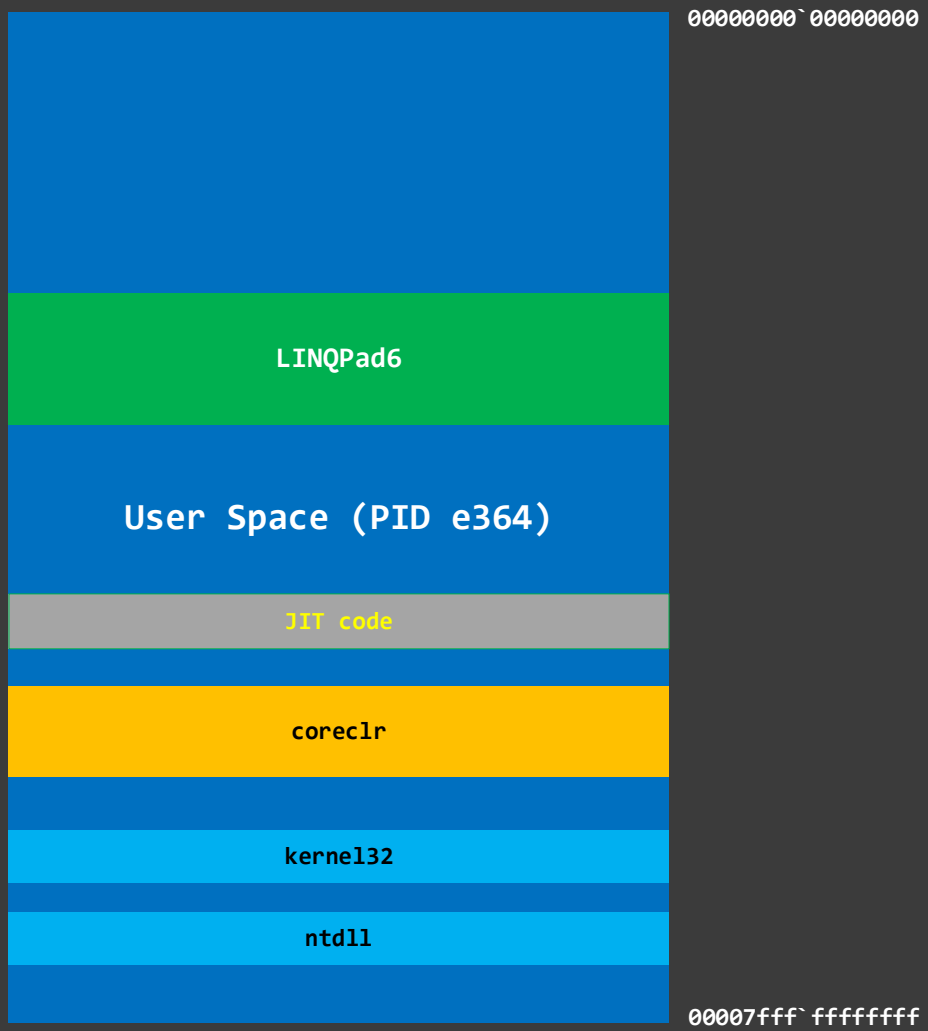
WinDbg Commands

lmv command lists all loaded modules (EXE and DLLs)

