Public Preview Version

Windows Memory Dump Analysis Accelerated

Version 2.0

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Software Diagnostics Services

Prerequisites

WinDbg Commands

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

Basic Windows troubleshooting

Training Goals

- Review fundamentals
- Learn how to analyze process dumps
- Learn how to analyze kernel dumps
- Learn how to analyze complete dumps

Training Principles

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

Schedule Summary

Day 1

- Analysis Fundamentals (1 hour)
- Process Memory Dumps (1 hour)

Day 2

- Process Memory Dumps (2 hours)

Day 3

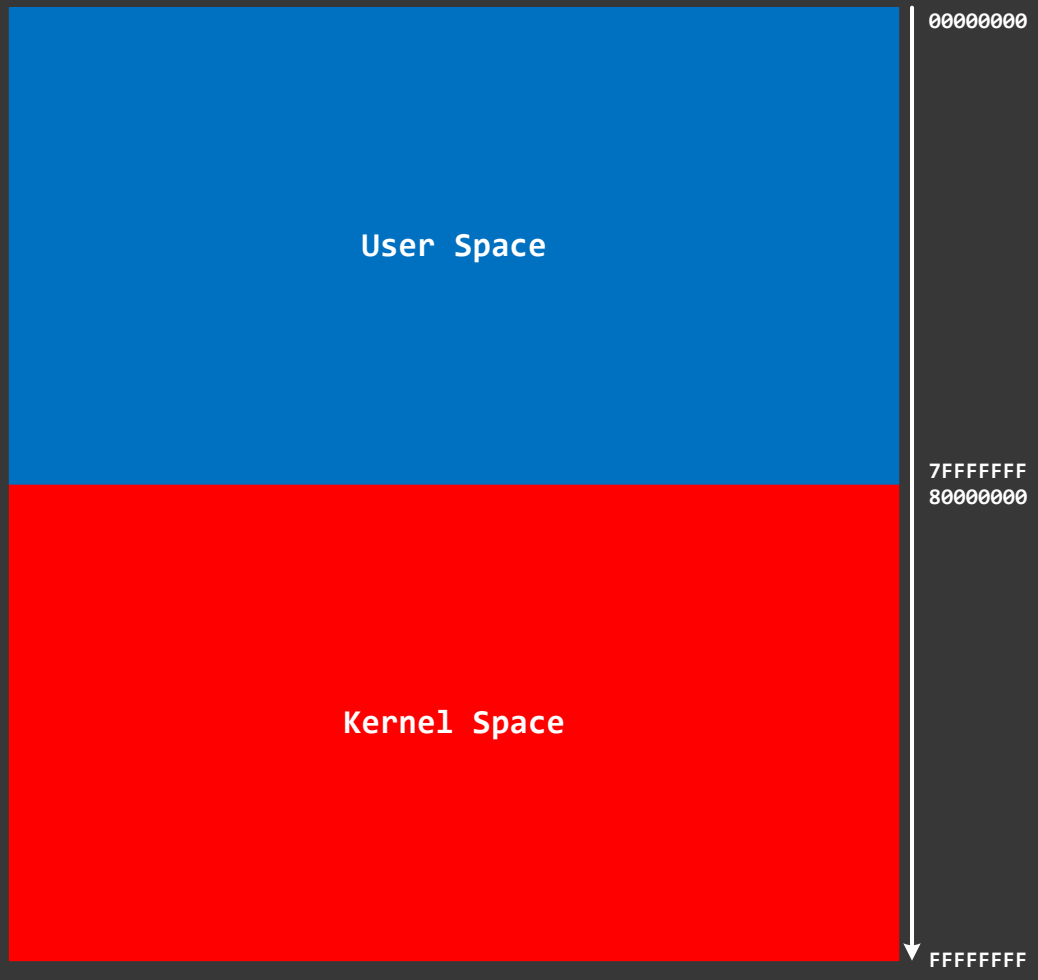
- Kernel Memory Dumps (2 hours)

Day 4

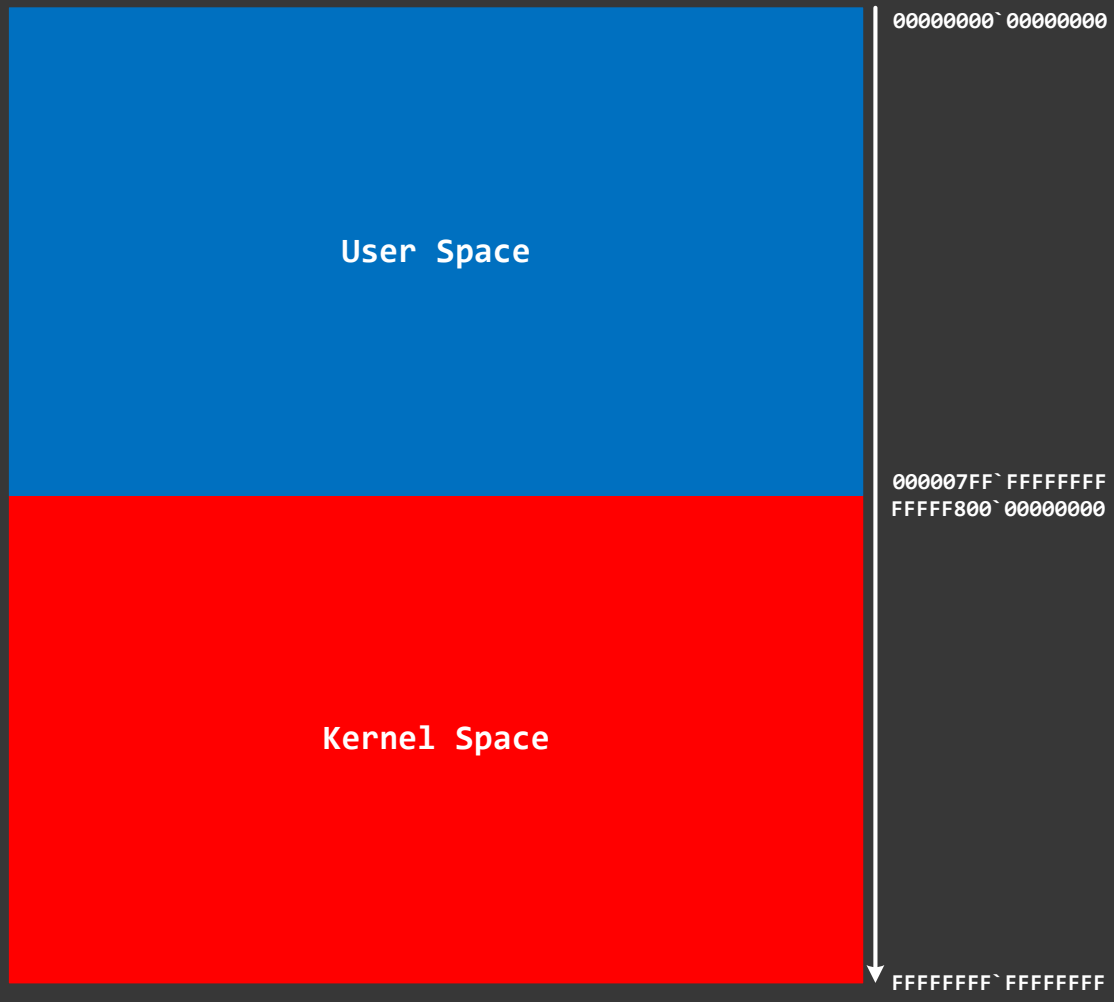
- Complete Memory Dumps (2 hours)
- Remaining Process Memory Dumps

Part 1: Fundamentals

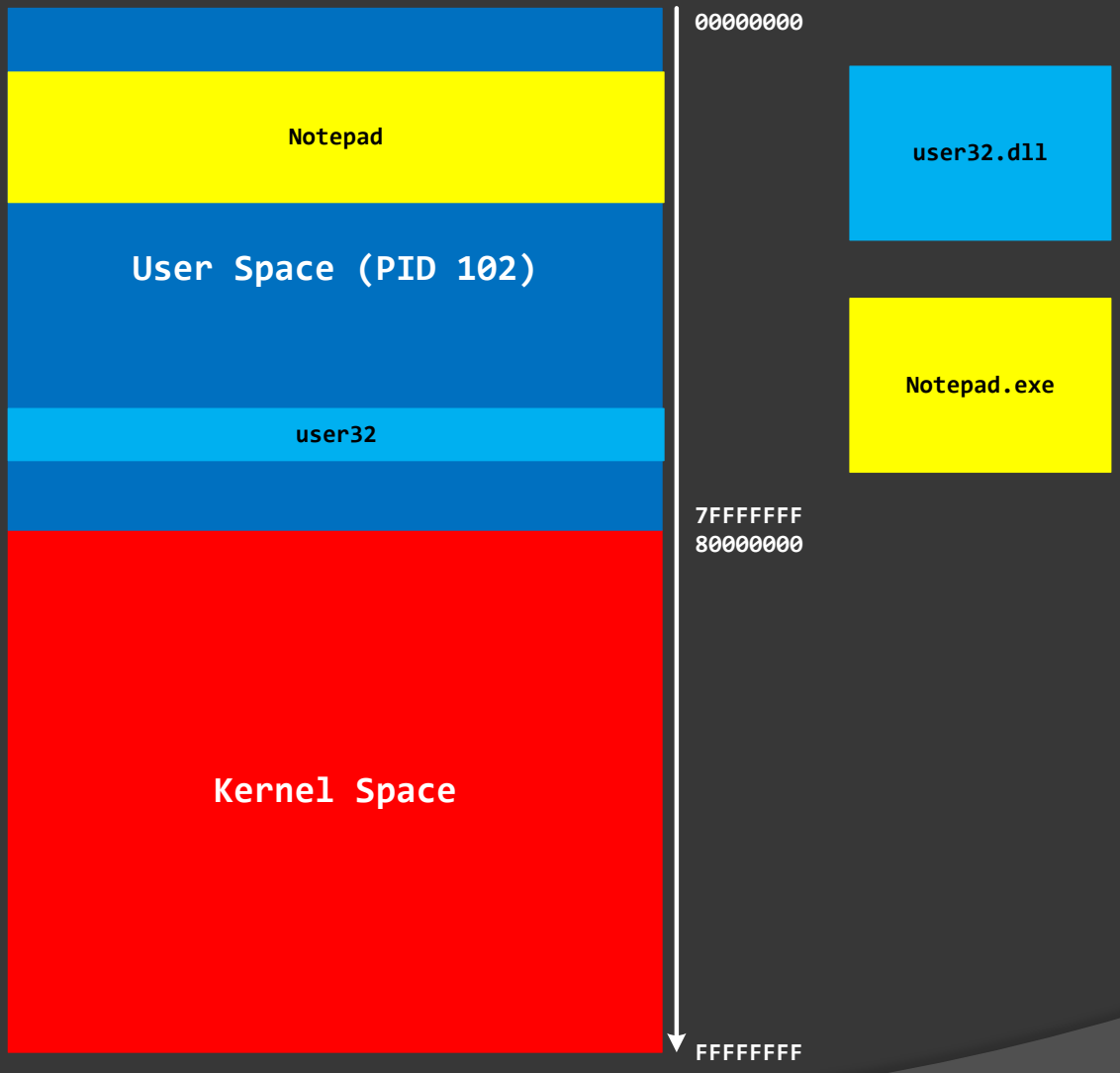
Process Space (x86)



