WinDbg. From A to Z!

Everything you need to know about WinDbg.
And nothing you don't.

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Why WinDbg?

Because WinDbg is:

- used by the Microsoft Windows product team to develop Windows
- much more powerful than the well-known Visual Studio debugger
- extensible through extension DLLs
- its debug engine is part of the Windows OS

Up from Windows XP dgbeng.dll and dbghelp.dll are installed in “C:\Windows\System32”.

Why “WinDbg. From A to Z” ?

- WinDbg's documentation is sub-optimal for people new to the topic
- Without good documentation and examples the learning curve for WinDbg is very steep

In fact many people give up soon after the installation.

- *“WinDbg. From A to Z!”* is a quick start and introduction to WinDbg. After reading it you will have a good feeling about what WinDbg is and what it can do for you.

While many parts of “*WinDbg. From A to Z!”* are based on user-mode examples, you will benefit from it even if you are doing kernel-mode development. Note that the same debugging engine is running behind the scenes, no matter if you debug user-mode or kernel-mode code. Essentially the only visible difference for kernel-mode debugging is that you will end up using another set of extension commands.

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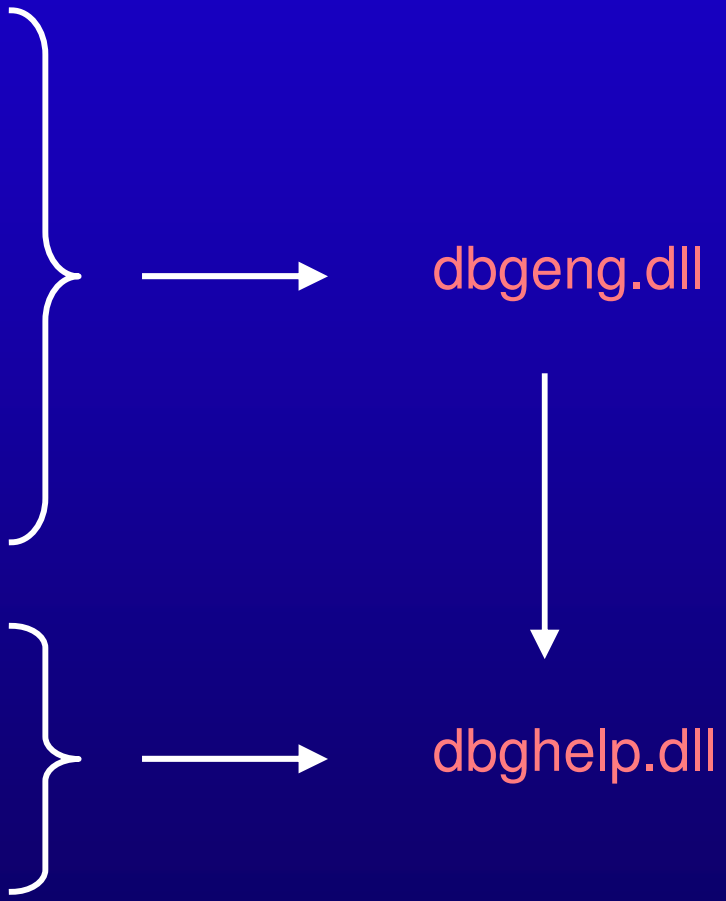
→ **Behind the Scenes**

- Using WinDbg
- Global Flags
- Application Verifier
- Process Dumps

Debugging Tools for Windows XP

- WinDbg.exe
- ntsd.exe
- cdb.exe
- kd.exe
- dbgsrv.exe
- userdump.exe
- drwtsn32.exe

- livekd.exe
- OlyDbg.exe
- ProcessExplorer.exe
- ...



Debug Help Library: dbghelp.dll

- Documented in MSDN
- Included in the operating system, starting with Windows 2000
- Contains support routines for:

  a) Process Dumping (MiniDumpWriteDump , DbgHelpCreateUSerDump, ..)

  b) Obtaining Stack Traces (StackWalk64, ...)

  c) Symbol Handling (SymFromAddr, Sym* ..)

  d) Obtaining info about executable images (ImageNtHeader, FindDebugInfoFile, ..)

Many c) and d) functions are duplicates (same declaration) also found and exported from imagehlp.dll. While many imaghlp functions are simply forwarded to dbghelp functions, a disassembly of some functions reveals that they are obviously build from the same sources (see disassembly on next slide). While some MS Tools prefer the usage of DbgHelp.dll, some tools like Visual Studio or Dependency Walker rely on imagehlp.dll or use both libraries.

dbghelp!ImageNtHeader vs. imagehlp!ImageNtHeader

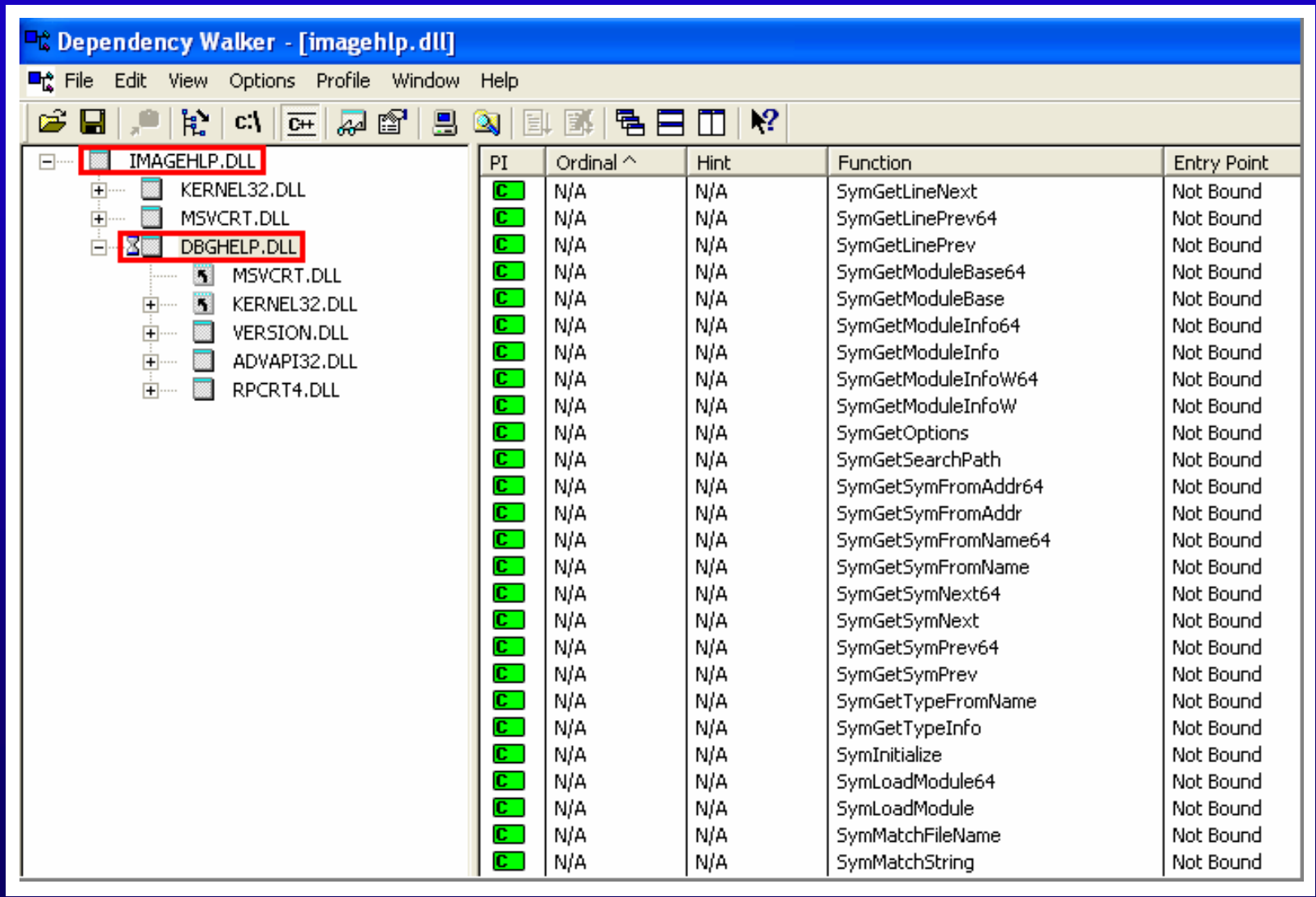
Command

```
0:000> uf dbgHelp!ImageNtHeader
dbghelp!RtlpImageNtHeader:
6d59a770 6a0c            push    0Ch
6d59a772 68e832586d      push    offset dbghelp!ArmFunctionEntryCache::`vftable'+0xc (6d5832e8)
6d59a777 e8d0e00100      call    dbghelp!_SEH_prolog (6d5b884c)
6d59a77c 33c0            xor     eax,eax
6d59a77e 8b4d08          mov     ecx,dword ptr [ebp+8]
6d59a781 85c9            test    ecx,ecx
6d59a783 743c            je      dbghelp!RtlpImageNtHeader+0x51 (6d59a7c1)

dbghelp!RtlpImageNtHeader+0x15:
6d59a785 83f9ff          cmp     ecx,0FFFFFFFFh
6d59a788 7437            je      dbghelp!RtlpImageNtHeader+0x51 (6d59a7c1)

dbghelp!RtlpImageNtHeader+0x1a:
6d59a78a 2145fc          and     dword ptr [ebp-4],eax
6d59a78d 6681394d5a      cmp     word ptr [ecx],5A4Dh
6d59a792 7529            jne     dbghelp!RtlpImageNtHeader+0x4d (6d59a7bd)

dbghelp!RtlpImageNtHeader+0x24:
6d59a794 8b513c          mov     edx,dword ptr [ecx+3Ch]
6d59a797 81fa00000010    cmp     edx,10000000h
6d59a79d 731e            jae     dbghelp!RtlpImageNtHeader+0x4d (6d59a7bd)

dbghelp!RtlpImageNtHeader+0x2f:
6d59a79f 8d040a          lea     eax,[edx+ecx]
6d59a7a2 8945e4          mov     dword ptr [ebp-1Ch],eax
6d59a7a5 813850450000    cmp     dword ptr [eax],4550h
6d59a7ab 7410            je      dbghelp!RtlpImageNtHeader+0x4d (6d59a7bd)

dbghelp!RtlpImageNtHeader+0x3d:
6d59a7ad 33c0            xor     eax,eax
6d59a7af 8945e4          mov     dword ptr [ebp-1Ch],eax
6d59a7b2 eb09            jmp     dbghelp!RtlpImageNtHeader+0x4d (6d59a7bd)

dbghelp!RtlpImageNtHeader+0x4d:
6d59a7bd 834dfcff        or      dword ptr [ebp-4],0FFFFFFFFh

dbghelp!RtlpImageNtHeader+0x51:
6d59a7c1 e8c1e00100      call    dbghelp!_SEH_epilog (6d5b8887)
6d59a7c6 c20400          ret     4

dbghelp!ImageNtHeader:
6d59a7ce 8bff            mov     edi,edi
6d59a7d0 55              push    ebp
6d59a7d1 8bec            mov     ebp,esp
6d59a7d3 5d              pop     ebp
6d59a7d4 e997ffffff      jmp     dbghelp!RtlpImageNtHeader (6d59a770)
```

Command

```
0:000> uf imagehlp!ImageNtHeader
imagehlp!RtlpImageNtHeader:
76c135d2 6a0c            push    0Ch
76c135d4 682036c176      push    offset imagehlp!`string'+0x2c (76c13620)
76c135d9 e80edcffff      call    imagehlp!_SEH_prolog (76c111ec)
76c135de 33c0            xor     eax,eax
76c135e0 8b4d08          mov     ecx,dword ptr [ebp+8]
76c135e3 85c9            test    ecx,ecx
76c135e5 7430            je      imagehlp!RtlpImageNtHeader+0x51 (76c13617)

imagehlp!RtlpImageNtHeader+0x15:
76c135e7 83f9ff          cmp     ecx,0FFFFFFFFh
76c135ea 742b            je      imagehlp!RtlpImageNtHeader+0x51 (76c13617)

imagehlp!RtlpImageNtHeader+0x1a:
76c135ec 2145fc          and     dword ptr [ebp-4],eax
76c135ef 6681394d5a      cmp     word ptr [ecx],5A4Dh
76c135f4 751d            jne     imagehlp!RtlpImageNtHeader+0x4d (76c13613)

imagehlp!RtlpImageNtHeader+0x24:
76c135f6 8b513c          mov     edx,dword ptr [ecx+3Ch]
76c135f9 81fa00000010    cmp     edx,10000000h
76c135ff 7312            jae     imagehlp!RtlpImageNtHeader+0x4d (76c13613)

imagehlp!RtlpImageNtHeader+0x2f:
76c13601 8d040a          lea     eax,[edx+ecx]
76c13604 8945e4          mov     dword ptr [ebp-1Ch],eax
76c13607 813850450000    cmp     dword ptr [eax],4550h
76c1360d 0f857c3d0000    jne     imagehlp!RtlpImageNtHeader+0x3d (76c1738f)

imagehlp!RtlpImageNtHeader+0x4d:
76c13613 834dfcff        or      dword ptr [ebp-4],0FFFFFFFFh

imagehlp!RtlpImageNtHeader+0x51:
76c13617 e80bdcffff      call    imagehlp!_SEH_epilog (76c11227)
76c1361c c20400          ret     4

imagehlp!RtlpImageNtHeader+0x3d:
76c1738f 33c0            xor     eax,eax
76c17391 8945e4          mov     dword ptr [ebp-1Ch],eax
76c17394 e97ac2ffff      jmp     imagehlp!RtlpImageNtHeader+0x4d (76c13613)

imagehlp!ImageNtHeader:
76c177ad 8bff            mov     edi,edi
76c177af 55              push    ebp
76c177b0 8bec            mov     ebp,esp
76c177b2 5d              pop     ebp
76c177b3 e91abeffff      jmp     imagehlp!RtlpImageNtHeader (76c135d2)
```

ImageHlp Dependencies



Debugger Engine API: dbgeng.dll

- Documented in WinDbg's documentation

  To get the header and lib files for dbgeng.dll: Chose "Custom Installation" and select "SDK" components in addition to the standard items.