!IP2MD command shows type method and module address

!DumpModule command shows module name

Process Threads



WinDbg Commands

.load *<a path to SOS>*
Loads SOS WinDbg extension

~<n>s command switches between threads

k command shows unmanaged stack trace

!Threads command shows managed threads

!CLRStack command shows managed stack trace

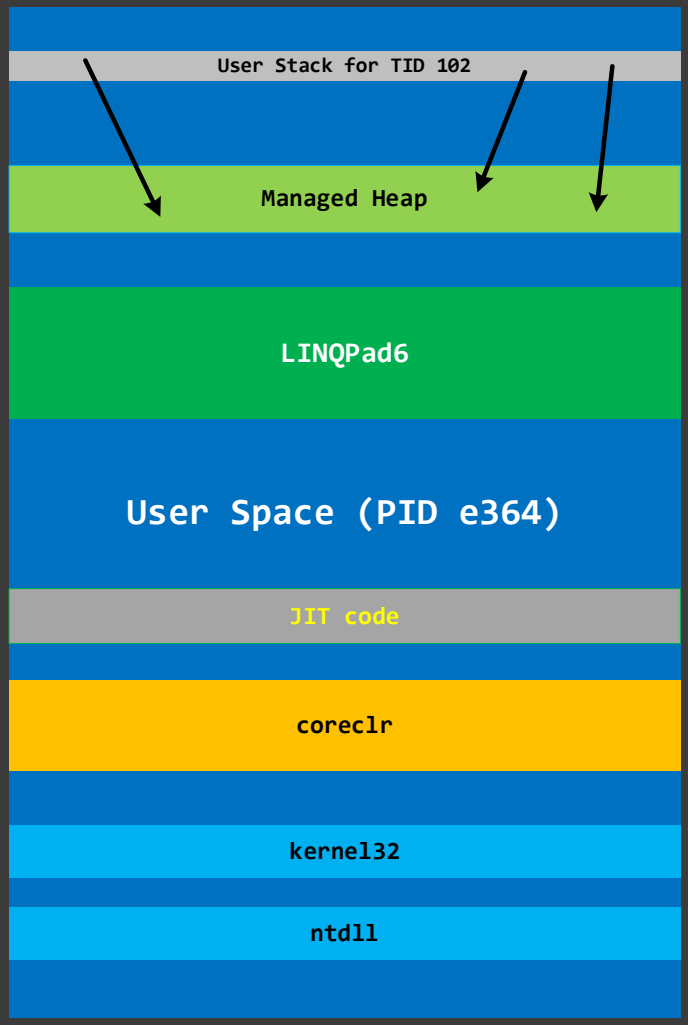
Example

```
0:000> kL
 # Child-SP          RetAddr           Call Site
00 00000029`6e3add78 00007ffa`7eb90458 win32u!NtUserWaitMessage+0x14
01 00000029`6e3add80 00007ffa`d7244d61 0x00007ffa`7eb90458
02 00000029`6e3ade40 00007ffa`d7247486 System_Windows_Forms!...+0x581
03 00000029`6e3adf50 00007ffa`d7247026 System_Windows_Forms!...+0x416
04 00000029`6e3ae000 00007ffa`d6ef212b System_Windows_Forms!...+0x46
05 00000029`6e3ae060 00007ffa`7cb021e4 System_Windows_Forms!...+0x3b
06 00000029`6e3ae0a0 00007ffa`7cae2534 0x00007ffa`7cb021e4
07 00000029`6e3ae350 00007ffa`7c70a16d 0x00007ffa`7cae2534
08 00000029`6e3ae680 00007ffa`7c7015c2 0x00007ffa`7c70a16d
09 00000029`6e3ae6e0 00007ffa`dc226ce3 0x00007ffa`7c7015c2
0a 00000029`6e3ae7b0 00007ffa`dc1bcc42 coreclr!CallDescrWorkerInternal+0x83
0b (Inline Function) --------`-------- coreclr!CallDescrWorkerWithHandler+0x57
0c 00000029`6e3ae7f0 00007ffa`dc1c3c09 coreclr!MethodDescCallSite::...+0x196
0d (Inline Function) --------`-------- coreclr!MethodDescCallSite::Call+0xb
0e 00000029`6e3ae930 00007ffa`dc1c4097 coreclr!RunMain+0x1f5
0f 00000029`6e3aeb10 00007ffa`dc1c4841 coreclr!Assembly::ExecuteMainMethod+0x1cb
10 00000029`6e3aeea0 00007ffa`dc0e21c1 coreclr!CorHost2::ExecuteAssembly+0x221
11 00000029`6e3af030 00007ffb`2ef54e2d coreclr!coreclr_execute_assembly+0x101
12 00000029`6e3af0d0 00007ffb`2ef62e27 hostpolicy!coreclr_t::execute_assembly+0x2d
13 00000029`6e3af120 00007ffb`2ef62a36 hostpolicy!run_app_for_context+0x387
14 00000029`6e3af280 00007ffb`2ef64262 hostpolicy!run_app+0x46
15 00000029`6e3af2d0 00007ffb`36ff3a7e hostpolicy!corehost_main+0x132
16 00000029`6e3af480 00007ffb`36ff72d8 hostfxr!execute_app+0x1de
17 (Inline Function) --------`-------- hostfxr!?A0xd51c85dd::read_config...+0x10a
18 00000029`6e3af570 00007ffb`36ff5b5b hostfxr!fx_muxer_t::handle_exec_...+0x214
19 00000029`6e3af660 00007ffb`36ff2109 hostfxr!fx_muxer_t::execute+0x39b
1a 00000029`6e3af7a0 00007ff6`ea712361 hostfxr!hostfxr_main_startupinfo+0x89
1b 00000029`6e3af8a0 00007ff6`ea712758 LINQPad6!exe_start+0x651
1c 00000029`6e3afad0 00007ff6`ea714608 LINQPad6!wmain+0x88
1d (Inline Function) --------`-------- LINQPad6!invoke_main+0x22
1e 00000029`6e3afb00 00007ffb`58387034 LINQPad6!__scrt_common_main_seh+0x10c
1f 00000029`6e3afb40 00007ffb`5a002651 kernel32!BaseThreadInitThunk+0x14
20 00000029`6e3afb70 00000000`00000000 ntdll!RtlUserThreadStart+0x21
```

```
0:000> !IP2MD 0x00007ffa`7cae2534
MethodDesc:   00007ffa7c7f5aa0
Method Name:  LINQPad.UIProgram.Go(System.String[])
Class:        00007ffa7c803a28
MethodTable:  00007ffa7c7f7078
mdToken:      00000000060001A4
Module:       00007ffa7c79f798
IsJitted:     yes
Current CodeAddr:     00007ffa7cae1b90
Version History:
  ILCodeVersion:      0000000000000000
  ReJIT ID:           0
  IL Addr:            0000000000000000
     CodeAddr:           00007ffa7cae1b90
(MinOptJitted)
     NativeCodeVersion:  0000000000000000

0:000> !DumpModule 00007ffa7c79f798
Name: C:\Program Files\LINQPad6\LINQPad.GUI.dll
Attributes:              PEFile
SupportsUpdateableMethods
Assembly:                00000177c5cdece0
BaseAddress:             00000177DFDE0000
PEFile:                  00000177C5CDE0E0
ModuleId:                00007FFA7C7D1860
ModuleIndex:             0000000000000001
LoaderHeap:              0000000000000000
TypeDefToMethodTableMap: 00007FFA7C7A0020
TypeRefToMethodTableMap: 00007FFA7C7A1860
MethodDefToDescMap:      00007FFA7C7A4138
FieldDefToDescMap:       00007FFA7C7AF300
MemberRefToDescMap:      0000000000000000
FileReferencesMap:       00007FFA7C7B7F78
AssemblyReferencesMap:   00007FFA7C7B7F80
MetaData start address:  00000177DFE887DC (719936
bytes)
```