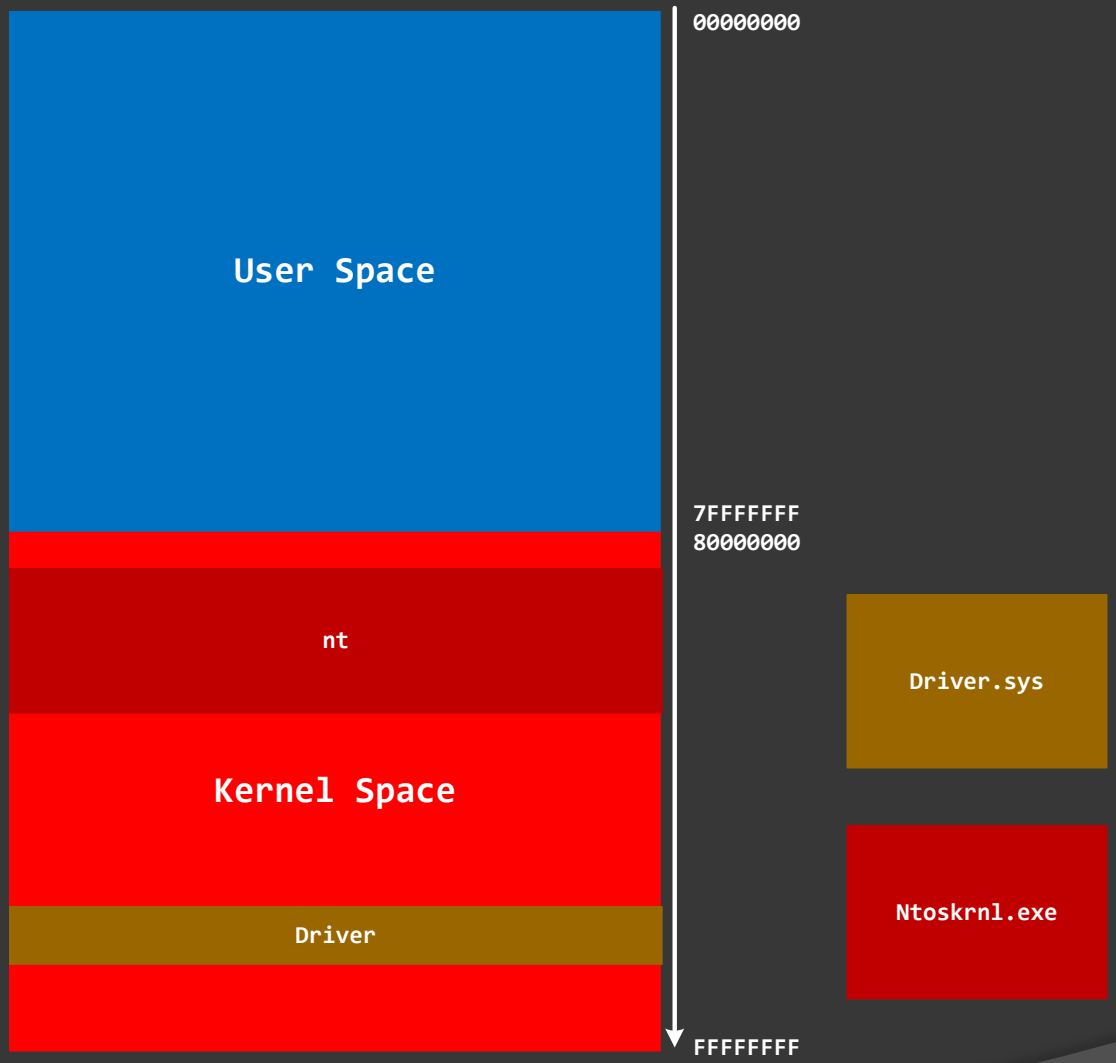
Process Space (x64)