- Included in the operating system, starting with Windows XP

- Accessible through interfaces:

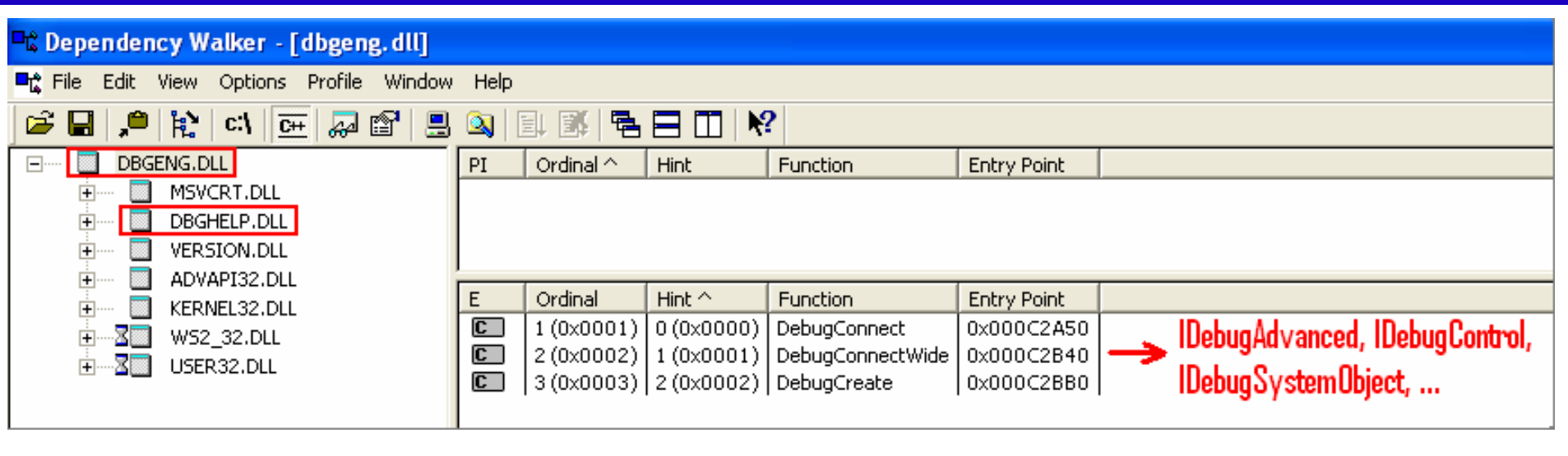
  →IDebugAdvanced, IDebugControl, IDebugSystemObjects, ...

- Everything that can be performed by a debugger is exposed by an interface

Fact 1: WinDbg is really just a shell on top of a debugging engine.

Fact 2: You can write new standalone tools on top of this engine.

DbgEng Dependencies



Debug Symbols

- Executables are just sequences of raw bytes
- Symbols help the debugger to:
  - map raw addresses in the executable to source-code lines
  - analyze internal layout and data of applications
- Program Database → PDB Files
  - The newest Microsoft debug information format
    COFF and CodeView are considered deprecated.
  - PDB's are stored in a file separately from the executable
  - PDB format is not documented
  - There are special APIs to work with it: DbgHelp.dll and MsDiaXY.dll

Kinds of Debug Information

Kind of information	Description
Public functions and variables	Functions and variables visible across several compilation units (source files)
FPO information	Additional information needed for retrieving stack-frames when compiling with FPO optimization (frame pointer omission)
Private functions and variables	All functions and variables including local variables, function parameters, ..
Source file and line information	Source file and line information
Type information	Additional information for functions and variables. Variables: type (int, string, ..) Functions: number and type of parameters, calling convention, return value

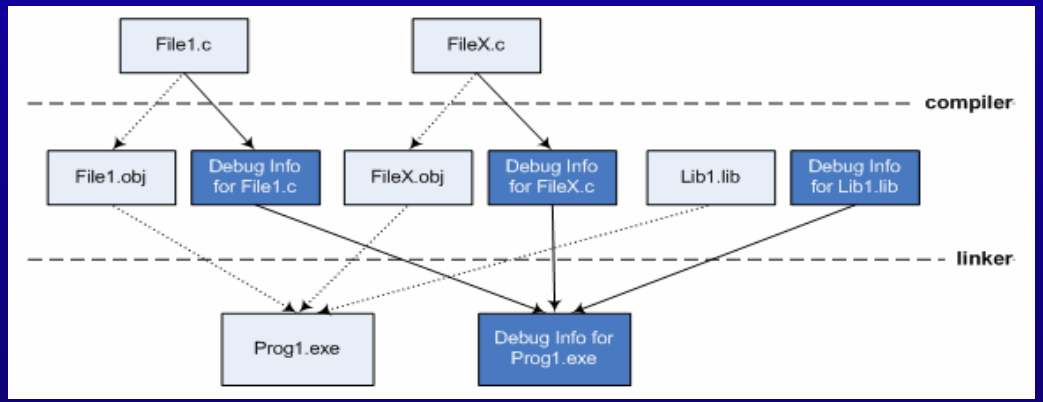
linker: /pdbstripped

Public Symbols for MS modules (kernel32.dll, user32.dll, ..) are always stripped.

Generating Debug Information

- The build process consists of two steps
  1) compiler: generates machine instructions which are stored into .OBJ files
  2) linker: combines all available .OBJ and .LIB files into the final executable

- For Debug Information we also need two steps:
  1) compiler: generates debug information for every source file
  2) linker: combines available debug information into the final set of debug information for the executable



- Compiler options: /Z7, /Zi, /ZI
- Linker options: /debug, /pdb, /pdbstripped

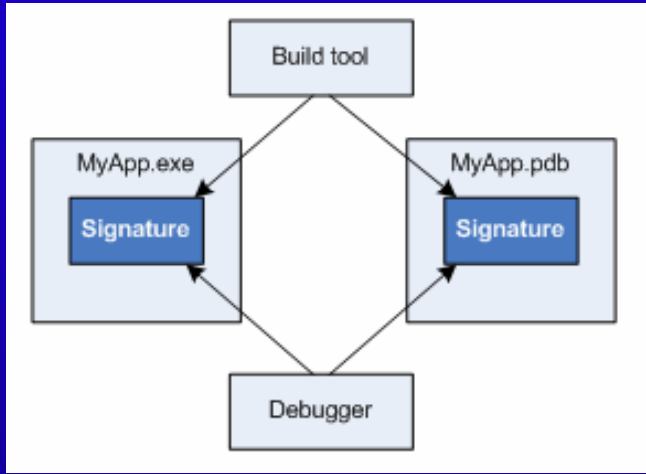
Point of interest for Static libraries: Use /Z7 to store the debug information in the resulting .LIB file.

Matching Debug Information

- Signature stored into executable and PDB file during build

  For PDB 2.0 files: Time Stamp
  For PDB 7.0 files: GUID generated during build

- For a debugger match this signature must be the same



- Algorithm to search PDB files:

  1. Try module (EXE or DLL) folder
  2. Try name and path specified in the PE file (the NB10 or RSDS debug header)
  3. Try environment variables:
     _NT_SYMBOL_PATH and _NT_ALT_SYMBOL_PATH

Call Stack

- **Without valid symbols**

```
002df350 ntdll!DbgBreakPoint
002df43c TestApplication+0x127eb
002df544 TestApplication+0x12862
002df550 MFC80UD!AfxDlgProc+0x3e
002df57c USER32!InternalCallWinProc+0x28
002df5f8 USER32!UserCallDlgProcCheckWow+0x102
002df648 USER32!DefDlgProcWorker+0xb2
002df668 USER32!DefDlgProcW+0x29
002df694 USER32!InternalCallWinProc+0x28
002df70c USER32!UserCallWinProcCheckWow+0x16a
002df744 USER32!CallWindowProcAorW+0xab
002df764 USER32!CallWindowProcW+0x1b
002df788 MFC80UD!CWnd::DefWindowProcW+0x32
002df7a4 MFC80UD!CWnd::Default+0x3b
002df7c8 MFC80UD!CDialog::HandleInitDialog+0xd3
002df900 MFC80UD!CWnd::OnWndMsg+0x817
002df920 MFC80UD!CWnd::WindowProc+0x30
002df99c MFC80UD!AfxCallWndProc+0xee
002df9bc MFC80UD!AfxWndProc+0xa4
002df9f8 MFC80UD!AfxWndProcBase+0x59
```

- **With valid symbols**

```
002df350 ntdll!DbgBreakPoint
002df43c TestApplication!CMyDlg::PreInit+0x3b [MyDlg.cpp @ 75]
002df544 TestApplication!CMyDlg::OnInitDialog+0x52 [MyDlg.cpp @ 91]
002df550 MFC80UD!AfxDlgProc+0x3e
002df57c USER32!InternalCallWinProc+0x28
002df5f8 USER32!UserCallDlgProcCheckWow+0x102
002df648 USER32!DefDlgProcWorker+0xb2
002df668 USER32!DefDlgProcW+0x29
002df694 USER32!InternalCallWinProc+0x28
002df70c USER32!UserCallWinProcCheckWow+0x16a
002df744 USER32!CallWindowProcAorW+0xab
002df764 USER32!CallWindowProcW+0x1b
002df788 MFC80UD!CWnd::DefWindowProcW+0x32
002df7a4 MFC80UD!CWnd::Default+0x3b
002df7c8 MFC80UD!CDialog::HandleInitDialog+0xd3
002df900 MFC80UD!CWnd::OnWndMsg+0x817
002df920 MFC80UD!CWnd::WindowProc+0x30
002df99c MFC80UD!AfxCallWndProc+0xee
002df9bc MFC80UD!AfxWndProc+0xa4
002df9f8 MFC80UD!AfxWndProcBase+0x59
```

Invasive vs. Noninvasive Debugging and Attaching

- Invasive attach:
  - DebugActiveProcess is called
  - break-in thread is created
  - prior to Windows XP: target application is killed on debugger exit or detach
  - there can be only one invasive debugger attached to a process at any time
- Noninvasive attach:
  - OpenProcess is called
  - no break-in thread is created
  - we don't attach to the process as a debugger
  - all threads of the target application are frozen
  - we can change and examine memory
  - we cannot set breakpoints
  - we cannot step through the application
  - we can exit or detach the debugger without killing the target application
  - we can attach several noninvasive debuggers to a process (+ one invasive debugger)
  - useful if:
    - the target application is being debugged by Visual Studio (or any other invasive debugger), we can still attach WinDBG as a noninvasive debugger in order to get additional information
    - the target application is completely frozen and cannot launch the break-in thread necessary for a true attach

Exceptions

- A system mechanism that isn't language specific.