Thread Stack Raw Data



WinDbg Commands

Get stack range:
!teb

Dump raw data:
dc / **dps** / **dpp** / **dpa** / **dpu**

Dump managed references:
!DumpStackObjects

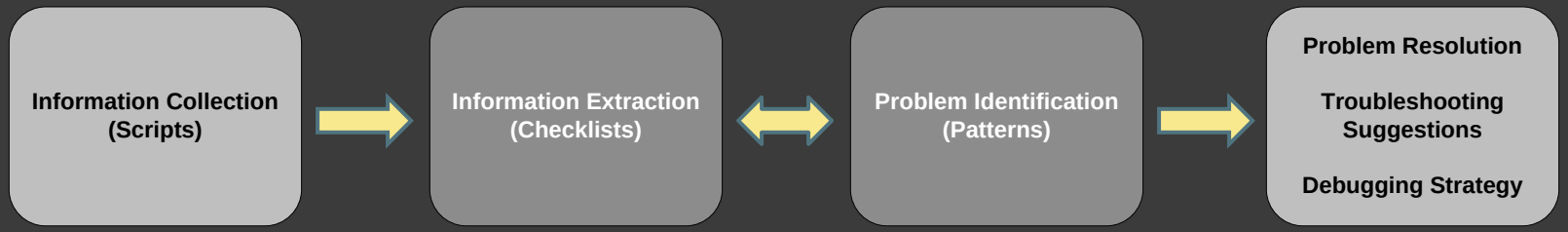
Pattern-Oriented Diagnostic Analysis

Diagnostic Pattern: a common recurrent identifiable problem together with a set of recommendations and possible solutions to apply in a specific context.

Diagnostic Problem: a set of indicators (symptoms, signs) describing a problem.

Diagnostic Analysis Pattern: a common recurrent analysis technique and method of diagnostic pattern identification in a specific context.

Diagnostics Pattern Language: common names of diagnostic and diagnostic analysis patterns. The same language for any operating system: Windows, Mac OS X, Linux, ...



Checklist: http://www.dumpanalysis.org/windows-memory-analysis-checklist

Part 2: Practice Exercises

Links

- Memory Dumps:

Not available in preview version

- Exercise Transcripts:

Not available in preview version

Exercise 0

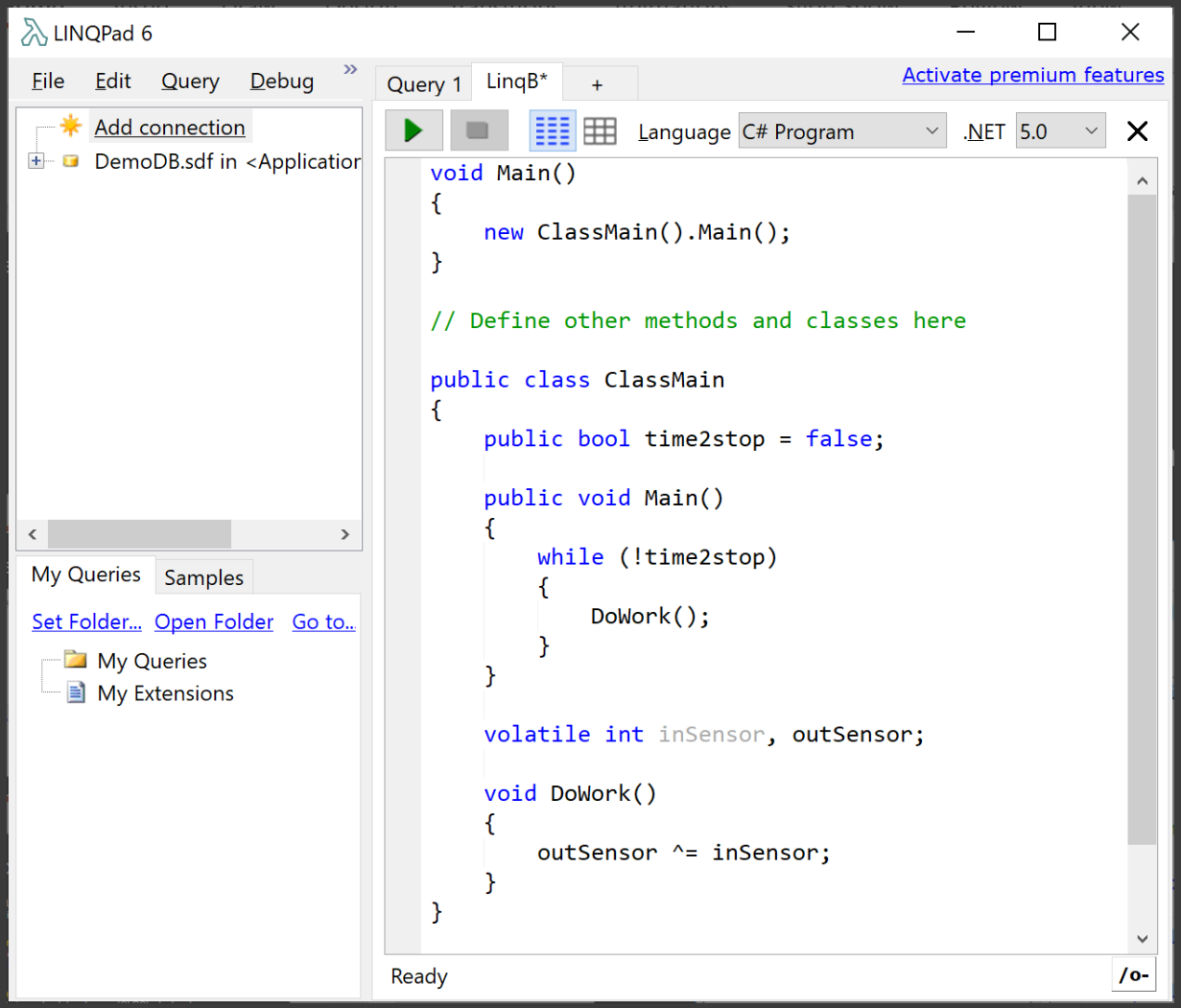
- **Goal:** Install Debugging Tools for Windows or WinDbg Preview or pull Docker WinDbg image and check that symbols are set up correctly
- **Patterns:** Incorrect Stack Trace; Truncated Stack Trace
- **Commands:** k
- \ANETMDA-Core-Dumps\Exercise-0-Download-Setup-WinDbg.pdf

Process Memory Dumps

Practice Exercises Core.PNx

.NET Core

Modeling with LINQPad 6



http://www.linqpad.net/

Exercise Core.PN1

- **Goal:** Learn how to load the correct .NET SOS WinDbg extension and analyze managed space
- **Patterns:** Stack Trace Collection; CLR Thread; Software Exception; Exception Stack Trace; Managed Code Exception; Managed Stack Trace; Invalid Pointer; NULL Pointer
- **Commands:** .logopen, ~*k, ~*kL, .load, !pe, ~*e, lmv, .chain, .unload, !analyze -v, !CLRStack, .logclose
- \ANETMDA-Core-Dumps\Exercise-Core-PN1-Analysis-process-dump-ApplicationA.pdf

Exercise Core.PN2

- **Goal:** Compare 64-bit process memory dump from exercise Core.PN1 with 32-bit process memory dump
- **Patterns:** Platform-Specific Debugger
- \ANETMDA-Core-Dumps\Exercise-Core-PN2-Analysis-process-dump-ApplicationA-32.pdf