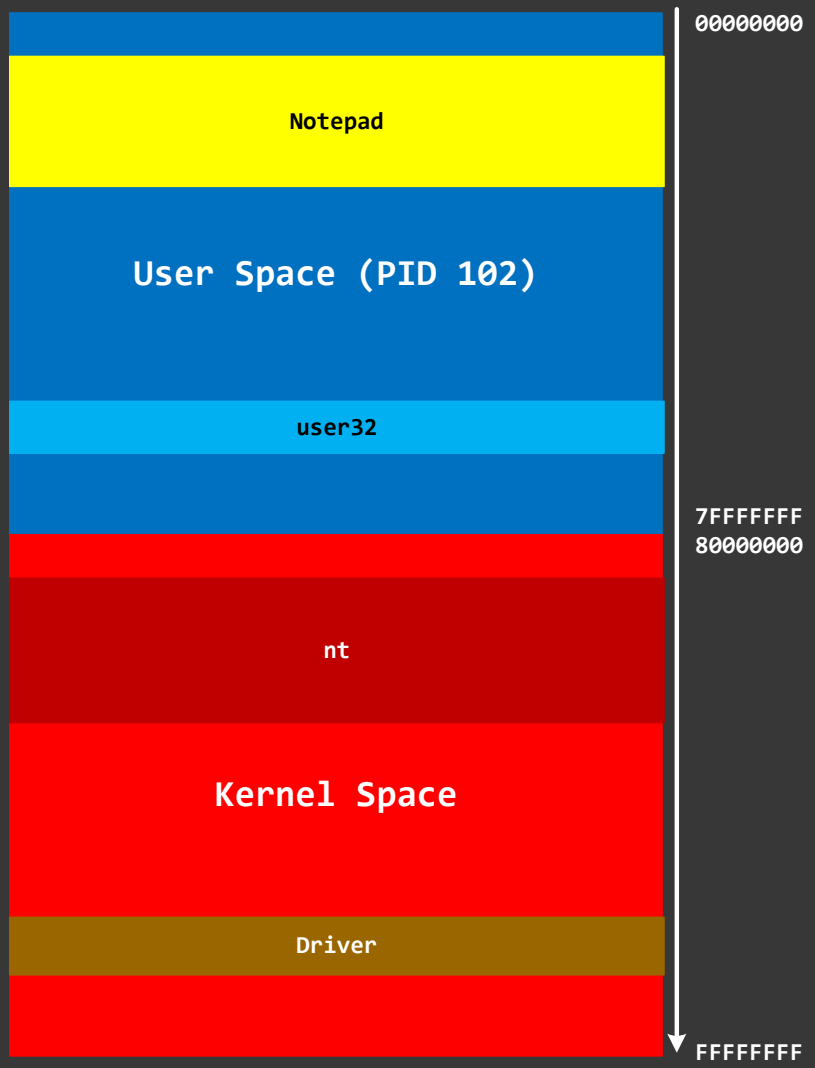
Application/Process/Module



OS Kernel/Driver/Module

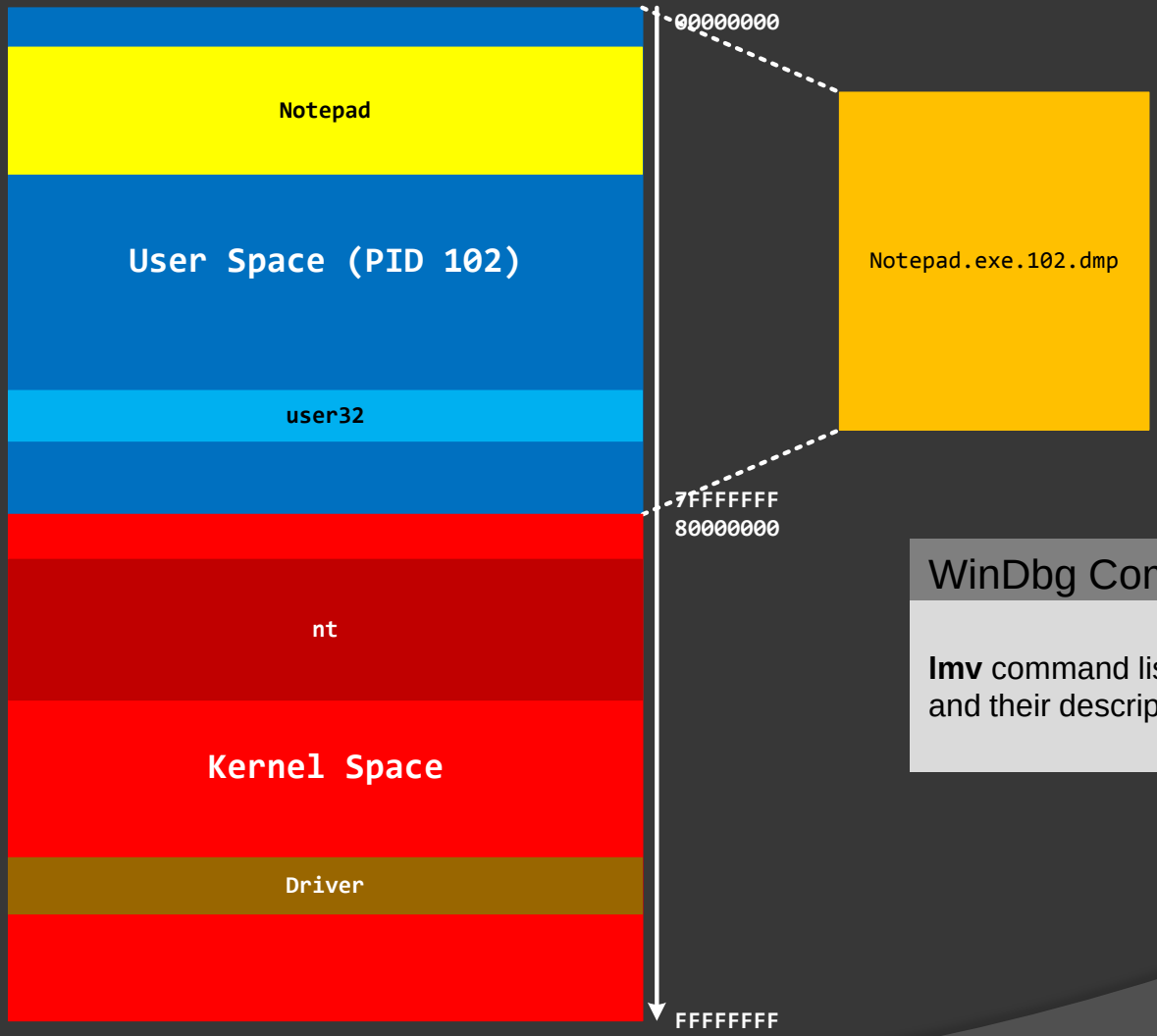


Process Virtual Space



00000000 ... FFFFFFFF

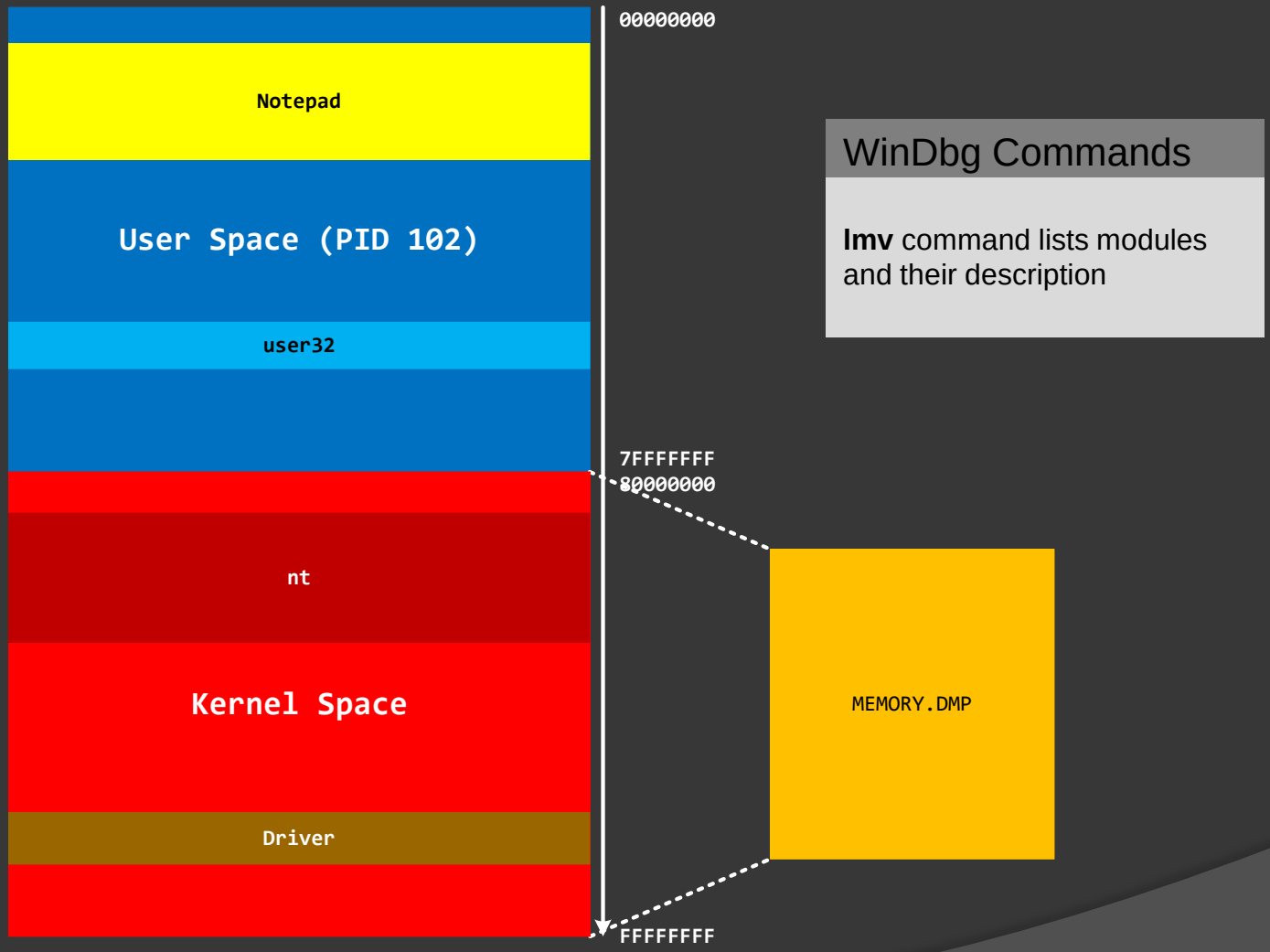
Process Memory Dump



WinDbg Commands

lmv command lists modules and their description

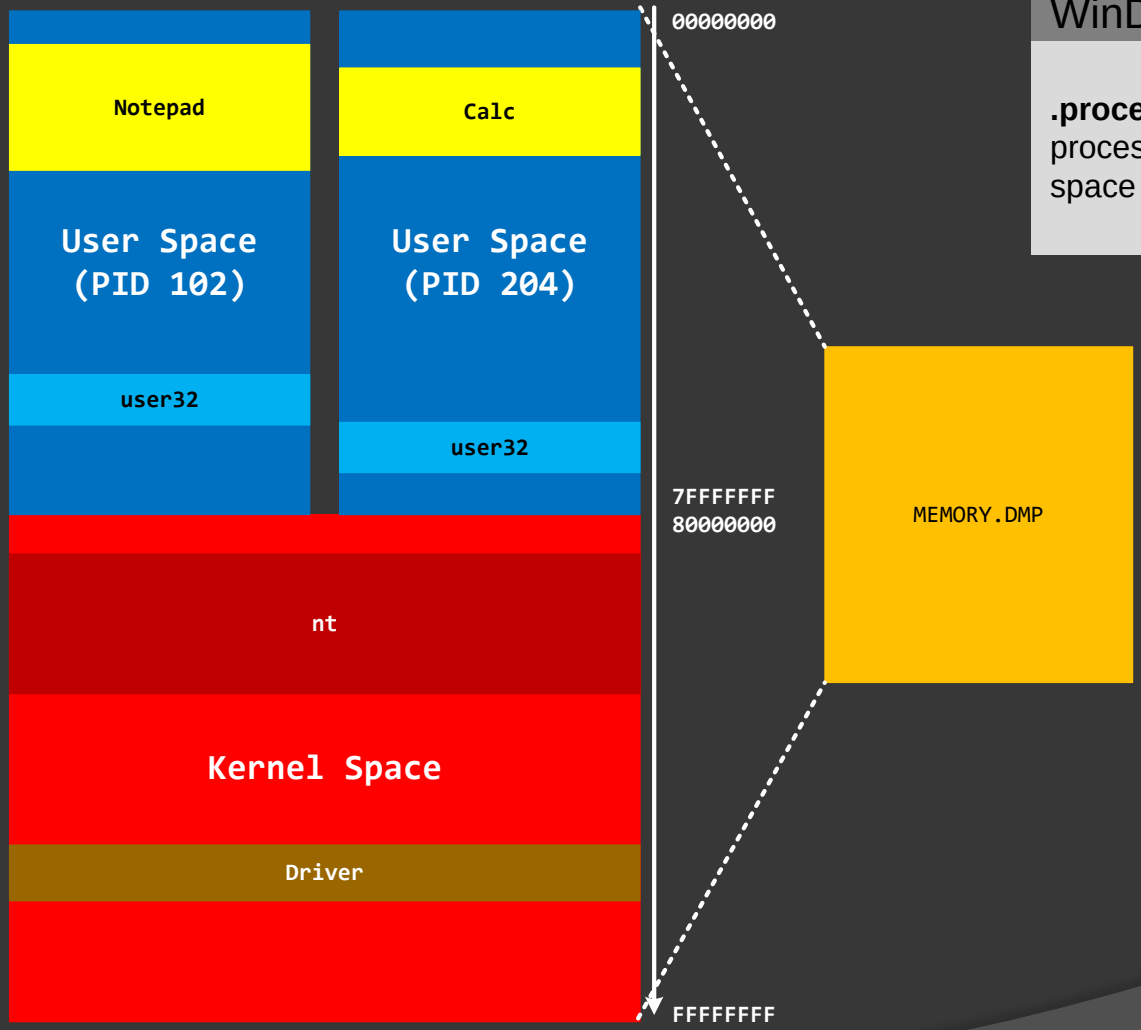
Kernel Memory Dump



WinDbg Commands

lmv command lists modules and their description

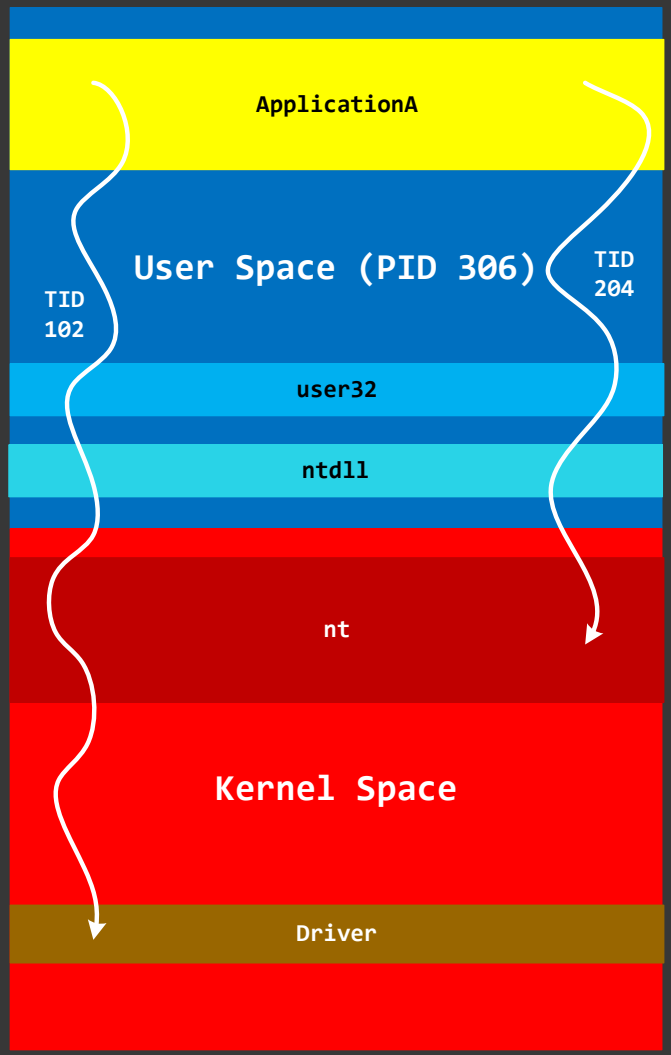
Complete Memory Dump



WinDbg Commands

.process switches between process virtual spaces (kernel space part remains the same)

Process Threads

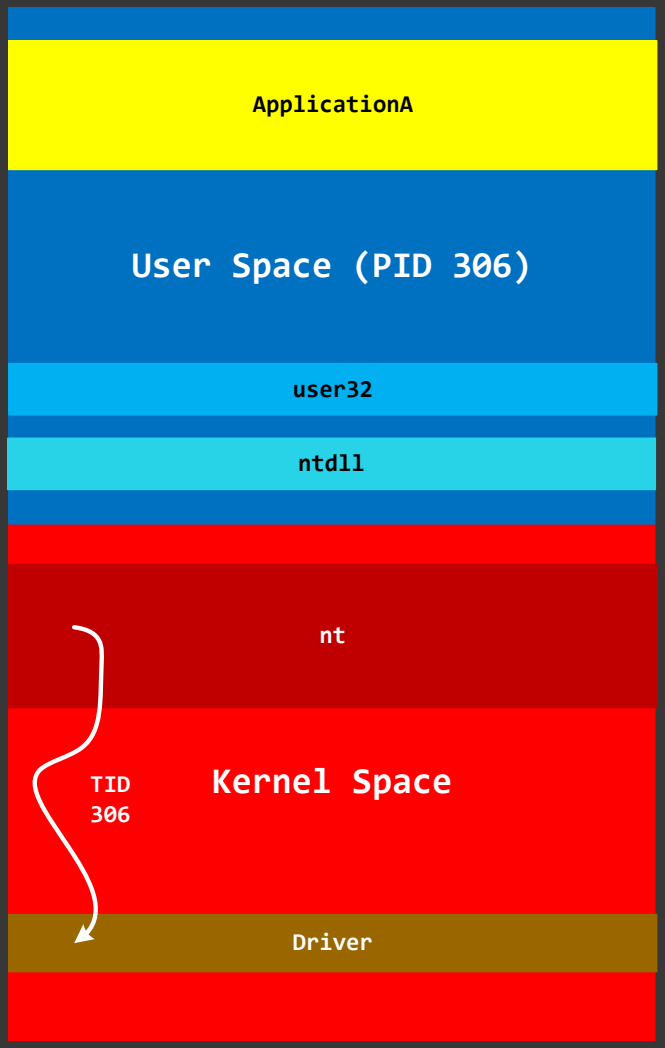


WinDbg Commands

Process dumps:
~<n>s switches between threads

Kernel/Complete dumps:
~<n>s switches between processors
.thread switches between threads

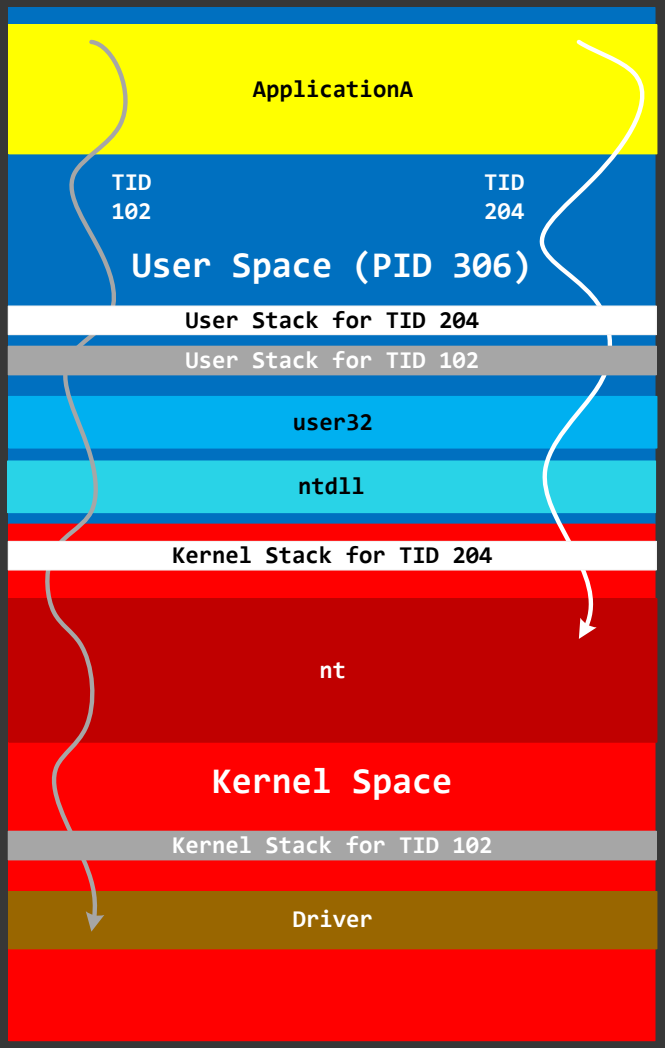