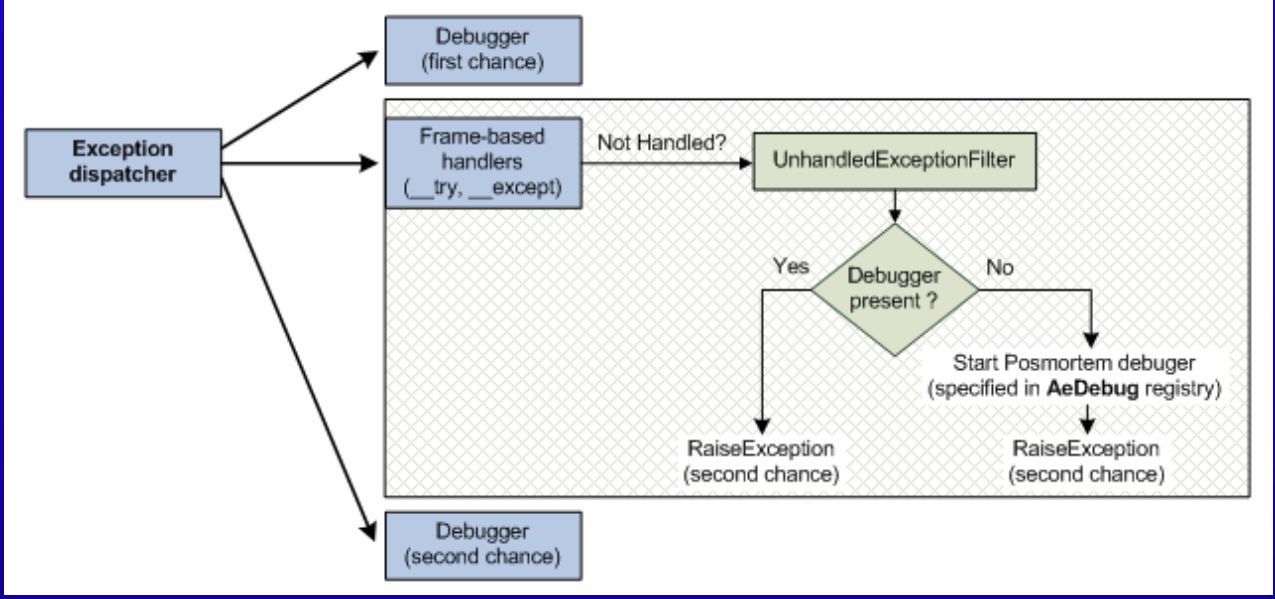
- Exceptions are made accessible through language extensions.

  Example: the __try & __except construct in C++.

- Don't use try-catch-except for condition checking in time critical parts of your application.

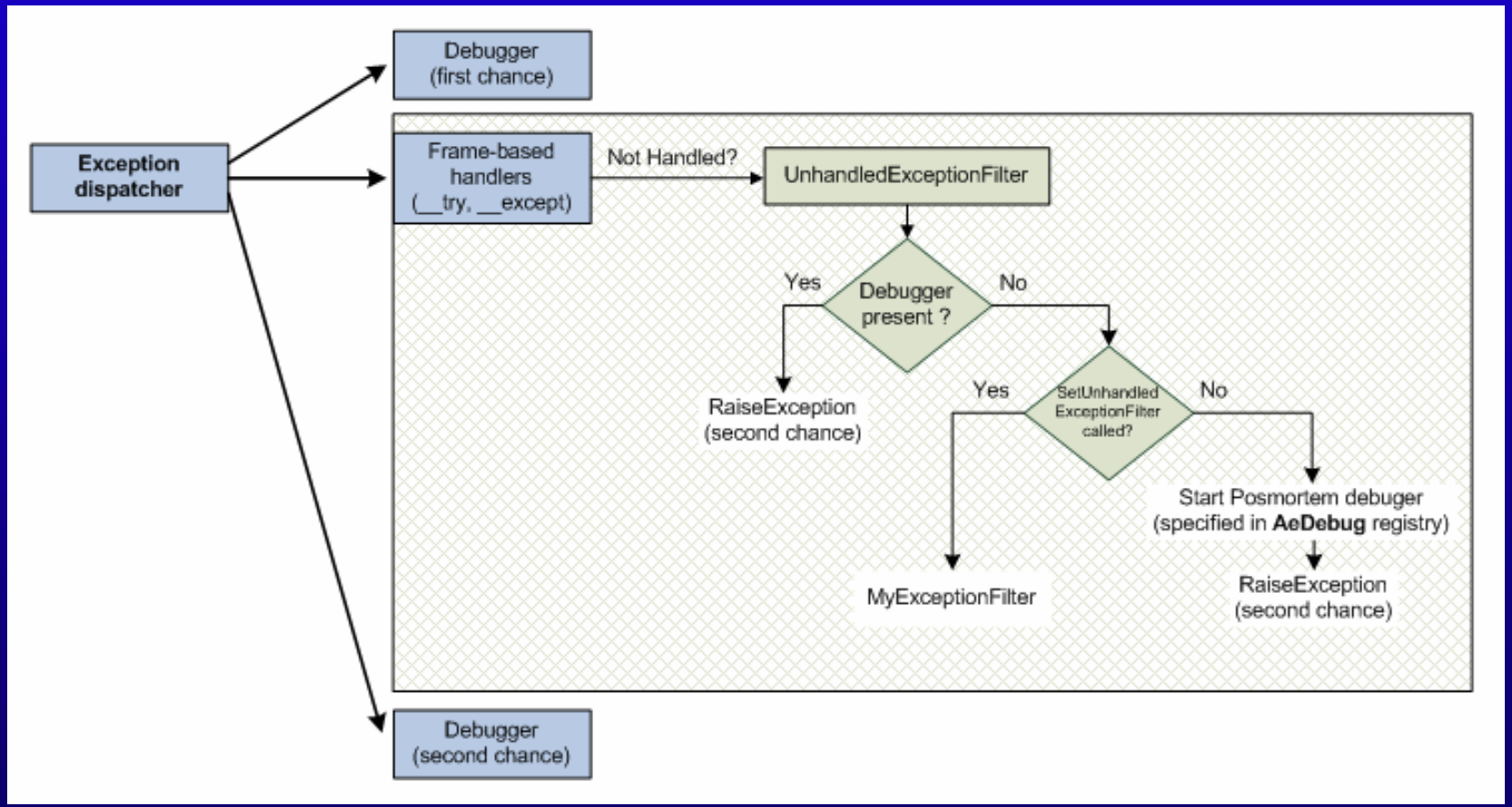
  For every exception the system creates an exception record, searches for frame based exception handlers (catch-except) through all stack frames in reverse order, and finally continues with program execution. This can result in performance degradation due to the execution of hundreds of instructions.

Exception Dispatching



1) The system first attempts to notify the process's debugger, if any
2) If the process is not being debugged, or if the associated debugger does not handle the exception (WinDbg → gN == Go with Exception Not Handled), the system attempts to locate a frame-based exception handler
3) If no frame-based handler can be found, or no frame-based handler handles the exception, the UnhandledExceptionFilter makes a second attempt to notify the process's debugger. This is known as second-chance or last-chance notification.
4) If the process is not being debugged, or if the associated debugger does not handle the exception, the postmortem debugger specified in AeDebug will be started.

Exception Dispatching and SetUnhandledExceptionFilter

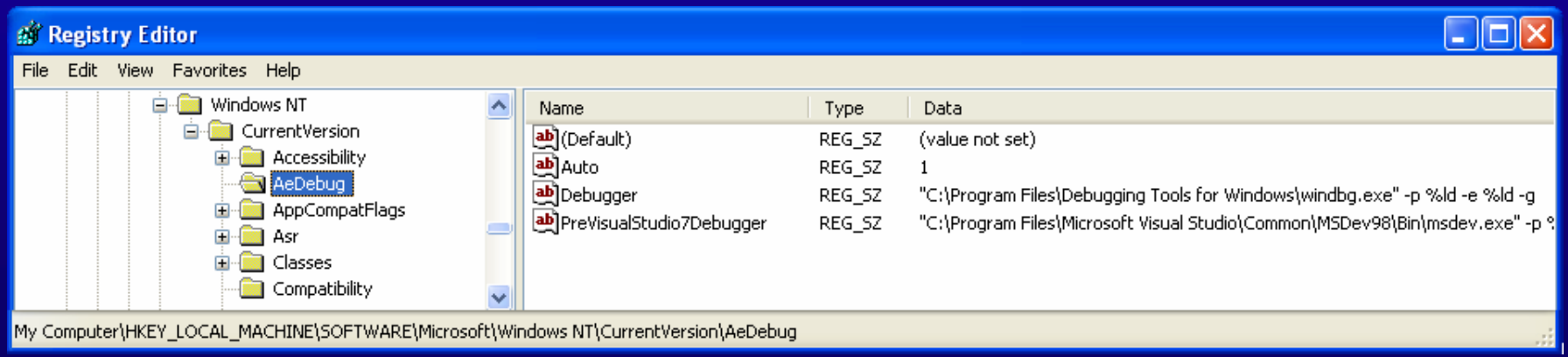


AeDebug? Postmortem Debugging!

- Set/Change postmortem debugger:
  - WinDbg -I
  - drwtsn32 -i

- Postmortem settings:
  HKLM\SOFTWARE\Microsoft\Windows NT\CurrentVersion\AeDebug

  Whatever program is specified in AeDebug is run.
  No validation is made that the program is actually a debugger!



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- Application Verifier
- Process Dumps

WinDbg Commands

- Regular commands
  - are used to debug processes
  - Examples: k, lm, g
- Meta or Dot-Commands
  - usually control the behavior of the debugger
  - Examples: .sympath, .cls, .lastevent, .detach, .if
- Extension Commands
  - implemented as exported functions in extension DLLs
  - are a large part of what makes WinDbg such a powerful debugger
  - there is a set of preinstalled extension DLLs: exts.dll, ntsdexts.dll, uext.dll, wow64exts.dll, kdexts.dll, ..
  - we can write our own extension DLLs
  - Examples: !analyze, !address, !handle, !peb

Main Extensions

- !exts.help → General Extensions
- !Uext.help → User-Mode Extensions (non-OS specific)
- !Ntsdexts.help → User-Mode Extensions (OS specific)
- !Kdexts.help → Kernel-Mode Extensions
- !logexts.help → Logger Extensions
- !clr10\sos.help → Debugging Managed Code
- !wow64exts.help → Wow64 Debugger Extensions
- ..

Symbols in WinDbg

- **_NT_SYMBOL_PATH** environment variable must be set

  Example for MS symbols:

  _NT_SYMBOL_PATH=srv*C:\Symbols\MsSymbols***http://msdl.microsoft.com/download/symbols;**

  With this setting WinDbg will automatically download all needed symbols for MS components (i.e. kernel32) from the MS server.