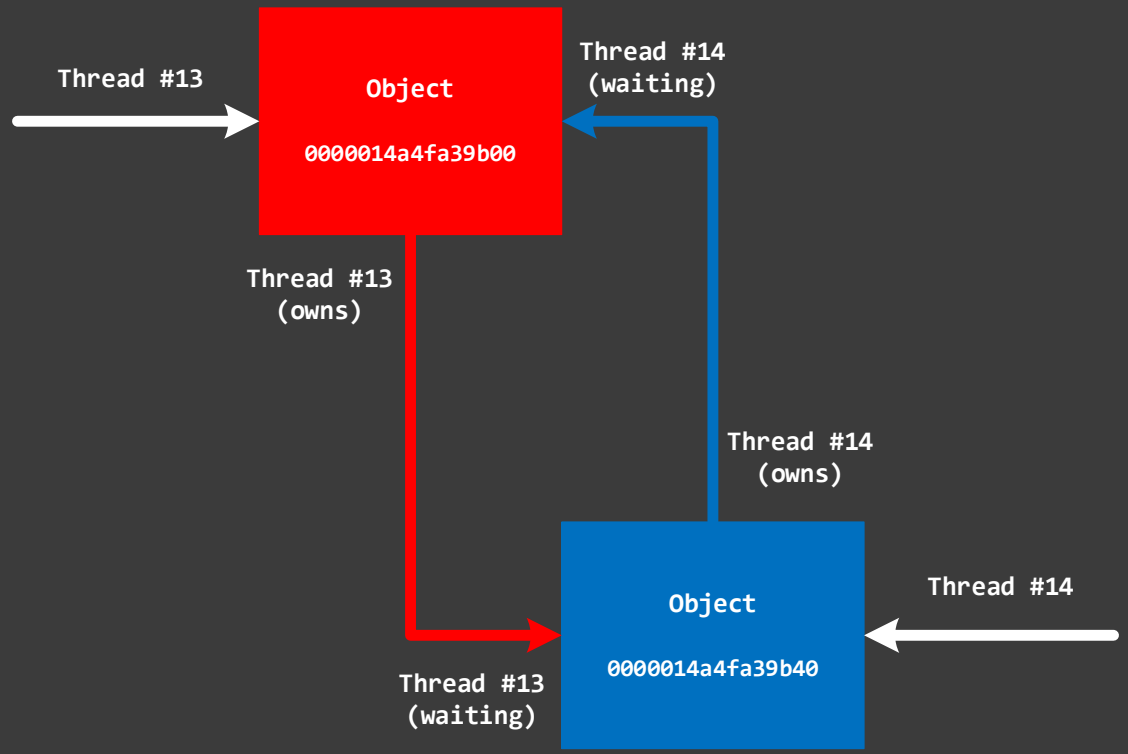
Exercise Core.PN3

- **Goal:** Learn how to find problem assemblies, modules, classes and methods, disassemble code, analyze CPU spikes
- **Patterns:** Active Thread; Manual Dump; Technology-Specific Subtrace; JIT Code; Spiking Thread; Annotated Disassembly
- **Commands:** !analyze -v -hang, !IP2MD, !runaway, ~<>k, !U, !DumpMD, !DumpClass, !DumpMT, !DumpModule, !DumpAssembly, !DumpDomain
- \ANETMDA-Core-Dumps\Exercise-Core-PN3-Analysis-process-dump-LINQPadB.pdf

Exercise Core.PN5

- **Goal:** Learn how to recognize and analyze deadlocks using SOS, execution residue, handled exceptions, dump object references
- **Patterns:** Special Thread; Wait Chain; Deadlock; Execution Residue (user space); Value References; Hidden Exception (user space); Coincidental Symbolic Information; Caller-n-Callee
- **Commands:** ~<>s, !Threads, !syncblk, !DumpObj, ub, dps, !DumpStack, !teb, dpS, !DumpStackObjects
- \ANETMDA-Core-Dumps\Exercise-Core-PN5-Analysis-process-dump-LINQPadC.pdf

Deadlock (x64, Core.PN5)



Exercise Core.PN7

- **Goal:** Learn how to analyze multiple managed exceptions
- **Patterns:** Managed Stack Trace Collection; Multiple Exceptions
- **Commands:** .sympath
- \ANETMDA-Core-Dumps\Exercise-Core-PN7-Analysis-process-dump-ApplicationD.pdf

Exercise Core.PN9

- **Goal:** Learn how to diagnose heap and handle leaks
- **Patterns:** Handle Leak; Memory Leak
- **Commands:** !heap, !address, !DumpHeap, ?, !eeheap, !GCHandles, !FinalizeQueue, !handle, .cxr
- \ANETMDA-Core-Dumps\Exercise-Core-PN9-Analysis-process-dump-LINQPadD.pdf

Exercise Core.PN11

- **Goal:** Learn how to recognize and analyze heap corruption
- **Patterns:** Regular Data; Managed Heap Corruption
- **Commands:** .formats, !VerifyHeap
- \ANETMDA-Core-Dumps\Exercise-Core-PN11-Analysis-process-dump-LINQPadE.pdf