System Threads



WinDbg Commands

Kernel/Complete dumps:
~<n>s switches between processors
.thread switches between threads

Thread Stack Raw Data



WinDbg Commands

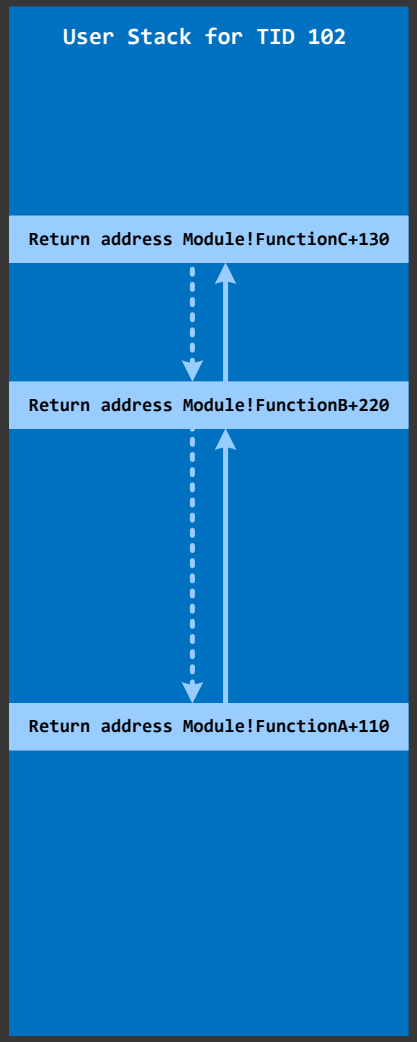
Process dumps:
!teb

Kernel dumps:
!thread

Complete dumps:
!teb for user space
!thread for kernel space

Data:
dc / **dps** / **dpp** / **dpa** / **dpu**

Thread Stack Trace




```
FunctionA()
{
  ...
  FunctionB();
  ...
}

FunctionB()
{
  ...
  FunctionC();
  ...
}

FunctionC()
{
  ...
  FunctionD();
  ...
}
```

Module!FunctionA

Resumes from address Module!FunctionA+110

Saves return address Module!FunctionA+110

Module!FunctionB

Resumes from address Module!FunctionB+220

Saves return address Module!FunctionB+220

Module!FunctionC

Resumes from address Module!FunctionC+130

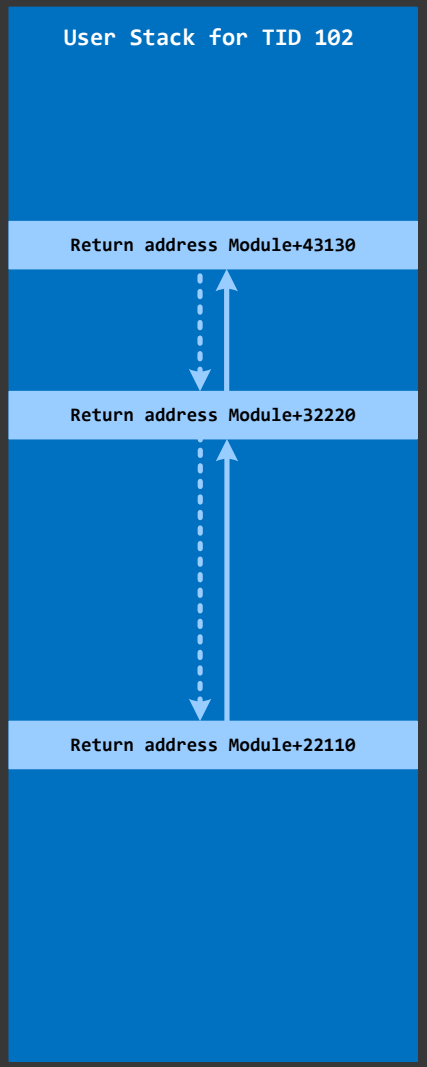
Saves return address Module!FunctionC+130