- In WinDbg's GUI you can access symbol settings from:
  - (Menu) File → Symbol File Path … (Ctrl+S)

- Useful Commands:
  - .sympath → get/set path for symbol search
  - .sympath +XY → append XY directory to the searched symbol path
  - !sym noisy → instructs the debugger to display information about its search for symbols
  - ld kernel32 → load symbols for kernel32.dll
  - ld * → load symbols for all modules
  - .reload → reloads symbol information
  - x kernel32!* → examine and list all symbols in kernel32
  - x kernel32!*LoadLibrary* → list all symbols in kernel32 which contain *LoadLibrary*
  - dt ntdll!* → display all variables in ntdll

Sources in WinDbg

- **_NT_SOURCE_PATH** environment variable must be set

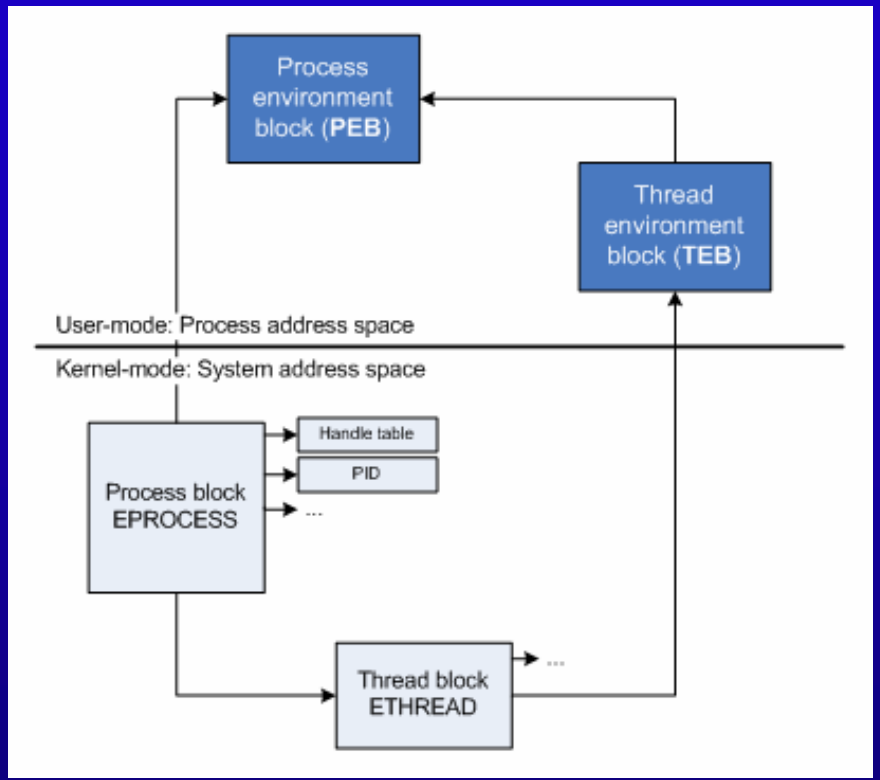
  Example:
  _NT_SOURCE_PATH=C:\Sources

- In WinDbg's GUI you can access source settings from:
  - (Menu) File → Source File Path … (Ctrl+P)

- Useful Commands:
  - .srcpath → get/set path for source-file search
  - .srcpath+ XY → append XY directory to the searched source path

Important: Be sure to **set up the symbols and sources for WinDbg correctly**. This is the first and most important step where people new to WinDbg often fail. Note that without symbols for MS components (kernel32.dll, ntdll.dll,..) many commands in the following sections will not work.

Processes and Threads on Windows NT



- Every Windows process is represented by an executive process block (EPROCESS) in kernel-mode
- EPROCESS points to a number of related data structures; for example, each process has one or more threads represented by executive thread blocks (ETHREAD)
- EPROCESS points to a process environment block (PEB) in process address space
- ETHREAD points to a thread environment block (TEB) in process address space

PEB and TEB

- PEB = Process Environment Block
  - basic image information (base address, version numbers, module list)
  - process heap information
  - environment variables
  - command-line parameter
  - DLL search path
  - Display it: !peb, dt nt!_PEB

- TEB = Thread Environment block
  - stack information (stack-base and stack-limit)
  - TLS (Thread Local Storage) array
  - Display it: !teb, dt nt!_TEB

FACT: Many WinDbg commands (lm, !dlls, !imgreloc, !tls, !gle) rely on the data retrieved from PEB and TEB.

Example - PEB “dump”

```
0:001> dt nt!_PEB -r @$peb                    // @$peb = address of our process's PEB (see pseudo-register syntax)
   +0x000 InheritedAddressSpace : 0 ''
   +0x001 ReadImageFileExecOptions : 0 ''
   +0x002 BeingDebugged    : 0x1 ''
   ..
   +0x008 ImageBaseAddress : 0x00400000
   +0x00c Ldr              : 0x7d6a01e0 _PEB_LDR_DATA
       +0x000 Length           : 0x28
       +0x004 Initialized      : 0x1 ''
       +0x008 SsHandle         : (null)
       +0x00c InLoadOrderModuleList : _LIST_ENTRY [ 0x2d1eb0 - 0x2da998 ]
          +0x000 Flink            : 0x002d1eb0 _LIST_ENTRY [ 0x2d1f08 - 0x7d6a01ec ]
          +0x004 Blink            : 0x002da998 _LIST_ENTRY [ 0x7d6a01ec - 0x2d9f38 ]
      +0x014 InMemoryOrderModuleList : _LIST_ENTRY [ 0x2d1eb8 - 0x2da9a0 ]
           ..
      +0x01c InInitializationOrderModuleList : _LIST_ENTRY [ 0x2d1f18 - 0x2da9a8 ]
           ..
      +0x024 EntryInProgress  : (null)
   +0x010 ProcessParameters : 0x001c0000 _RTL_USER_PROCESS_PARAMETERS
      +0x000 MaximumLength    : 0x102c
      +0x004 Length           : 0x102c
      +0x008 Flags            : 0x4001
      +0x00c DebugFlags       : 0
      ..
      +0x024 CurrentDirectory : _CURDIR
          +0x000 DosPath          : _UNICODE_STRING "D:\Development\Utils\"
          +0x008 Handle           : 0x00000024
      +0x030 DllPath          : _UNICODE_STRING "C:\WINDOWS\system32;C:\WINDOWS\system;C:\WINDOWS;...”
      ..
```

WinDbg Commands for Retrieving Process and Module Information

Command	Description
!peb	displays a formatted view of the information in the process environment block (PEB)
dt nt!_PEB Addr	full PEB dump
lm	list loaded and unloaded modules
lmD	-||- (output in Debugger Markup Language)
lm vm kernel32	verbose output (including image and symbol information) for kernel32
!lmi kernel32	similar implementation as an extension
!dlls	display list of loaded modules with loader specific information (entry point, load count)
!dlls –c kernel32	same as before for kernel32 only
!imgreloc	display relocation information
!dh kernel32	display the headers for kernel32

Example - Module Information

```
0:001>!dlls -c msvcrt
Dump dll containing 0x77ba0000:
0x002d40c0: C:\WINDOWS\system32\msvcrt.dll
      Base   0x77ba0000  EntryPoint  0x77baf78b  Size        0x0005a000
      Flags  0x80084006  LoadCount   0x00000007  TlsIndex    0x00000000
             LDRP_STATIC_LINK
             LDRP_IMAGE_DLL
             LDRP_ENTRY_PROCESSED
             LDRP_PROCESS_ATTACH_CALLED

0:001> lm vm msvcrt
start    end        module name
77ba0000 77bfa000   msvcrt     (deferred)
    Image path: C:\WINDOWS\system32\msvcrt.dll
    Image name: msvcrt.dll
    Timestamp:        Fri Mar 25 03:33:02 2005 (4243785E)
    CheckSum:         0006288A
    ImageSize:        0005A000
    File version:     7.0.3790.1830
    Product version:  6.1.8638.1830
    ...
    CompanyName:      Microsoft Corporation
    ProductName:      Microsoft® Windows® Operating System
    InternalName:     msvcrt.dll
    OriginalFilename: msvcrt.dll
    ProductVersion:   7.0.3790.1830
    FileVersion:      7.0.3790.1830 (srv03_sp1_rtm.050324-1447)
    FileDescription:  Windows NT CRT DLL
    LegalCopyright:   © Microsoft Corporation. All rights reserved.
```

WinDbg Commands for Retrieving Thread Information

Command	Description
~	thread status for all threads
~0	thread status for thread 0
~.	thread status for currently active thread
~*	thread status for all threads with some extra info (priority, StartAdress)
~* k	call stacks for all threads ~ !uniqstack
~<thread>s	set current thread
!gle	Get last error
!runaway	→ displays information about time consumed by each thread → quick way to find out which threads are spinning out of control or consuming too much CPU time
!teb	displays a formatted view of the information in the thread environment block (TEB)
dt nt!_TEB Addr	full TEB dump

Example - Threads

```
0:001> !runaway 7
 User Mode Time
  Thread       Time
   0:d28       0 days 0:00:00.015
   1:2b0       0 days 0:00:00.000
 Kernel Mode Time
  Thread       Time
   0:d28       0 days 0:00:00.093
   1:2b0       0 days 0:00:00.000
 Elapsed Time
  Thread       Time
   0:d28       0 days 0:04:04.156
   1:2b0       0 days 0:03:53.328


0:000> ~*
.  0  Id: dac.d28 Suspend: 1 Teb: 7efdd000 Unfrozen
      Start: TestApp!ILT+1415(_wWinMainCRTStartup) (0041158c)
      Priority: 0  Priority class: 32  Affinity: 3

   1  Id: dac.2b0 Suspend: 1 Teb: 7efda000 Unfrozen
      Start: 00000001
      Priority: 0  Priority class: 32  Affinity: 3



0:000> !gle
LastErrorValue: (Win32) 0 (0) - The operation completed successfully.
LastStatusValue: (NTSTATUS) 0 - STATUS_WAIT_0
```

Windows and Menus in WinDbg

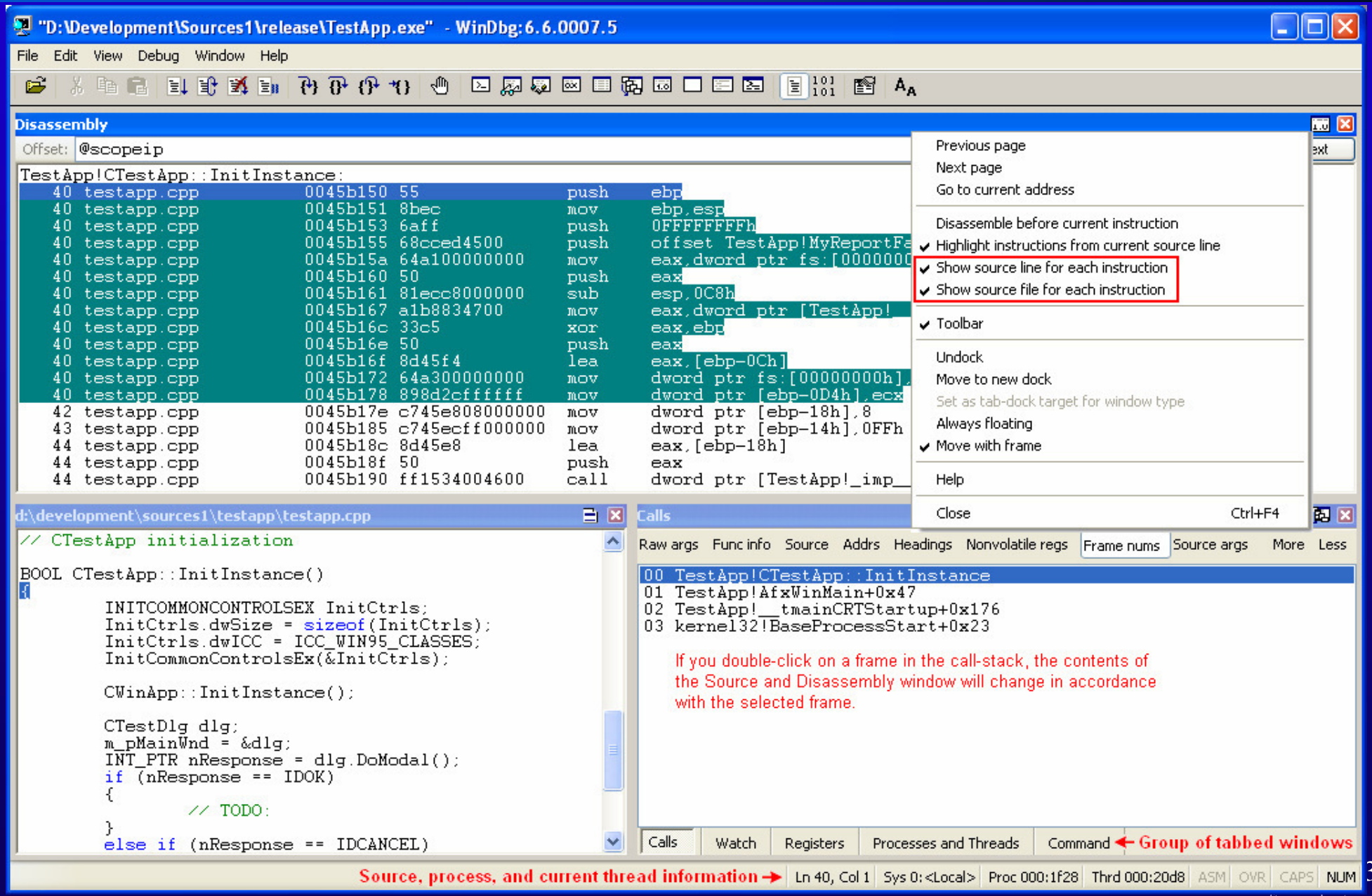
WinDbg's windows can be docked or floating.

1) Docked Windows = the preferred way of using windows
   - Shrink and grow with the WinDbg frame
   - Are positioned and sized relatively to each other as the frame changes
   - Can be tabbed. Tabbed windows are overlaid
   - WinDbg supports multiple docks (handy for a multi-monitor system)
   - Ctrl-Tab iterates through all windows in all docks
2) Undocked or floating windows
   - Are always on top of the WinDbg window

Each window in WinDbg has its own menu.