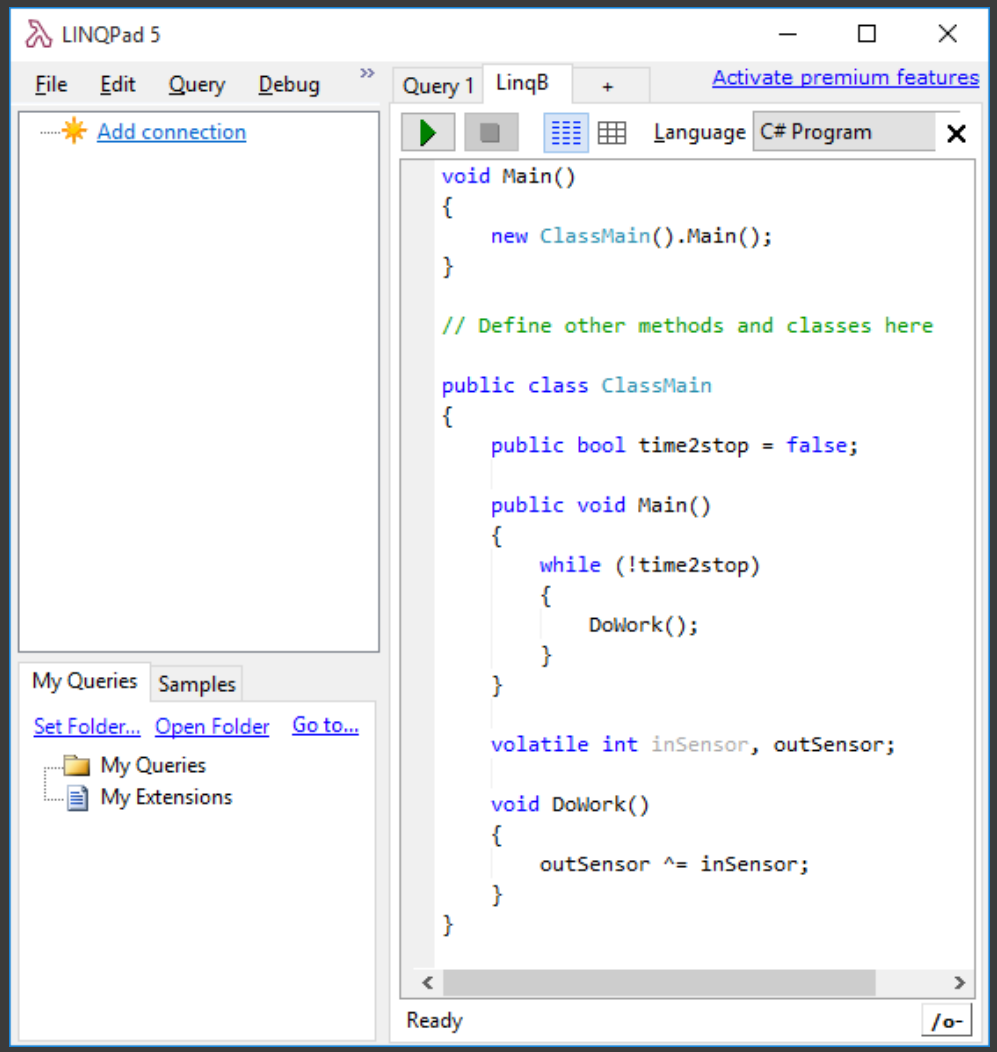
Process Memory Dumps

Practice Exercises

Framework.PN1 – Framework.PN12

.NET Framework

Modeling with LINQPad 5



http://www.linqpad.net/

Exercise Framework.PN1

- **Goal:** Learn how to load the correct .NET SOS WinDbg extension and analyze managed space
- **Patterns:** Stack Trace Collection; CLR Thread; Version-Specific Extension; Software Exception; Exception Stack Trace; Managed Code Exception; Managed Stack Trace
- **Commands:** .logopen, .symfix, .reload, ~*k, .load, !pe, ~*e, lmv, .chain, .unload, !analyze -v, !CLRStack, .logclose
- \ANETMDA-Dumps\Exercise-Framework-PN1-Analysis-process-dump-ApplicationA.pdf

Exercise Framework.PN2

- **Goal:** Compare 64-bit process memory dump from exercise Framework.PN1 with 32-bit process memory dump
- **Patterns:** Platform-Specific Debugger
- \ANETMDA-Dumps\Exercise-Framework-PN2-Analysis-process-dump-ApplicationA-32.pdf

Exercise Framework.PN3

- **Goal:** Learn how to find problem assemblies, modules, classes and methods, disassemble code, analyze CPU spikes
- **Patterns:** Active Thread; Technology-Specific Subtrace; JIT Code; Spiking Thread; Annotated Disassembly
- **Commands:** !analyze -v -hang, !IP2MD, !runaway, .prompt_allow, ~<>s, ~<>k, !U, !DumpMD, !DumpClass, !DumpMT, !DumpModule, !DumpAssembly, !DumpDomain
- \ANETMDA-Dumps\Exercise-Framework-PN3-Analysis-process-dump-LINQPadB.pdf