Module!FunctionD

WinDbg Commands

```
0:000> k
Module!FunctionD
Module!FunctionC+130
Module!FunctionB+220
Module!FunctionA+110
```

Thread Stack Trace (no PDB)

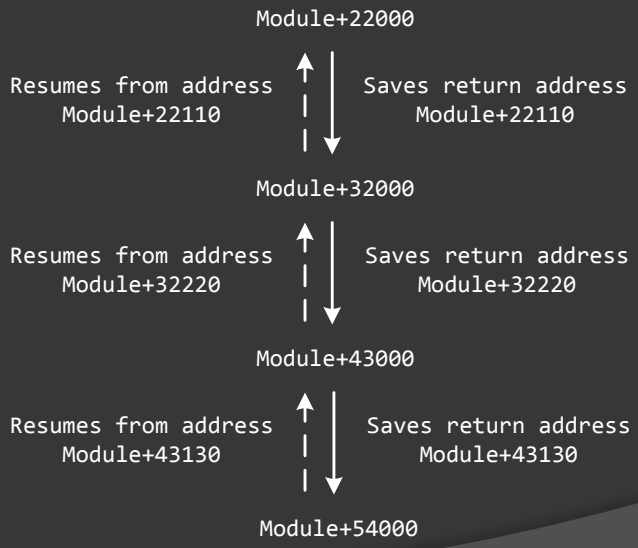



```
FunctionA()
{
  ...
  FunctionB();
  ...
}
FunctionB()
{
  ...
  FunctionC();
  ...
}
FunctionC()
{
  ...
  FunctionD();
  ...
}
```

Symbol file Module.pdb

FunctionA 22000 - 23000
FunctionB 32000 - 33000
FunctionC 43000 – 44000
FunctionD 54000 - 55000

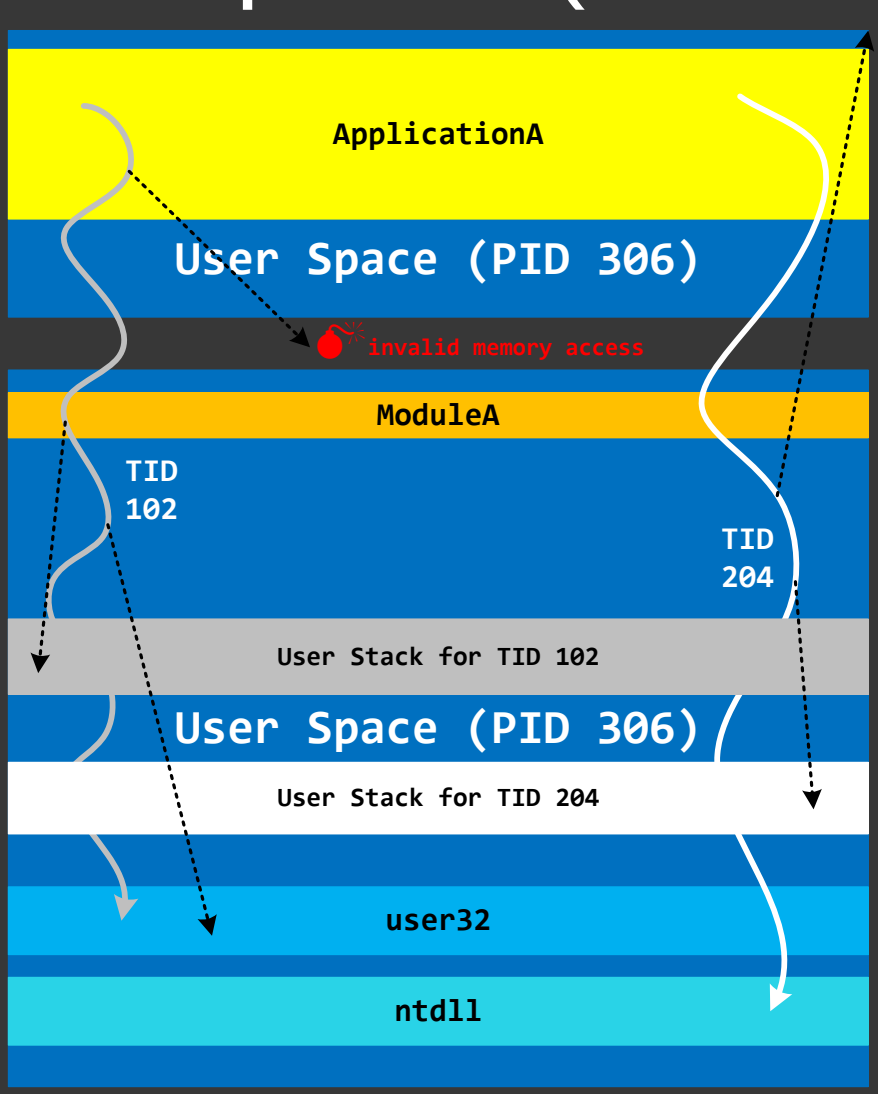
No symbols for Module



WinDbg Commands

```
0:000> k
Module+0
Module+43130
Module+32220
Module+22110
```

Exceptions (Access Violation)



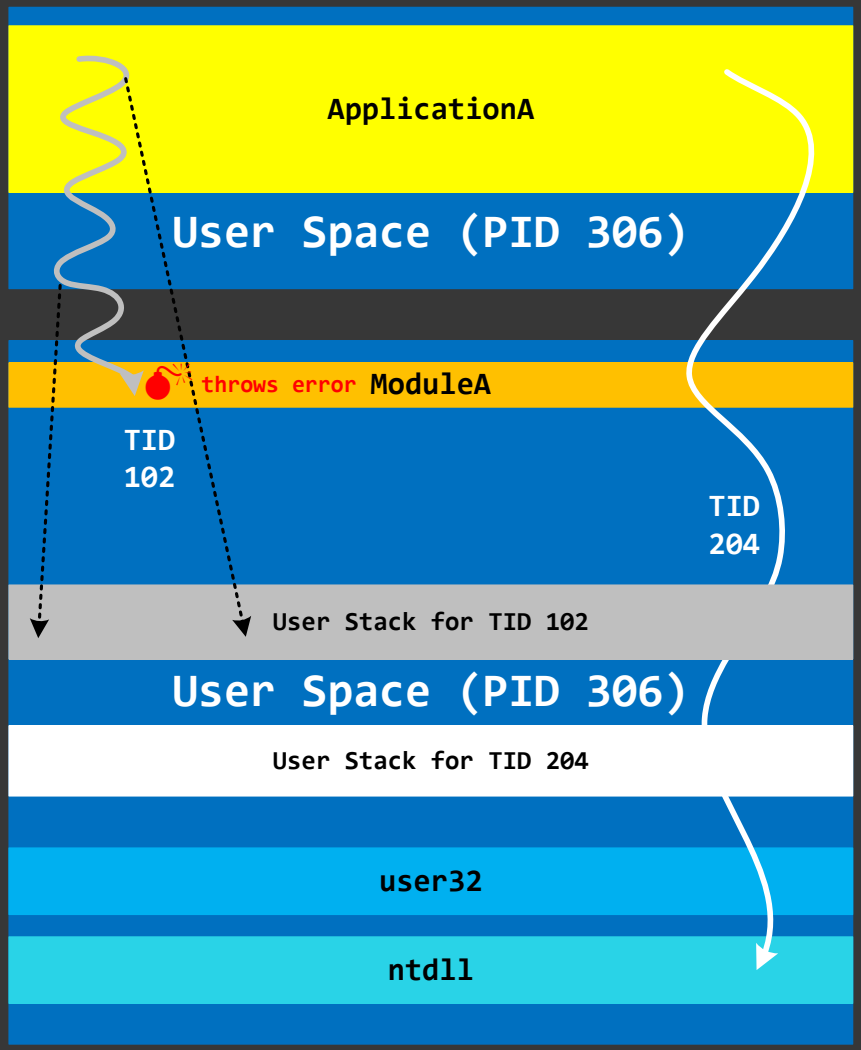
WinDbg Commands

`address=????????`

Set exception context (process dump):
.cxr

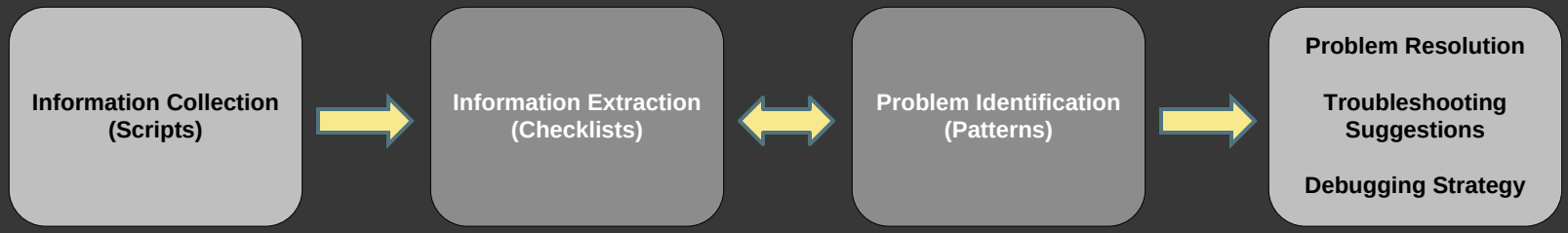
Set trap context (kernel/complete dump):
.trap
Check address:
!pte

Exceptions (Runtime)



Pattern-Driven Analysis

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



Patterns: http://www.dumpanalysis.org/blog/index.php/crash-dump-analysis-patterns/
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 and learn how to set up symbols correctly
- **Patterns:** Incorrect Stack Trace

Process Memory Dumps

Exercises P1-P16

Exercise P1

- **Goal:** Learn how to see dump file type and version, get a stack trace, check its correctness, perform default analysis, list modules, check their version information, check process environment
- **Patterns:** Manual Dump; Stack Trace; Not My Version; Environment Hint

Exercise P2

- **Goal:** Learn how to list stack traces, check their correctness, perform default analysis, list modules, check their version information, check process environment; dump module data