- Menus can be accessed by a:
  - left-click on the menu button (next to the close button)
  - right-click on the title bar of a window
  - right-click on the tab of a tabbed window
- Be sure to **check these menus**. They are often hiding interesting features.

Example of a Running Instance of WinDbg

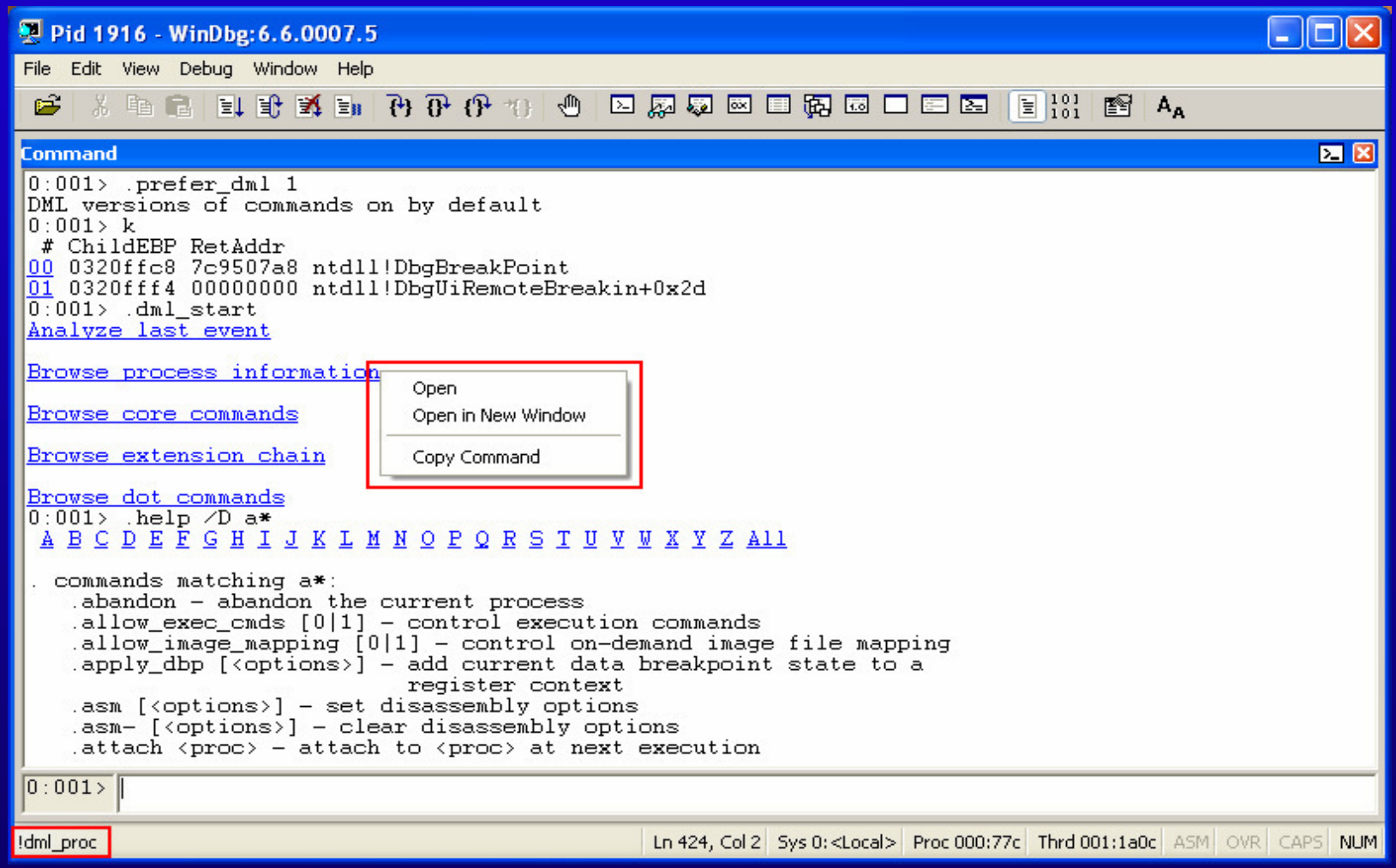


Debugger Markup Language (DML)

- DML allows debugger output to include directives and extra non-display information in the form of tags
- Debugger user interfaces parse out the extra information to provide new behaviors
- DML is primarily intended to address the following issues:
  - Linking of related information
  - Discoverability of debugger and extension functionality
  - Enhancing output from the debugger and extensions
- DML was introduced with version 6.6.0.7 of Debugging Tools

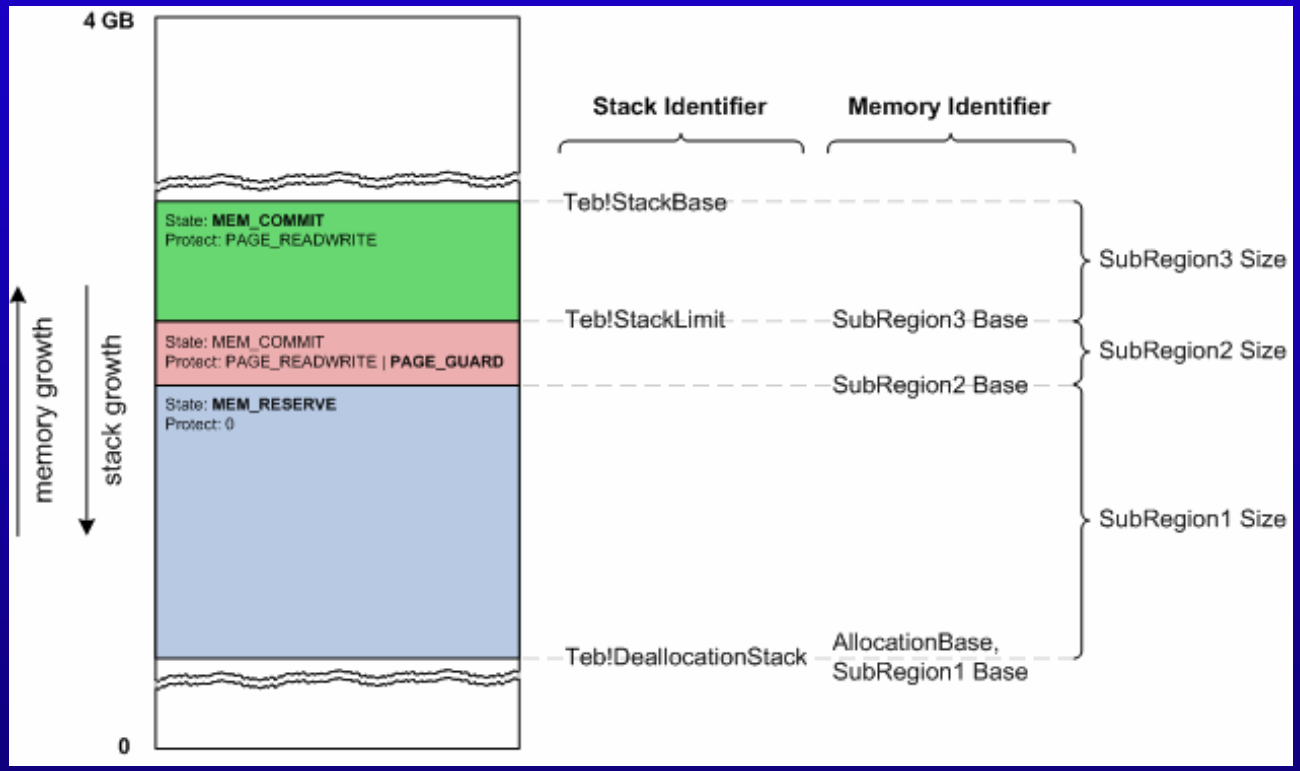
DML Command	Description
.dml_start	Kick of to other DML commands
.prefer_dml 1	Global setting: all DML-enhanced commands will produce DML output
.help /D a*	.help has a new DML mode where a top bar of links is given
.chain /D	.chain has a new DML mode where extensions are linked to a .extmatch
	Check "..\Debugging Tools for Windows**dml.doc**" for more commands.

DML in WinDbg



- Note that you can click on any “link”
- If you right-click on it, you can even start the command in a new window

Memory: Stack Details



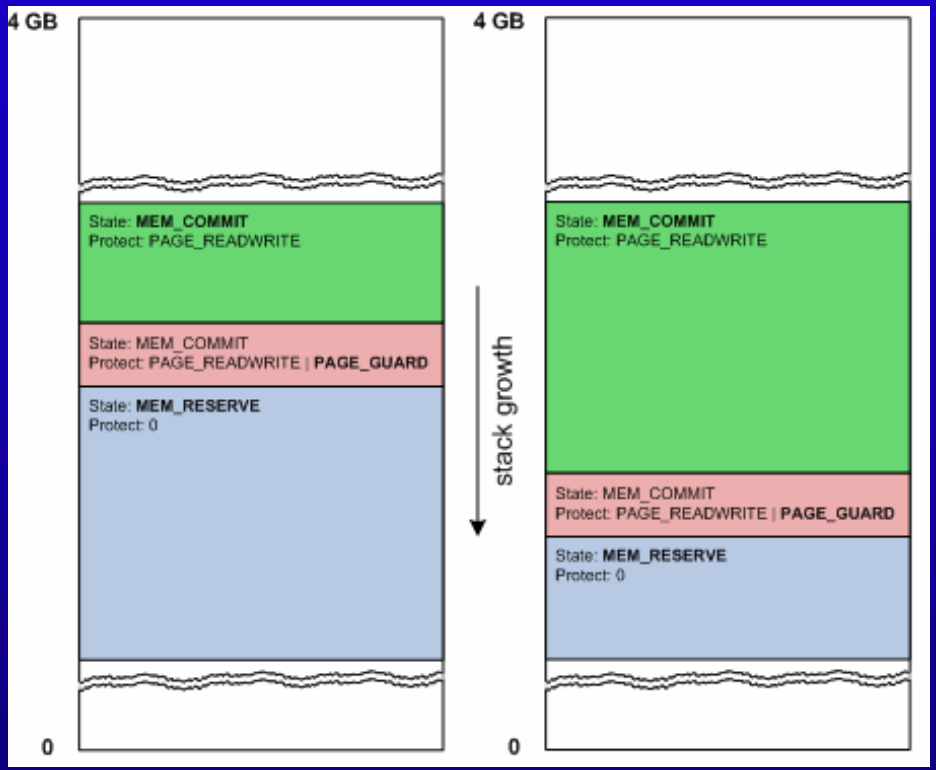
- From MSDN:
  - Each new thread receives its own stack space, consisting of both committed and reserved memory.
  - By default, each thread uses 1 Mb of reserved memory, and one page of committed memory.
  - The system will commit one page block from the reserved stack memory as needed. (see MSDN CreateThread > dwStackSize > "Thread Stack Size").

Example - Stack Size for a Thread

```
0:000> !teb
TEB at 7ffdf000
    ExceptionList:        0012f784
    StackBase:            00130000
    StackLimit:           0012c000
    …

0:000> dt ntdll!_TEB DeallocationStack 7ffdf000
   +0xe0c DeallocationStack : 0x00030000

0:000> !address esp
   AllocBase : SubRegionBase - SubRegionSize
    00030000 : 0012c000 - 00004000
                    Type     00020000 MEM_PRIVATE
                    Protect  00000004 PAGE_READWRITE
                    State    00001000 MEM_COMMIT
                    Usage    RegionUsageStack
                    Pid.Tid  e34.e78


0:000> ? 00130000 - 0012c000
Evaluate expression: 16384 = 00004000

0:000> ? 00130000 - 00030000
Evaluate expression: 1048576 = 00100000
```

0x004000 → Our thread has 4 pages or 16KB of committed memory.
0x100000 → Our thread has 256 pages or 1MB of reserved memory.

Memory: Stack Growth



- The ESP register points to the current stack location of a thread.
- If a program attempts to access an address within a guard page, the system raises a STATUS_GUARD_PAGE_VIOLATION (0x80000001) exception. A guard page provides a one-shot alarm for memory page access.
- If a stack grows until the end of reserved memory, a STATUS_STACK_OVERFLOW is raised.