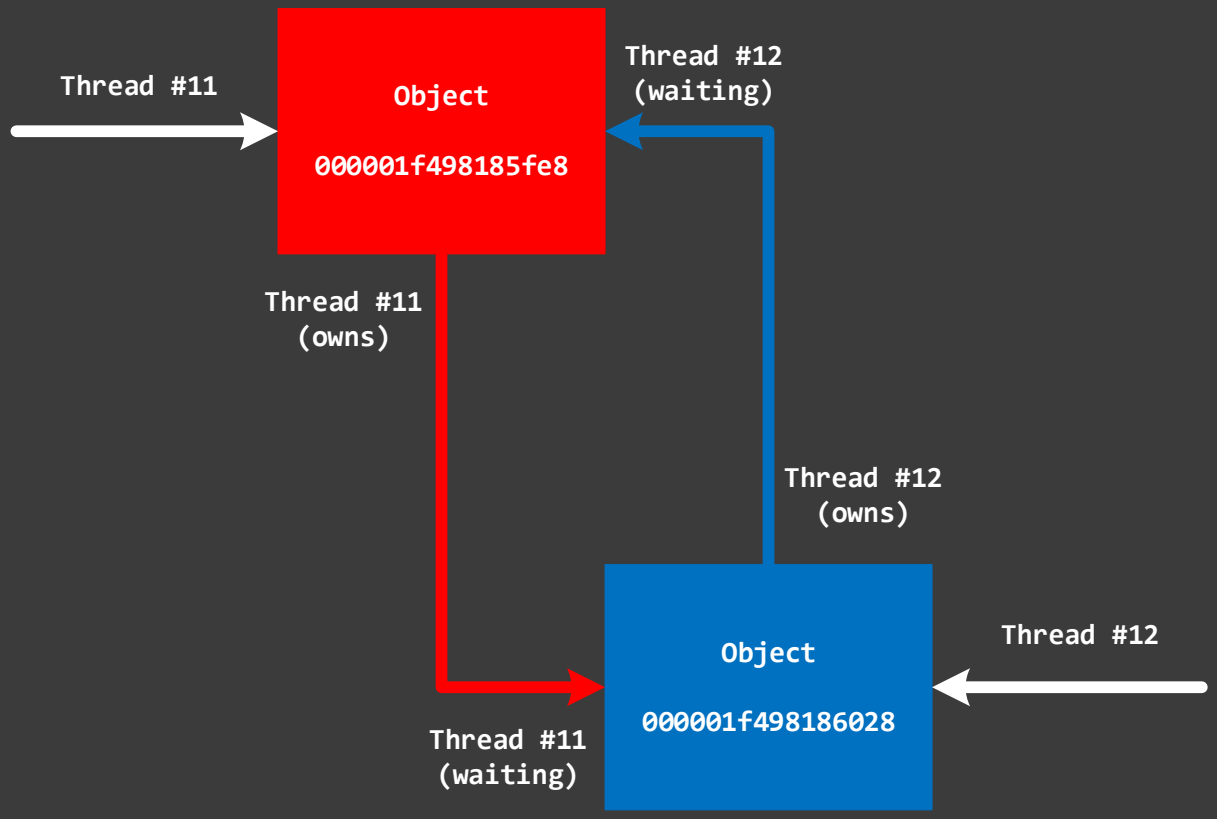
Exercise Framework.PN4

- **Goal:** Compare 64-bit process memory dump from exercise Framework.PN3 with 32-bit process memory dump
- \ANETMDA-Dumps\Exercise-Framework-PN4-Analysis-process-dump-LINQPadB-32.pdf

Exercise Framework.PN5

- **Goal:** Learn how to recognize and analyze deadlocks using SOS(EX), execution residue, handled exceptions, dump object references
- **Patterns:** Special Thread; Wait Chain; Deadlock; Execution Residue (user space); Hidden Exception (user space); Coincidental Symbolic Information; Caller-n-Callee
- **Commands:** ~*kL, !Threads, !syncblk, !DumpObj, ub, dp, !dlk, !DumpStack, !teb, dpS
- \ANETMDA-Dumps\Exercise-Framework-PN5-Analysis-process-dump-LINQPadC.pdf

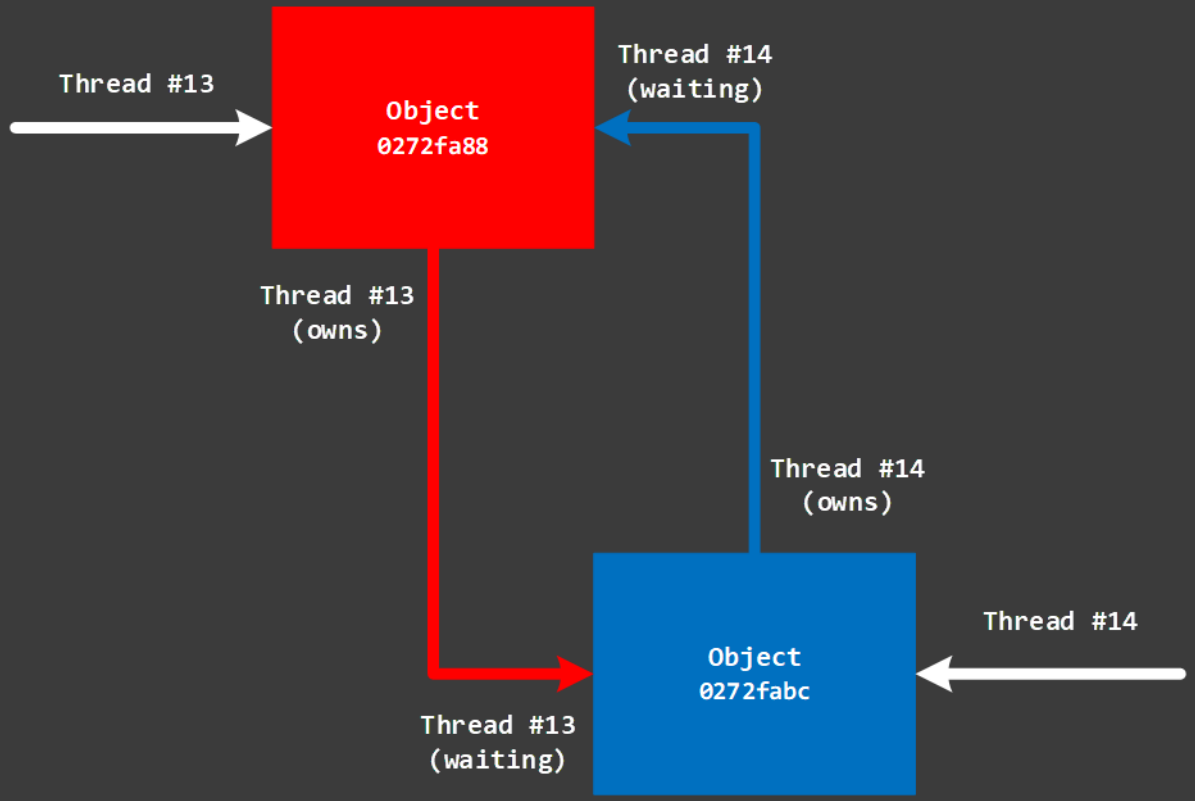
Deadlock (x64, Framework.PN5)