- **Patterns:** Manual Dump; Stack Trace; Not My Version; Environment Hint; Unknown Component

Exercise P3

- **Goal:** Learn how to list stack traces, check their correctness, perform default analysis, list modules, check their version information, check thread age and CPU consumption
- **Patterns:** Stack Trace Collection

Exercise P4

- **Goal:** Learn to recognize exceptions in process memory dumps and get their context
- **Patterns:** Exception Thread; Multiple Exceptions; NULL Pointer

Exercise P5

- **Goal:** Learn how to load application symbols, recognize exceptions in process memory dumps and get their context
- **Patterns:** Exception Thread; Multiple Exceptions; NULL Pointer

Exercise P6

- **Goal:** Learn how to recognize heap corruption
- **Patterns:** Exception Thread; Dynamic Memory Corruption

Exercise P7

- **Goal:** Learn how to recognize heap corruption and check error and status codes
- **Patterns:** Exception Thread; Dynamic Memory Corruption

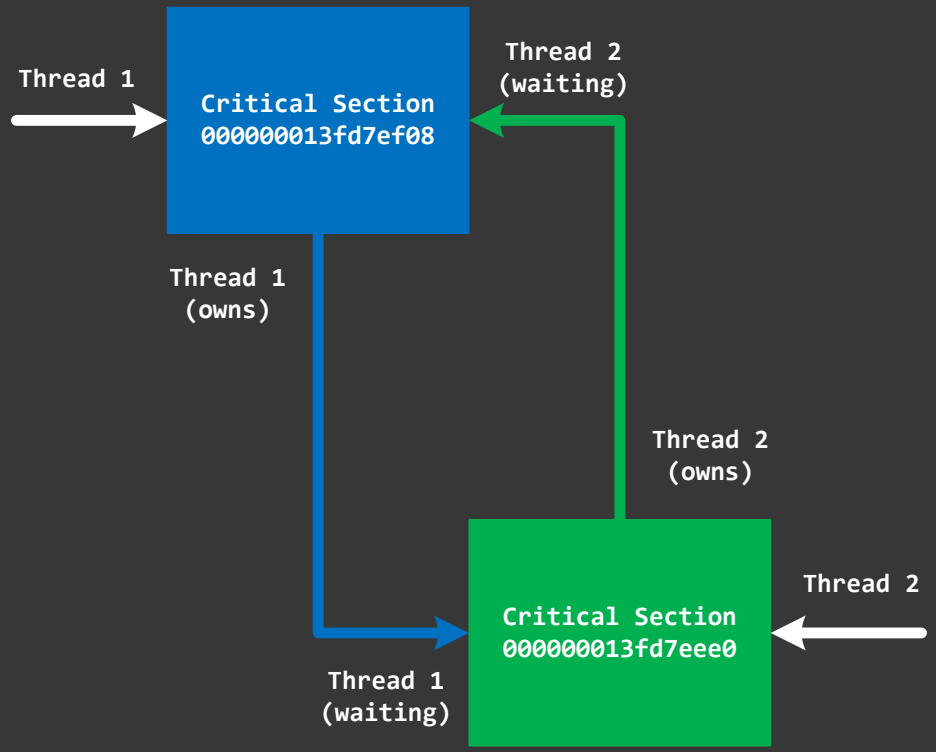
Exercise P8

- **Goal:** Learn how to recognize CPU spikes, invalid pointers and disassemble code
- **Patterns:** Exception Thread; Wild Code; CPU Spike; Mutiple Exceptions; NULL Code Pointer; Invalid Pointer

Exercise P9

- **Goal:** Learn how to recognize critical section waits and deadlocks, dump raw stack data and see hidden exceptions
- **Patterns:** Wait Chain; Deadlock; Hidden Exception

Deadlock



Exercise P10

- **Goal:** Learn how to recognize application heap problems, buffer and stack overflow patterns and analyze raw stack data
- **Patterns:** Double Free; Local Buffer Overflow; Stack Overflow

Exercise P11

- **Goal:** Learn how to analyze various patterns, raw stacks and execution residue
- **Patterns:** Divide by Zero; C++ Exception; Multiple Exceptions; Execution Residue

Exercise P12

- **Goal:** Learn how to load the correct .NET WinDbg extension and analyze managed space
- **Patterns:** CLR Thread; Version-Specific Extension; Managed Code Exception; Managed Stack Trace

Exercise P13

- **Goal:** Learn how to analyze 32-process saved as a 64-bit process memory dump
- **Patterns:** Virtualized Process; Message Box; Execution Residue

Exercise P14

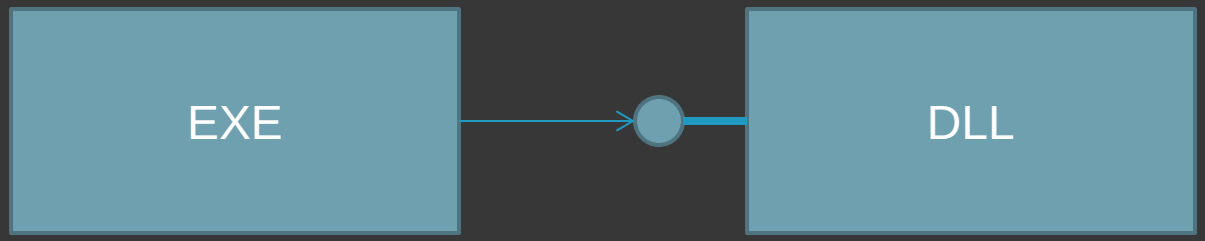
- **Goal:** Learn how to analyze process memory leaks
- **Patterns:** Spiking Thread; Thread Age; Memory Leak (process heap)

Parameters and Locals

Debugging TV Frames episode 0x18

Symbol Types

- Exported and imported names



- Function and variable names
- Data types

Exercise P15

- **Goal:** Learn how to navigate function parameters in cases of reduced symbolic information in 32-bit process memory dumps
- **Patterns:** Reduced Symbolic Information

Exercise P16

- **Goal:** Learn how to navigate function parameters in x64 process memory dumps
- **Patterns:** False Function Parameters, Injected Symbols

Pattern Links

Spiking Thread
C++ Exception
Divide by Zero
Heap Corruption
Execution Residue
Invalid Pointer
Manual Dump
Managed Stack Trace
Not My Version
NULL Code Pointer
Stack Trace Collection
Environment Hint
Unknown Component
Virtualized Process
Version-Specific Extension
False Function Parameters
Reduced Symbolic Information
CLR Thread
Critical Section Deadlock
Double Free
Exception Stack Trace
Hidden Exception
Local Buffer Overflow
Managed Code Exception
Multiple Exceptions
NULL Data Pointer
Stack Trace
Stack Overflow
Wild Code
Wait Chain
Message Box
Memory Leak
Injected Symbols

Kernel Memory Dumps

Exercises K1-K5

Exercise K1

- **Goal:** Learn how to get various information related to hardware, system, sessions, processes, threads and modules
- **Patterns:** Invalid Pointer; Virtualized System; Stack Trace Collection

Exercise K2

- **Goal:** Learn how to check and compare kernel pool usage
- **Patterns:** Manual Dump; Insufficient Memory (kernel pool)

Exercise K3

- **Goal:** Learn how to recognize pool corruption and check pool data
- **Patterns:** Dynamic Memory Corruption (kernel pool); Execution Residue

Exercise K4

- **Goal:** Learn how to check hooked or invalid code and kernel raw stack
- **Patterns:** Null Pointer; Hooked Functions (kernel space); Execution Residue; Coincidental Symbolic Information

Exercise K5

- **Goal:** Learn how to check I/O requests
- **Patterns:** Blocking File

Pattern Links

Manual Dump
Virtualized System
Insufficient Memory
Execution Residue
Hooked Functions
Blocking File
Invalid Pointer
Stack Trace Collection
Dynamic Memory Corruption
Null Pointer
Coincidental Symbolic Information

Additional Pattern Links

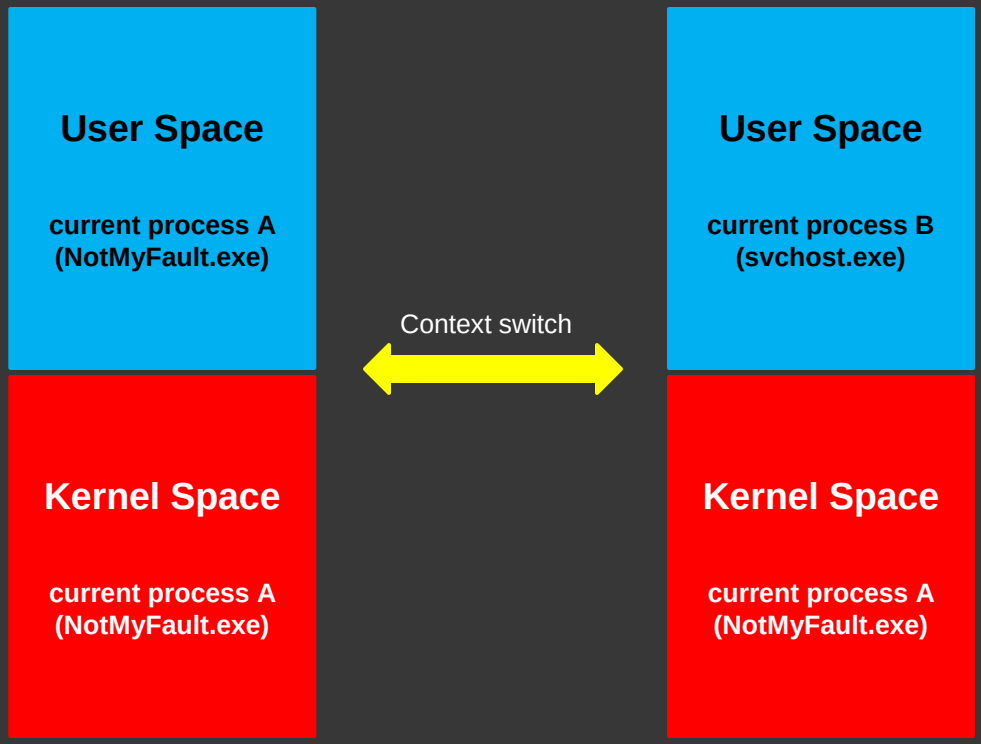
ERESOURCE patterns and case studies

Complete Memory Dumps

Exercises C1-C2

Memory Spaces

- Complete memory == Physical memory
- We always see the current process space



WinDbg Commands

switching to a different process context:

.process /r /p

Major Challenges

- Multiple processes (user spaces) to examine
- User space view needs to be correct when we examine another thread

WinDbg Commands
dump all stack traces: **!process 0 3f**

Common Commands

- **.logopen <file>**
  Opens a log file to save all subsequent output
- View commands
  Dump everything or selected processes and threads (context changes automatically)
- Switch commands
  Switch to a specific process or thread for a fine-grain analysis

View Commands

- **!process 0 3f**
  Lists all processes (including times, environment, modules) and their thread stack traces
- **!process 0 1f**
  The same as the previous command but without PEB information (more secure)
- **!process <address> 3f or !process <address> 1f**
  The same as the previous commands but only for an individual process
- **!thread <address> 1f**
  Shows thread information and stack trace
- **!thread <address> 16**
  The same as the previous command but shows the first 3 parameters for every function

Switch Commands

- **.process /r /p <address>**

  Switches to a specified process. Its context becomes current. Reloads symbol files for user space. Now we can use commands like !cs

```
0: kd> .process /r /p fffffa80044d8b30
Implicit process is now fffffa80`044d8b30
Loading User Symbols
...............................
```

- **.thread <address>**

  Switches to a specified thread. Assumes the current process context

  Now we can use commands like k*

- **.thread /r /p <address>**

  The same as the previous command but makes the thread process context current and reloads symbol files for user space:

```
0: kd> .thread /r /p fffffa80051b7060
Implicit thread is now fffffa80`051b7060
Implicit process is now fffffa80`044d8b30
Loading User Symbols
...............................
```

Exercise C1

- **Goal:** Learn how to get various information related to processes, threads and modules
- **Patterns:** Stack Trace Collection

Example: Blocked Thread

```
THREAD fffffa800451db60  Cid 07f4.0b8c  Teb: 000007fffffd6000 Win32Thread: fffff900c27c0c30 WAIT: (WrUserRequest) UserMode Non-
      Alertable
          fffffa8004e501e0  SynchronizationEvent
       Not impersonating
       DeviceMap                 fffff8a001e84c00
       Owning Process            fffffa8004514630       Image:         ApplicationA.exe
       [...]
       Stack Init fffff88005b7fdb0 Current fffff88005b7f870
       Base fffff88005b80000 Limit fffff88005b77000 Call 0
       Priority 11 BasePriority 8 UnusualBoost 0 ForegroundBoost 2 IoPriority 2 PagePriority 5
       Child-SP          RetAddr           Call Site
       fffff880`05b7f8b0 fffff800`01a93992 nt!KiSwapContext+0x7a
       fffff880`05b7f9f0 fffff800`01a95cff nt!KiCommitThreadWait+0x1d2
       fffff880`05b7fa80 fffff960`0011b557 nt!KeWaitForSingleObject+0x19f
       fffff880`05b7fb20 fffff960`0011b5f1 win32k!xxxRealSleepThread+0x257
       fffff880`05b7fbc0 fffff960`0012e22e win32k!xxxSleepThread+0x59
       fffff880`05b7fbf0 fffff800`01a8b993 win32k!NtUserWaitMessage+0x46
       fffff880`05b7fc20 00000000`775cbf5a nt!KiSystemServiceCopyEnd+0x13 (TrapFrame @ fffff880`05b7fc20)
       00000000`022ff7c8 00000000`775d7214 USER32!ZwUserWaitMessage+0xa
       00000000`022ff7d0 00000000`775d74a5 USER32!DialogBox2+0x274
       00000000`022ff860 00000000`776227f0 USER32!InternalDialogBox+0x135
       00000000`022ff8c0 00000000`77621ae5 USER32!SoftModalMessageBox+0x9b4
       00000000`022ff9f0 00000000`7762133b USER32!MessageBoxWorker+0x31d
       00000000`022ffbb0 00000000`77621232 USER32!MessageBoxTimeoutW+0xb3
   >>> 00000000`022ffc80 00000001`3f3c1089 USER32!MessageBoxW+0x4e
       00000000`022ffcc0 00000001`3f3c11fb ApplicationA+0x1089
       00000000`022ffcf0 00000001`3f3c12a5 ApplicationA+0x11fb
       00000000`022ffd20 00000000`776cf56d ApplicationA+0x12a5
       00000000`022ffd50 00000000`77803281 kernel32!BaseThreadInitThunk+0xd
       00000000`022ffd80 00000000`00000000 ntdll!RtlUserThreadStart+0x1d
```

Example: Wait Chain

```
THREAD fffffa8004562b60  Cid 0b34.0858  Teb: 000007fffffae000 Win32Thread: 0000000000000000 WAIT: (UserRequest) UserMode Non-
      Alertable
>>>         fffffa8004b96ce0  Mutant - owning thread fffffa8004523b60
       Not impersonating
       DeviceMap                 fffff8a001e84c00
       Owning Process            fffffa8005400b30       Image:         ApplicationC.exe
       Attached Process          N/A            Image:         N/A
       Wait Start TickCount      36004          Ticks: 4286 (0:00:01:06.862)
       Context Switch Count      2
       UserTime                  00:00:00.000
       KernelTime                00:00:00.000
       Win32 Start Address ApplicationC (0x000000013f7012a0)
       Stack Init fffff88005b1ddb0 Current fffff88005b1d900
       Base fffff88005b1e000 Limit fffff88005b18000 Call 0
       Priority 11 BasePriority 8 UnusualBoost 0 ForegroundBoost 2 IoPriority 2 PagePriority 5
       Child-SP          RetAddr           Call Site
       fffff880`05b1d940 fffff800`01a93992 nt!KiSwapContext+0x7a
       fffff880`05b1da80 fffff800`01a95cff nt!KiCommitThreadWait+0x1d2
       fffff880`05b1db10 fffff800`01d871d2 nt!KeWaitForSingleObject+0x19f
       fffff880`05b1dbb0 fffff800`01a8b993 nt!NtWaitForSingleObject+0xb2
       fffff880`05b1dc20 00000000`7781fefa nt!KiSystemServiceCopyEnd+0x13 (TrapFrame @ fffff880`05b1dc20)
       00000000`00e2f658 000007fe`fda910ac ntdll!NtWaitForSingleObject+0xa
       00000000`00e2f660 00000001`3f70112e KERNELBASE!WaitForSingleObjectEx+0x79
       00000000`00e2f700 00000001`3f70128b ApplicationC+0x112e
       00000000`00e2f730 00000001`3f701335 ApplicationC+0x128b
       00000000`00e2f760 00000000`776cf56d ApplicationC+0x1335
       00000000`00e2f790 00000000`77803281 kernel32!BaseThreadInitThunk+0xd
       00000000`00e2f7c0 00000000`00000000 ntdll!RtlUserThreadStart+0x1d
```

Example: Handle Leak

```
1: kd> !process 0 0
**** NT ACTIVE PROCESS DUMP ****
PROCESS fffffa8003baa890
    SessionId: none  Cid: 0004    Peb: 00000000  ParentCid: 0000
    DirBase: 00187000  ObjectTable: fffff8a000001a80  HandleCount: 558.
    Image: System

PROCESS fffffa8004277870
    SessionId: none  Cid: 011c    Peb: 7fffffdf000  ParentCid: 0004
    DirBase: 133579000  ObjectTable: fffff8a00000f3d0  HandleCount:  35.
    Image: smss.exe

PROCESS fffffa80048f3950
    SessionId: 0  Cid: 016c    Peb: 7fffffdf000  ParentCid: 0154
    DirBase: 128628000  ObjectTable: fffff8a001d62f90  HandleCount: 387.
    Image: csrss.exe


[...]

PROCESS fffffa800541a060
    SessionId: 1  Cid: 0b94    Peb: 7fffffde000  ParentCid: 06ac
>>> DirBase: a6ba9000  ObjectTable: fffff8a0098efaf0  HandleCount:
      20013.
    Image: ApplicationE.exe

[...]
```

Example: Corruption

```
THREAD fffffa8004514060  Cid 0abc.087c  Teb: 000007fffffae000 Win32Thread: 0000000000000000 WAIT: (UserRequest) UserMode
      Alertable
          fffffa800518fb30  ProcessObject
       [...]
       Child-SP          RetAddr           Call Site
       fffff880`05a6c940 fffff800`01a93992 nt!KiSwapContext+0x7a
       fffff880`05a6ca80 fffff800`01a95cff nt!KiCommitThreadWait+0x1d2
       fffff880`05a6cb10 fffff800`01d871d2 nt!KeWaitForSingleObject+0x19f
       fffff880`05a6cbb0 fffff800`01a8b993 nt!NtWaitForSingleObject+0xb2
       fffff880`05a6cc20 00000000`7781fefa nt!KiSystemServiceCopyEnd+0x13 (TrapFrame @ fffff880`05a6cc20)
       00000000`00dde928 00000000`77895ce2 ntdll!NtWaitForSingleObject+0xa
       00000000`00dde930 00000000`77895e85 ntdll!RtlReportExceptionEx+0x1d2
       00000000`00ddea20 00000000`77895eea ntdll!RtlReportException+0xb5
       00000000`00ddeaa0 00000000`77896d25 ntdll!RtlpTerminateFailureFilter+0x1a
       00000000`00ddead0 00000000`777e5148 ntdll!RtlReportCriticalFailure+0x96
       00000000`00ddeb00 00000000`7780554d ntdll!_C_specific_handler+0x8c
       00000000`00ddeb70 00000000`777e5d1c ntdll!RtlpExecuteHandlerForException+0xd
       00000000`00ddeba0 00000000`777e62ee ntdll!RtlDispatchException+0x3cb
       00000000`00ddf280 00000000`77896cd2 ntdll!RtlRaiseException+0x221
       00000000`00ddf8c0 00000000`77897396 ntdll!RtlReportCriticalFailure+0x62
       00000000`00ddf990 00000000`778986c2 ntdll!RtlpReportHeapFailure+0x26
       00000000`00ddf9c0 00000000`7789a0c4 ntdll!RtlpHeapHandleError+0x12
       00000000`00ddf9f0 00000000`7783d1cd ntdll!RtlpLogHeapFailure+0xa4
       00000000`00ddfa20 00000000`776d2c7a ntdll! ?? ::FNODOBFM::`string'+0x123b4
>>>    00000000`00ddfaa0 00000001`3fa71274 kernel32!HeapFree+0xa
       00000000`00ddfad0 00000001`3fa710c3 ApplicationD+0x1274
       00000000`00ddfb00 00000001`3fa71303 ApplicationD+0x10c3
       00000000`00ddfb30 00000001`3fa713ad ApplicationD+0x1303
       00000000`00ddfb60 00000000`776cf56d ApplicationD+0x13ad
       00000000`00ddfb90 00000000`77803281 kernel32!BaseThreadInitThunk+0xd
       00000000`00ddfbc0 00000000`00000000 ntdll!RtlUserThreadStart+0x1d
```