Example - Stack Growth

```
0:000> !teb
TEB at 7ffdf000
    ExceptionList:        0012f784
    StackBase:            00130000
    StackLimit:           0012c000
    …

0:000> dt ntdll!_TEB DeallocationStack 7ffdf000
   +0xe0c DeallocationStack : 0x00030000

0:000> ? 00130000 - 0012c000
Evaluate expression: 16384 = 00004000
```

0x004000 → Our thread has 4 pages or 16KB of committed memory.
0x100000 → Our thread has 256 pages or 1MB of reserved memory.

```
0:000> !teb
TEB at 7ffdf000
    ExceptionList:        0012f784
    StackBase:            00130000
    StackLimit:           00033000
    …

0:000> ? 00130000 - 00033000
Evaluate expression: 1036288 = 000fd000
```

0x0fd000 → Now our thread has 253 pages of committed memory.
The system will throw a stack-overflow exception if another page will be requested.

WinDbg Commands for Retrieving Call-Stack Information

Command	Description
!uniqstack	displays call-stacks for all of the threads in the current process
!findstack MySymbol 2	locates all call-stacks that contain MySymbol
k	display call stack for current thread
kP	P == full parameters for each function called
kf	f == distance between adjacent frames to be displayed (useful to check stack consumption of each frame)
kv	v == display FPO information + calling convention
kb	b == display the first three parameters passed to each function
kM	Output in DML format; frame numbers link to a .frame/dv command which displays locals for the frame

Example - UniqStack

```
0:000> !uniqstack
Processing 2 threads, please wait

.  0  Id: dac.154c Suspend: 1 Teb: 7efdd000 Unfrozen
      Start: TestApp!ILT+1415(_wWinMainCRTStartup) (0041158c)
      Priority: 0  Priority class: 32  Affinity: 3
ChildEBP RetAddr
002df44c 00411eeb ntdll!DbgBreakPoint
002df52c 783c2100 TestApp!CMyDialog::OnBnClicked_ExecuteBreakPoint+0x2b [d:\TestApp\MyDialog.cpp @ 72]
002df570 783c2842 MFC80UD!_AfxDispatchCmdMsg+0xb0
002df5d4 7839d671 MFC80UD!CCmdTarget::OnCmdMsg+0x2e2
002df610 7836142d MFC80UD!CDialog::OnCmdMsg+0x21
...
002dffb8 0041371d TestApp!__tmainCRTStartup+0x289 [f:\sp\vctools\crt_bld\self_x86\crt\src\crtexe.c @ 589]
002dffc0 7d4e992a TestApp!wWinMainCRTStartup+0xd [f:\sp\vctools\crt_bld\self_x86\crt\src\crtexe.c @ 414]
002dfff0 00000000 kernel32!BaseProcessStart+0x28

.  1  Id: dac.127c Suspend: 1 Teb: 7efda000 Unfrozen
      Start: 00000001
      Priority: 0  Priority class: 32  Affinity: 3
ChildEBP RetAddr
0242f550 7d626c3f ntdll!NtQueryAttributesFile+0x12
..
0242ff08 7d62b958 ntdll!LdrpCallInitRoutine+0x14
0242ffbc 7d674613 ntdll!LdrShutdownThread+0xd2
0242ffc4 7d665017 ntdll!RtlExitUserThread+0xa
0242fff4 00000000 ntdll!DbgUiRemoteBreakin+0x41

Total threads: 2
```

WinDbg Commands for Memory Handling

Command	Description
d, dd, da, du, ..	Display memory dd == double word values da == display ASCII characters du == display Unicode characters
f	fill memory
!vprot MyAddr	Displays virtual memory protection information for MyAddr
!address MyAddr	Display information (type, protection, usage, ..) about the memory specified by MyAddr
!address -RegionUsageStack	Display stack regions for all threads in the process
dds	Display Words and Symbols
ddp	Display Referenced Memory. If a match to a known symbol is found, this symbol is displayed as well.

Example – Process's Memory Information

```
0:000> !address
    00000000 : 00000000 - 00010000
                    Type     00000000
                    Protect  00000001 PAGE_NOACCESS
                    State    00010000 MEM_FREE
                    Usage    RegionUsageFree
    00010000 : 00010000 - 00001000
                    Type     00020000 MEM_PRIVATE
                    Protect  00000004 PAGE_READWRITE
                    State    00001000 MEM_COMMIT
                    Usage    RegionUsageEnvironmentBlock
     …
------------------- Usage SUMMARY --------------------------
    TotSize (      KB)   Pct(Tots) Pct(Busy)   Usage
    1950000 (   25920) : 01.24%    36.03%    : RegionUsageIsVAD
   7b9b1000 ( 2025156) : 96.57%    00.00%    : RegionUsageFree
    12e2000 (   19336) : 00.92%    26.88%    : RegionUsageImage
     110000 (    1088) : 00.05%    01.51%    : RegionUsageStack
       2000 (       8) : 00.00%    00.01%    : RegionUsageTeb
     2a0000 (    2688) : 00.13%    03.74%    : RegionUsageHeap
    1658000 (   22880) : 01.09%    31.81%    : RegionUsagePageHeap
       1000 (       4) : 00.00%    00.01%    : RegionUsagePeb
       1000 (       4) : 00.00%    00.01%    : RegionUsageProcessParametrs
       1000 (       4) : 00.00%    00.01%    : RegionUsageEnvironmentBlock
       Tot: 7fff0000 (2097088 KB) Busy: 0463f000 (71932 KB)
…
------------------- State SUMMARY --------------------------
    TotSize (      KB)   Pct(Tots)  Usage
    2efa000 (   48104) : 02.29%   : MEM_COMMIT
   7b9b1000 ( 2025156) : 96.57%   : MEM_FREE
    1745000 (   23828) : 01.14%   : MEM_RESERVE
```

WinDbg Commands for Retrieving Heap Information

Command	Description
!heap -?	Brief help
!heap -h	List heaps with index and range (= startAddr, endAddr)
!heap -s 0	Summary for all heaps = reserved and committed memory, ..
!heap -flt s Size	Dump info for allocations matching Size
!heap -stat	Dump HeapHandle list HeapHandle = value returned by HeapCreate or GetProcessHeap
!heap -stat -h 0	Dump usage statistic for every AllocSize = AllocSize, #blocks, and TotalMem for each AllocSize
!heap -p	GFlags settings, HeapHandle list
!heap -p -all	Details of all allocations in all heaps in the process = all HeapAlloc calls listed
!heap -p -a UserAddr	Details of heap allocation containing UserAddr (i.e. the address returned by HeapAlloc). Prints back traces when available.

More Heap Structs

If page heap **is disabled** for your application, then the following structs apply.

Note that page heap is disabled by default.

- _HEAP struct
  - Defined in ntdll.dll: dt ntdll!_HEAP
  - For every **HeapCreate** there is a unique **_HEAP**
  - You can use "!heap -p -all" to get addresses for all _HEAP structs in your process

- _HEAP_ENTRY struct
  - Defined in ntdll.dll: dt ntdll!_HEAP_ENTRY
  - For every **HeapAlloc** there is a unique **_HEAP_ENTRY**
  - You can use "!heap -p -all" to get addresses for all heap entries in your process

Page Heap Structs

If page heap **is enabled** for your application, then the following structs apply.

You can enable page heap with Global Flags (gflags.exe).

- _DPH_HEAP_ROOT struct
  - Defined in ntdll.dll: dt ntdll!_DPH_HEAP_ROOT
  - For every **HeapCreate** there is a unique **_DPH_HEAP_ROOT**
  - You can use "!heap -p -all" to get addresses for all heap roots in your process
    - Usually address of a _DPH_HEAP_ROOT = value of HeapHandle + 0x1000

- _DPH_HEAP_BLOCK struct
  - Defined in ntdll.dll: dt ntdll!_DPH_HEAP_BLOCK
  - For every **HeapAlloc** there is a unique **_DPH_HEAP_BLOCK**
  - You can use "!heap -p -all" to get addresses for all heap blocks in your process

Who called HeapAlloc?

- Enable stack traces and page heap for you application
  - Start GFlags, select "Create user mode stack trace database" and “Enable page heap” for your image
  - Or from the command line: gflags.exe /i <IMAGE.EXE> +ust +hpa
- Restart your application and attach WinDbg

From WinDbg’s command line:

- **!heap -p -a <UserAddr>**
  - <UserAddr> = address of our allocation (returned by HeapAlloc, new, ..)
  - Will dump the call-stack but without source information
- **dt ntdll!_DPH_HEAP_BLOCK StackTrace <MyHeapBlockAddr>**
  - <MyHeapBlockAddr> = DPH_HEAP_BLOCK address retrieved in previous step
  - StackTrace = member of DPH_HEAP_BLOCK which stores the call stack for our HeapAlloc
- **dds <StackTrace>**
  - <StackTrace> = value retrieved in previous step
  - dds will dump the call-stack with source information included

Example - Who called HeapAlloc?

```
// HeapAlloc( 0x00150000, 8, dwBytes =0x00A00000 ) -->> 0x025F1000;

0:000> !heap -p -a 0x025F1000
    address 025f1000 found in
    _DPH_HEAP_ROOT @ 151000
    in busy allocation (  DPH_HEAP_BLOCK:    UserAddr     UserSize -    VirtAddr    VirtSize)
                                 15449c:    25f1000      a00000 -      25f0000     a02000
    7c91b298 ntdll!RtlAllocateHeap+0x00000e64
    0045b8b1 TestApp!CMyDlg::OnBnClicked_HeapAlloc+0x00000051
    004016e0 TestApp!_AfxDispatchCmdMsg+0x00000043
    004018ed TestApp!CCmdTarget::OnCmdMsg+0x00000118
    00408f7f TestApp!CDialog::OnCmdMsg+0x0000001b
    …

0:000> dt ntdll!_DPH_HEAP_BLOCK StackTrace 15449c
   +0x024 StackTrace : 0x0238e328 _RTL_TRACE_BLOCK

0:000> dds 0x0238e328
0238e328  abcdaaaa
…
0238e334  00000001
0238e338  00a00000
0238e33c  00151000
0238e340  01b17b1c
0238e344  0238e348
0238e348  7c91b298 ntdll!RtlAllocateHeap+0xe64
0238e34c  0045b8b1 TestApp!CMyDlg::OnBnClicked_HeapAlloc+0x51 [d:\development\sources\TestApp\MyDlg.cpp @ 366]
0238e350  004016e0 TestApp!_AfxDispatchCmdMsg+0x43 [f:\sp\vctools\vc7libs\ship\atlmfc\src\mfc\cmdtarg.cpp @ 82]
0238e354  004018ed TestApp!CCmdTarget::OnCmdMsg+0x118 [f:\sp\vctools\vc7libs\ship\atlmfc\src\mfc\cmdtarg.cpp @ 381]
0238e358  00408f7f TestApp!CDialog::OnCmdMsg+0x1b [f:\sp\vctools\vc7libs\ship\atlmfc\src\mfc\dlgcore.cpp @ 85]
…
```

Who called HeapCreate?