Exercise Framework.PN6

- **Goal:** Compare 64-bit process memory dump from exercise Framework.PN5 with 32-bit process memory dump
- **Patterns:** Execution Residue (managed space); Hidden Exception (managed space), Handled Exception
- **Commands:** !DumpStackObjects
- \ANETMDA-Dumps\Exercise-Framework-PN6-Analysis-process-dump-LINQPadC-32.pdf

Deadlock (x86, Framework.PN6)



Exercise Framework.PN7

- **Goal:** Learn how to analyze multiple managed exceptions
- **Patterns:** Managed Stack Trace Collection; Multiple Exceptions; Nested Exceptions; NULL Pointer
- \ANETMDA-Dumps\Exercise-Framework-PN7-Analysis-process-dump-ApplicationD.pdf

Exercise Framework.PN8

- **Goal:** Compare 64-bit process memory dump from exercise Framework.PN7 with 32-bit process memory dump
- \ANETMDA-Dumps\Exercise-Framework-PN8-Analysis-process-dump-ApplicationD-32.pdf

Exercise Framework.PN9

- **Goal:** Learn how to diagnose heap and handle leaks
- **Patterns:** Handle Leak; Memory Leak
- **Commands:** !heap, !address, !DumpHeap, ?, !eeheap, !GCHandles, !FinalizeQueue, !handle, .cxr
- \ANETMDA-Dumps\Exercise-Framework-PN9-Analysis-process-dump-LINQPadD.pdf

Exercise Framework.PN10

- **Goal:** Compare 64-bit process memory dump from exercise Framework.PN9 with 32-bit process memory dump
- \ANETMDA-Dumps\Exercise-Framework-PN10-Analysis-process-dump-LINQPadD-32.pdf

Exercise Framework.PN11

- **Goal:** Learn how to recognize and analyze heap corruption
- **Patterns:** Invalid Pointer; Regular Data; Managed Heap Corruption
- **Commands:** .formats, !VerifyHeap
- \ANETMDA-Dumps\Exercise-Framework-PN11-Analysis-process-dump-LINQPadE.pdf

Exercise Framework.PN12

- **Goal:** Compare 64-bit process memory dump from exercise Framework.PN11 with 32-bit process memory dump
- \ANETMDA-Dumps\Exercise-Framework-PN12-Analysis-process-dump-LINQPadE-32.pdf

Pattern Links

CLR Thread
Managed Code Exception
Nested Exceptions
Mixed Exception
Memory Leak
JIT Code
Managed Stack Trace
Multiple Exceptions
Version-Specific Extension
Caller-n-Callee
Hidden Exception
Deadlock
Duplicate Extension
Stack Trace Collection
Dynamic Memory Corruption
Special Thread
Execution Residue
Handled Exception
Annotated Disassembly
Technology-Specific Subtrace
Wait Chain
Object Distribution Anomaly

CLR-related and managed

Incorrect Stack Trace
Execution Residue
NULL Pointer
Handle Leak
Exception Stack Trace
Software Exception
Platform-Specific Debugger
Spiking Thread
Hidden Exception
Regular Data
Coincidental Symbolic Information
Active Thread
Truncated Stack Trace
Value References
Manual Dump

Unmanaged user space

SOS Checklist

- CLR module and SOS extension versions (lmv and .chain)
- Managed exceptions (~*e !pe -nested)
- Managed threads (!Threads -special)
- Managed stack traces (~*e !CLRStack)
- Managed execution residue (~*e !DumpStackObjects)
- Managed heap (!VerifyHeap, !DumpHeap -stat and !eeheap -gc)
- GC handles (!GCHandles)
- Finalizer queue (!FinalizeQueue)
- Sync blocks (!syncblk)

Resources

- WinDbg Help / WinDbg.org (quick links) / DumpAnalysis.org
- WinDbg images https://hub.docker.com/r/patterndiagnostics/windbg
- .NET Runtime https://github.com/dotnet/runtime
- Accelerated Windows Memory Dump Analysis, 5th Edition
- Encyclopedia of Crash Dump Analysis Patterns, 3rd Edition
- Memory Dump Analysis Anthology (Volumes 1 – 13)

Q&A

Please send your feedback using the contact form on PatternDiagnostics.com

Thank you for attendance!