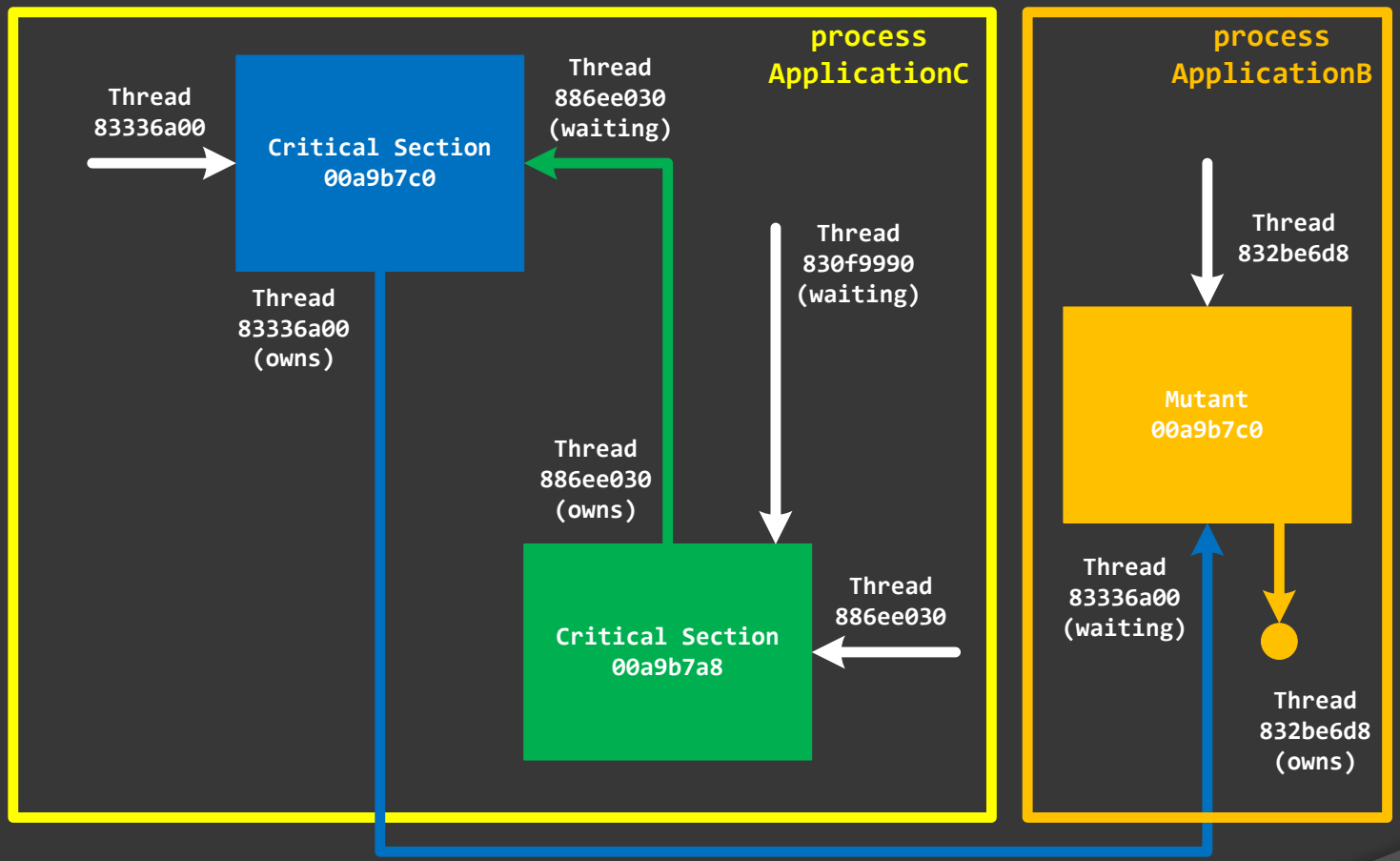
Example: Special Process

```
1: kd> !vm

[...]

        0744 svchost.exe      19725 (     78900 Kb)
        06ac explorer.exe     11444 (     45776 Kb)
        0920 iexplore.exe      8828 (     35312 Kb)
        0354 svchost.exe       5589 (     22356 Kb)
        040c audiodg.exe       4003 (     16012 Kb)
        0334 svchost.exe       3852 (     15408 Kb)
        04e4 spoolsv.exe       3230 (     12920 Kb)
        012c svchost.exe       2802 (     11208 Kb)
        0168 iexplore.exe      2106 (      8424 Kb)
        0384 svchost.exe       2090 (      8360 Kb)
        042c svchost.exe       1938 (      7752 Kb)
        0218 lsass.exe         1314 (      5256 Kb)
        03d4 svchost.exe       1128 (      4512 Kb)
>>>     0a78 WerFault.exe      1107 (      4428 Kb)
        0210 services.exe      1106 (      4424 Kb)
        0288 svchost.exe        980 (      3920 Kb)
        02d8 svchost.exe        891 (      3564 Kb)
        0438 msdtc.exe          851 (      3404 Kb)
        071c mscorsvw.exe       821 (      3284 Kb)
        0378 taskhost.exe       795 (      3180 Kb)
        01a8 psxss.exe          685 (      2740 Kb)
        08a0 jusched.exe        667 (      2668 Kb)
        09e0 jucheck.exe        621 (      2484 Kb)
        0828 mscorsvw.exe       600 (      2400 Kb)
        0538 mdm.exe            595 (      2380 Kb)
        0220 lsm.exe            595 (      2380 Kb)
[...]
```

Exercise C2

- **Goal:** Learn how to recognize various abnormal software behavior patterns
- **Patterns:** Special Process; Handle Leak; Spiking Thread; Stack Trace Collection; Message Box; Wait Chain; Exception Thread

Wait Chain



Pattern Links

Special Process
Handle Leak
Spiking Thread
Stack Trace Collection
Message Box
Wait Chain (critical sections)
Exception Stack Trace

Also other patterns are present in C2 memory dump (not shown in exercise transcript):

Wait Chain (window messaging) Paged Out Data
Wait Chain (LPC/ALPC)

Common Mistakes

- Not switching to the appropriate context
- Not looking at full stack traces
- Not looking at all stack traces
- Not using checklists
- Not looking past the first found evidence

Note: Listing both x86 and x64 stack traces
http://www.dumpanalysis.org/blog/index.php/2010/02/09/complete-stack-traces-from-x64-system/

Kernel Minidumps

Memory Dump Analysis Anthology, Volume 1

pp. 43 - 67

Pattern Classification

Space/Mode
Hooksware
DLL Link Patterns
Contention Patterns
Stack Trace Patterns
Exception Patterns
Module Patterns
Thread Patterns
Dynamic Memory Corruption Patterns
.NET / CLR / Managed Space Patterns
Memory dump type
Wait Chain Patterns
Insufficient Memory Patterns
Stack Overflow Patterns
Symbol Patterns
Meta-Memory Dump Patterns
Optimization Patterns
Process Patterns
Deadlock and Livelock Patterns
Executive Resource Patterns

Pattern Case Studies

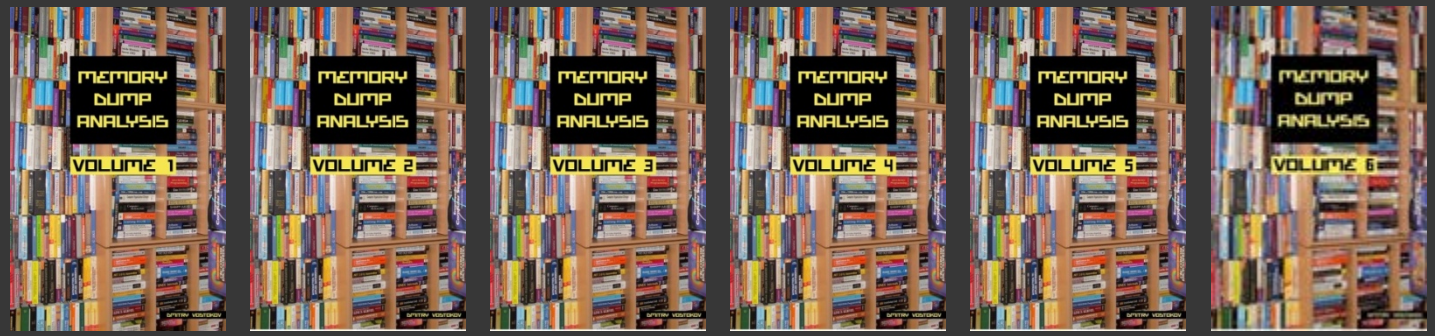
70 multiple pattern case studies:

http://www.dumpanalysis.org/blog/index.php/pattern-cooperation/

Pattern Interaction chapters in Memory Dump Analysis Anthology

Resources

- WinDbg Help / WinDbg.org (quick links)
- DumpAnalysis.org
- Debugging.TV
- Windows Internals, 6th ed.
- Windows Debugging: Practical Foundations
- x64 Windows Debugging: Practical Foundations
- Advanced Windows Debugging
- Windows Debugging Notebook: Essential User Space WinDbg Commands
- Memory Dump Analysis Anthology



Q&A

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

Thank you for attendance!