- Enable stack traces and page heap for you application
  - Start GFlags, select "Create user mode stack trace database" and “Enable page heap” for your image
  - Or from the command line: gflags.exe /i <IMAGE.EXE> +ust +hpa
- Restart your application and attach WinDbg

From WinDbg’s command line:

- **!heap -p –h <HeapHandle>**
  - <HeapHandle> = value returned by HeapCreate
  - You can do a “!heap -stat” or “!heap -p” to get a list of heaps for you process and their handles
- **dt ntdll!_DPH_HEAP_ROOT CreateStackTrace <MyHeapRootAddr>**
  - <MyHeapRootAddr> = DPH_HEAP_ROOT address retrieved in previous step
  - CreateStackTrace = member of DPH_HEAP_ROOT which stores the call stack for our HeapCreate call
- **dds <CreateStackTrace>**
  - <CreateStackTrace> = value retrieved in previous step
  - dds will dump the call-stack with source information included

Example - Who called HeapCreate?

```
// HeapCreate( 0x0000000A, 0, 0 ) -->> 0x03000000;

0:000> !heap -p -h 0x03000000
    _DPH_HEAP_ROOT @ 3001000
    Freed and decommitted blocks
      DPH_HEAP_BLOCK : VirtAddr VirtSize
    Busy allocations
      DPH_HEAP_BLOCK : UserAddr  UserSize - VirtAddr VirtSize
     …


0:000> dt ntdll!_DPH_HEAP_ROOT CreateStackTrace 3001000
   +0x08c CreateStackTrace : 0x0238e328 _RTL_TRACE_BLOCK

0:000> dds 0x0238e328
0238e328  abcdaaaa
0238e32c  00000001
0238e330  00000010
0238e334  00000000
0238e338  00000000
0238e33c  00000000
0238e340  00000000
0238e344  0238e348
0238e348  7c93a874 ntdll!RtlCreateHeap+0x41
0238e34c  7c812bff kernel32!HeapCreate+0x55
0238e350  0045b841 TestApp!CMyDlg::OnBnClicked_HeapCreate+0x31 [d:\development\sources\TestApp\MyDlg.cpp @ 345]
0238e354  0040b122 TestApp!_AfxDispatchCmdMsg+0x43 [f:\sp\vctools\vc7libs\ship\atlmfc\src\mfc\cmdtarg.cpp @ 82]
0238e358  0040b32f TestApp!CCmdTarget::OnCmdMsg+0x118 [f:\sp\vctools\vc7libs\ship\atlmfc\src\mfc\cmdtarg.cpp @ 381]
0238e35c  00408838 TestApp!CDialog::OnCmdMsg+0x1b [f:\sp\vctools\vc7libs\ship\atlmfc\src\mfc\dlgcore.cpp @ 85]
…
```

Finding Memory Leaks on the Heap

- **!address –summary**
  - Summary about memory usage for your process. If **RegionUsageHeap** or **RegionUsagePageHeap** is growing constantly, then you might have a memory leak on the heap. Proceed with the following steps.
- Enable stack traces and page heap for you application
- Restart your application and attach WinDbg

From WinDbg's command line:

- **!heap –stat –h 0**
  - Will list down handle specific allocation statistics for every AllocSize. For every AllocSize the following is listed: AllocSize, #blocks, and TotalMem.
  - Take the AllocSize with maximum TotalMem.
- **!heap –flt –s <size>**
  - <size> = size being allocated by HeapAlloc. Value retrieved in previous step.
- **!heap -p -a <UserAddr>**
  - <UserAddr> = address of our allocation (returned by HeapAlloc, new, ..)
  - Will dump the call-stack but without source information. Check the "**Who called HeapAlloc?**" slide for how to proceed to get a call-stack with source information included.

Example - Finding Memory Leaks on the Heap

```
0:001> !heap -stat -h 0
Allocations statistics for
 heap @ 00150000
group-by: TOTSIZE max-display: 20
    size     #blocks    total       ( %) (percent of total busy bytes)
    100000   101        - 10100000  (99.99)      → 0x101 * 1MB allocated. Looks like a good candidate for a memory leak.
    928      2          - 1250      (0.00)
    64       24         - e10       (0.00)
    …

0:001> !heap -flt s 100000                       → get all allocations with size: 100000
    _DPH_HEAP_ROOT @ 151000
    Freed and decommitted blocks
      DPH_HEAP_BLOCK : VirtAddr VirtSize
    Busy allocations
      DPH_HEAP_BLOCK : UserAddr  UserSize - VirtAddr VirtSize
        024f0698 :     13831000  00100000 - 13830000 00102000
        024f0620 :     13721000  00100000 - 13720000 00102000
        …  → There should be 0x101 entries with size 100000 output here.
             Let's take the first one with UserAddr=0x13831000

0:001> !heap -p -a 13831000
    address 13831000 found in
    _DPH_HEAP_ROOT @ 151000
    in busy allocation (  DPH_HEAP_BLOCK:         UserAddr         UserSize -         VirtAddr         VirtSize)
                                24f0698:         13831000           100000 -         13830000           102000
    7c91b298 ntdll!RtlAllocateHeap+0x00000e64
    0045b74e TestApp!CMyDlg ::OnBnClicked_DoMemoryLeak+0x0000003e
    0040b122 TestApp!_AfxDispatchCmdMsg+0x00000043
    0040b32f TestApp!CCmdTarget ::OnCmdMsg+0x00000118
    00408838 TestApp!CDialog ::OnCmdMsg+0x0000001b
    …
```

Critical Section Related Commands

Command	Description
!locks	displays a list of locked critical sections for the process
!locks -v	display all critical sections for the process
!cs [Opt] [CsAddr]	Displays one or more critical sections, or the entire critical section tree. Options: -l == display only locked sections -s == causes each CS's initialization stack to be displayed -o == causes the owner's stack to be displayed -t == display critical section tree → EnterCntr, WaitCnt, …
!avrf -cs	Display a list of deleted critical sections (DeleteCriticalSection API)

Example – Critical Section

```
0:000> !cs -s -o 0x0012fe08
-----------------------------------------
Critical section   = 0x0012fe08 (+0x12FE08)
DebugInfo          = 0x031c4fe0
LOCKED
LockCount          = 0x0
OwningThread       = 0x00000c8c
…
OwningThread Stack =
     ChildEBP RetAddr  Args to Child
     0012f488 004badd9 0012f810 02854f10 00000000 ntdll!DbgBreakPoint
     0012f568 0054fd2c 00000000 004bb621 00681d70 TestApp!CMyDialog::OnBnClicked_EnterCs+0x39
     0012f594 00550365 0012fd78 0000001c 00000000 TestApp!_AfxDispatchCmdMsg+0x9c
     0012f5f0 005517f1 0000001c 00000000 00000000 TestApp!CCmdTarget::OnCmdMsg+0x285
     …
Stack trace for DebugInfo (Initialization Stack)= 0x031c4fe0:
0x7c911a93: ntdll!RtlInitializeCriticalSectionAndSpinCount+0xC9
0x7c809eff: kernel32!InitializeCriticalSection+0xE
0x004c101d: TestApp!CCriticalSection::Init+0x3D
0x004c10a0: TestApp!CCriticalSection::CCriticalSection+0x40
…

0:000> !cs -t
Verifier package version >= 3.00
Tree root 02fd8fd0
Level     Node       CS     Debug   InitThr EnterThr  WaitThr TryEnThr LeaveThr EnterCnt  WaitCnt
-------------------------------------------------------------------------------------------------
    0 02fd8fd0 0012fe08 031c4fe0      c8c      c8c        0        0        0        1        0
    1 02fa8fd0 006807f4 03148fe0      c8c        0        0        0        0        0        0
    2 02fa2fd0 00680f70 02850fe0      c8c      c8c        0        0      c8c     4848        0
…
```

Other useful WinDbg Commands

Command	Description
dt	Display information about a local variable, function parameter, global variable or data type
dt ntdll!*peb*	List all ntdll.dll variables which contain the word peb
dt ntdll!_PEB	Display type for PEB
dt ntdll!_PEB 7efde000	Dump PEB at address 7efde000
dv	Display local variables
dv /t /i /V	Display local variables /i == classify them into categories (parameters or locals) /V == show addresses and offsets for the relevant base frame register (usually EBP) /t == display type information

Example – dt & dv

```
0:000> dt  TestApp!CMyDialog
   +0x000 __VFN_table : Ptr32
   =00400000 classCObject     : CRuntimeClass
   =00400000 classCCmdTarget  : CRuntimeClass
   =00400000 _commandEntries  : [0] AFX_OLECMDMAP_ENTRY
   =00400000 commandMap       : AFX_OLECMDMAP
   =00400000 _dispatchEntries : [0] AFX_DISPMAP_ENTRY
   ..
   +0x004 m_dwRef           : Int4B
   +0x008 m_pOuterUnknown   : Ptr32 IUnknown
   +0x00c m_xInnerUnknown   : Uint4B
   +0x010 m_xDispatch       : CCmdTarget::XDispatch
   +0x014 m_bResultExpected : Int4B
   +0x018 m_xConnPtContainer : CCmdTarget::XConnPtContainer
   +0x01c m_pModuleState    : Ptr32 AFX_MODULE_STATE
   =00400000 classCWnd        : CRuntimeClass
   +0x020 m_hWnd            : Ptr32 HWND__
   ..
   +0x064 m_lpDialogInit    : Ptr32 Void
   +0x068 m_pParentWnd      : Ptr32 CWnd
   +0x06c m_hWndTop         : Ptr32 HWND__
   +0x070 m_pOccDialogInfo : Ptr32 _AFX_OCC_DIALOG_INFO
   +0x074 m_hIcon           : Ptr32 HICON__
   +0x078 m_nn              : Int4B

0:000> dv /t /i /V
prv local  002df440 @ebp-0x08 class CMyDialog * this = 0x002dfe24
prv param  002df450 @ebp+0x08 int nn = 1
```

Pseudo-Registers in WinDbg

- Virtual registers provided by the debugger
- Begin with a dollar sign ($)

1) Automatic pseudo-registers
   - are set by the debugger to certain useful values
   - examples: $ra, $peb, $teb, ..

2) User-defined pseudo-registers
   - there are twenty user-defined registers: $t0, $t1, $t2, .., $t19
   - integer variables that can be used to store intermediate data
   - can additionally hold type-information
   - r? assigns a typed result to an lvalue
     - r? $t0 = @peb->ProcessParameter
       - Assigns a typed value to $t0
       - $t0's type is remembered so it can be used in further expressions
     - ?? @$t0->CommandLine

Automatic Pseudo-Registers

Command	Description
$ra	Return address currently on the stack. Useful in execution commands, i.e.: “g $ra”
$ip	The instruction pointer x86 = EIP, Itanium = IIP, x64 = RIP
$exentry	Entry point of the first executable of the current process
$retreg	Primary return value register X86 = EAX, Itanium = ret0, x64 = rax
$csp	Call stack pointer X86 = ESP, Itanium = BSP, x64 = RSP
$peb	Address of the process environment block (PEB)
$teb	Address of the thread environment block (TEB) of current thread
$tpid	Process ID (PID)
$tid	Thread ID (tID)
$ptrsize	Size of a pointer
$pagesize	Number of bytes in one page of memory
…	See “Pseudo-Registry Syntax” in WinDbg’s help.

Expressions in WinDbg

1) MASM expressions
   - evaluated by the ? command
   - each symbol is treated as an addresses (the numerical value of a symbol is the memory address of that symbol →to get its value you must dereference it with poi)
   - source line expressions can be used (`myfile.c:43`)
   - the at sign for register values is optional (eax or @eax are both fine)
   - used in almost all examples in WinDbg's help
   - the only expression syntax used prior to WinDbg version 4.0 of Debugging Tools

2) C++ expressions
   - evaluated by the ?? command
   - symbols are understood as appropriate data types
   - source line expressions cannot be used
   - the at sign for register values is required (eax will not work)

MASM operations are always byte based. C++ operations follow C++ type rules (including the scaling of pointer arithmetic). In both cases numerals are treated internally as ULON64 values.

More About Expressions

- MASM:
  - The numerical value of any symbol is its memory address
  - Any operator can be used with any number
  - Numerals: are interpreted according to the current radix: n [8 | 10 | 16]

    Can be overridden by a prefix: 0x (hex), 0n (decimal), 0t (octal), 0y (binary)

- C++:
  - The numerical value of a variable is its actual value
  - Operators can be used only with corresponding data types
  - A symbol that does not correspond to a C++ data type will result in a syntax error
  - Data structures are treated as actual structures and must be used accordingly. They do not have numerical values.
  - The value of a function name or any other entry point is the memory address, treated as a function pointer
  - Numerals: the default is always decimal

    Can be overridden by a prefix: 0x (hex), 0 (=zero- octal)

Example – Value of a variable

```
// ------------------------------------------------------------------------
void MyFunction() {
     int nLocalVar = 7;
.. }
// ------------------------------------------------------------------------

0:000> dd nLocal1 L1
0012f830  00000007


// MASM syntax
// -------------
0:000> ? nLocalVar                // get address (memory location) of nLocalVar
Evaluate expression: 1243184 = 0012f830

0:000> ? dwo(nLocalVar)           // get value of nLocalVar - dereference it
Evaluate expression: 7 = 00000007 // (dwo = double-word, poi = pointer sized data)
0:000> ? poi(nLocalVar)
Evaluate expression: 7 = 00000007


// C++ syntax
// -------------
0:000> ?? nLocalVar               // get value of nLocalVar
int 7

0:000> ?? & nLocalVar             // get address (memory location) of nLocalVar
int * 0x0012f830
```

Example – MASM vs. C++ Expressions

```
// ------------------------------------------------------------
// The following examples will return:
//   eax == ebx ? 0
//   eax >  ebx ? 1
//   eax <  ebx ? -1
//
// Note that in the C++ syntax:
//  -> the @ is needed to indicate a register value
//  -> an explicit cast from BOOL to int is necessary
//  -> the comparisation operator is a double equal sign (==)
// ------------------------------------------------------------

0:000> r eax = 4, ebx = 3

0:000> ? 0*(eax = ebx)  + 1*(eax > ebx) + -1*(eax < ebx)
Evaluate expression: 1 = 00000001

0:000> ?? 0*(int)(@eax == @ebx)  + 1*(int)(@eax > @ebx) + -1*(int)(@eax < @ebx)
int 1


0:000> r eax = 3, ebx = 4

0:000> ? 0*(eax = ebx)  + 1*(eax > ebx) + -1*(eax < ebx)
Evaluate expression: -1 = ffffffff

0:000> ?? 0*(int)(@eax == @ebx)  + 1*(int)(@eax > @ebx) + -1*(int)(@eax < @ebx)
int -1
```

Common Numeric MASM Operators

Unary operators

Operator	Description
dwo, qwo, poi	dwo = dword from specified address; qwo = qword from specified address; poi = pointer-size data from specified address
wo, by	wo = low-order word from specified address by = low-order byte from specified address

Binary operators

Operator	Description
= (or ==), !=	Equal to, not equal to
<, >, <=, >=	Less than, greater than, less than or equal to, greater or equal to
and (or &), xor (or ^), or (or |)	Bitwise AND, bitwise XOR, bitwise OR
+, -, *, /	Addition, subtraction, multiplication, division
<<, >>, >>>	Left shift, right shift, arithmetic right shift

Some Non-Numeric Operators in MASM

Operator	Description
$iment(Address)	Returns the image entry point. Address = image base address
$scmp(“String1”, “String2”)	Evaluates to -1, 0, or 1. See strcmp.
$sicmp (“String1”, “String2”)	Evaluates to -1, 0, or 1. See stricmp.
$spat (“String”, “Pattern”)	TRUE → String matches Pattern; FALSE → String doesn’t match Pattern; Pattern = can be an alias or string constant but not a memory pointer (i.e. you cannot use a “poi (address)” directly with $spat. You must save the result into an alias first). Pattern may contain a variety of wildcard specifiers.
$vvalid(Address, Length)	1 → memory in the given range is valid 0 → memory is invalid

Optimizations

To avoid unnecessary symbol lookup time:

- MASM:
  - The usage of @ for registers is recommended. Otherwise they may be interpreted as symbols.
- C++:
  - Prefix for local symbols: **$!**MySymbol
  - Prefix for global symbols: **<moduleName>!**MySymbol

Example – Structs in C++ Syntax

```
// ------------------------------------------------------------------------
// For better performance: $!symName              … for local symbols
//                         <ModuleName>!symName   … for global symbols
// ------------------------------------------------------------------------
0:000> ?? dlg.m_nn
int 0
0:000> ?? $!dlg.m_nn
int 0
0:000> ?? sizeof($!dlg.m_nn)
unsigned int 0xac

0:000> ?? ((MyModule!CMyDlg*) 0x12f878)->m_nn
int 0


0:000> ?? ((ntdll!_TEB*) 0x7ffdf000)->ClientId
struct _CLIENT_ID
   +0x000 UniqueProcess    : 0x000017d8     // → PID
   +0x004 UniqueThread     : 0x00000ea8     // → TID

0:000> ?? @$teb->ClientId                   // The C++ expression evaluator casts
struct _CLIENT_ID                           // pseudo-registers to their appropriate types
   +0x000 UniqueProcess    : 0x000017d8
   +0x004 UniqueThread     : 0x00000ea8

0:001> r? $t0 = @$peb->ProcessParameters    // Note that type information is preserved
0:001> ?? @$t0->CommandLine                 // for user-defined pseudo registers
struct _UNICODE_STRING
 ""D:\Development\Sources\CrashMe\release\CrashMe.exe" "
   +0x000 Length           : 0x6a
   +0x002 MaximumLength    : 0x6c
   +0x004 Buffer           : 0x00020724  ""D:\Development\Sources\CrashMe\release\CrashMe.exe" "
```

Example – Pointer Arithmetic

```
// ------------------------------------------------------------
// int myInt[2] = { 1,2 };
// Note that MASM operations are always byte based,
// whereas pointer arithmetic is used for c++ operations.
// ------------------------------------------------------------

// MASM syntax
// -------------
0:000> ? myInt
Evaluate expression: 1243256 = 0012f878
0:000> ? dwo(myInt)
Evaluate expression: 1 = 00000001

0:000> ? myInt+4
Evaluate expression: 1243260 = 0012f87c
0:000> ? dwo(myInt+4)
Evaluate expression: 2 = 00000002


// C++ syntax
// -------------
0:000> ?? (&myInt)
int * 0x0012f878
0:000> ?? myInt
int [2] 0x0012f878
1

0:000> ?? (&myInt+1)
int * 0x0012f87c
0:000> ?? *(&myInt+1)
int 2
```

Default Expression Evaluator

- The following always use the C++ expression evaluator:
  - ?? command (evaluate C++ expression)
  - the watch window
  - the locals window
- All other commands and debugging information windows use the default expression evaluator
- You can use the .expr command to change the default evaluator
  - .expr → show current evaluator
  - .expr /q → show available evaluators
  - **.expr /s c++** → set c++ as the default expression evaluator
  - **.expr /s masm** → set masm as the default expression evaluator

Mixing Both Evaluators “on-the-fly”

- You can use both expression evaluators within one command
- For mixing both modes: **@@(…)**
  - If any portion of an expression is enclosed in parentheses and prefixed by a double @@, it will be evaluated by the opposite of the current expression evaluator
  - this way you can use two different evaluators for different parameters of a single command
  - It is possible to nest these symbols; each appearance of this symbol switches to the other expression evaluator
- Explicitly specify an expression evaluator
  - → **@@c++(…)**
  - → **@@masm(…)**

Example – Mixed Expression

```
// ------------------------------------------------------------------
// The following command will set the default expression evaluator to
// MASM, and then evaluate Expression1 and Expression3 as MASM
// expressions, while evaluating Expression2 as a C++ expression:
// ------------------------------------------------------------------
0:000> .expr /s masm
0:000> ? Expression1 + @@( Expression2) + Expression3


0:000> ? `myFile.cpp:118`                  // get address of line 118 in myFile.cpp
Evaluate expression: 4570359 = 0045bcf7


// ------------------------------------------------------------------
// source-line expressions cannot be used in C++ expressions
// let's nest a MASM expression within a C++ expression
// → store address of line 43 of "myFile.cpp" into nLocalVar
// ------------------------------------------------------------------

0:000> ?? nLocalVar = @@(`myFile.cpp:118`)
int 4570359
```

Aliases in WinDbg

- Strings that are automatically replaced with other character strings
- Consist of: alias name + alias equivalent

1) User-named aliases
   - Set and named by the user (both are case-sensitive)
   - Manipulate by: as or aS (Set Alias), ad (Delete Alias), al (List Aliases)

2) Fixed-name aliases
   - Set by the user, named $u0, $u1, .. $u9
   - Set by the r (register) command + . (dot) before the “u”

     Example: **r $.u0** = “dd esp+8; g”

3) Automatic aliases
   - Set and named by the debugger
   - Are similar to automatic pseudo registers, except that they can be used with alias-related tokens such as ${ .. } (pseudo-registers cannot)
   - Examples: $ntsym, $CurrentDumpFile, $CurrentDumpPath, ...

User-Named and Fixed-Name Aliases

1) User-named aliases

- By default a user-named alias must be separated from other characters. The first and last character of an alias name must either:
  - begin/end the line or
  - be preceded/followed by a space, semicolon, or quotation mark
- If a user-named alias is touching other text, it must be enclosed in **${ }** (Alias interpreter)
- Can be used in the definition of a fixed-name alias
  - To use a user-named alias in the definition of another user-named alias, you need to prefix the **as** or **aS** command with a semicolon (else no alias replacement will occur on that line). Explanation: Any text entered into a line that begins with **as**, **aS**, **ad**, or **al** will not receive alias replacement. If you need aliases replaced in a line that begins with these characters, prefix it with a semicolon.
- Are easier to use than fixed-name aliases
  - Their definition syntax is simpler
  - they can be listed using the al (List Aliases) command

2) Fixed-named aliases

- Are automatically replaced if they are used adjacent to other text
- Can be used in the definition of any alias

Commands for User-Named Aliases

Operator	Description
as Name Equivalent as /ma Name Address as /mu Name Address ..	Set alias Set alias to the NULL-terminated ASCII string at Address Set alias to the NULL-terminated Unicode string at Address
ad Name ad *	Delete alias with Name Delete all aliases
al	List user-named aliases
${Alias} ${/f:Alias} ${/n:Alias} ${/d:Alias}	${*Alias*} is replaced by the alias equivalent, even if it is touching other text. If the alias is not defined, the ${Alias} is not replaced Same as above except that ${/f:Alias} is replaced with an empty string if the alias is not defined Evaluates to the alias name Evaluates: 1 = alias defined; 0 = alias not defined

Example - Aliases

```
0:001> as Short kernel32!CreateRemoteThread          // → user-named alias
0:001> uf Short

0:001> r $.u0 = kernel32!CreateRemoteThread          // → fixed-name alias
0:001> uf $u0

0:001> as DoInc r eax=eax+1; r ebx=ebx+1             // → alias used as a macro for commands
0:001> DoInc
0:001> DoInc

// ------------------------------------------------------------------
// aliases are replaced as soon as they are used
// ------------------------------------------------------------------
0:001> r $.u2 = 2
0:001> r $.u1 = 1+$u2
0:001> r $.u2 = 6
0:001> ? $u1
Evaluate expression: 3 = 00000003

0:001> as two 2
0:001> r $.u1 = 1+ two       // → notice the empty space before two!
0:001> as two 6
0:001> ? $u1
Evaluate expression: 3 = 00000003

// ------------------------------------------------------------------
// using a named alias within another named alias
// ------------------------------------------------------------------
0:001> as two 2
0:001> as xy1 two + 1      // → xy1 = two + 1
0:001> ;as xy2 two + 1     // → xy2 = 2 + 1        (you must prefix as with a semicolon for a replacement to occur)
```

Debugger Command Programs

- Consist of
  - **debugger commands**
  - **control flow tokens (.if, .for, .while, ..)**
- Variables
  - Use user-named aliases or fixed-name aliases as "local variables"
  - Use pseudo-registers ($t0, ..) for numeric or typed variables
- For comments use $$ [any text]
- A pair of braces {} is used to surround a block of statements
  - When each block is entered all aliases within a block are evaluated
  - There must be a control flow token before the opening brace
  - To create a block solely to evaluate aliases use the .block { .. }
  - Use ${Alias} (alias interpreter) for user-named aliases that touch other text

Control Flow Tokens

- Used to create execution loops and for conditional execution
- Each condition must be an expression (commands are not permitted)

Command	Description
.block	Performs no action. It is used solely to introduce a block. Note that you cannot simply use {} to create a block.
.if, .else, .elseif	Like the **if**, **else** or **else if** keyword in C
.for, .while, .Break, .continue	Like the **for**, **while**, **break** or **continue** keyword in C
.foreach	Parses the output of debugger commands, a string or a text file. It then takes each item it finds and uses it as the input to a specified list of debugger commands.

Command Programs Execution

There are several possible ways to execute a program:

- Enter all statements into the debugger window as a single string (commands separated by semicolons)

- Store all statements into a script file and use **$$><** to run the file.

  $$>< (Run Script File):

  → opens the specified file

  → replaces all carriage returns with semicolons

  → executes the resulting text as a single command block

Example – Debugger Command Program

```
$$ ---------------------------------------------------------------------
$$ From WinDbg's help: "Debugger Command Program Examples"
$$ You will find the full explanation there.
$$ ---------------------------------------------------------------------


$$ Get module list LIST_ENTRY in $t0.
r? $t0 = &@$peb->Ldr->InLoadOrderModuleList

$$ Iterate over all modules in list.
.for (r? $t1 = *(ntdll!_LDR_DATA_TABLE_ENTRY**)@$t0;
          (@$t1 != 0) & (@$t1 != @$t0);
           r? $t1 = (ntdll!_LDR_DATA_TABLE_ENTRY*)@$t1->InLoadOrderLinks.Flink)
{
    $$ Get base address in $Base.
    as /x ${/v:$Base} @@c++(@$t1->DllBase)

    $$ Get full name into $Mod.
    as /msu ${/v:$Mod} @@c++(&@$t1->FullDllName)

    .block
    {
        .echo ${$Mod} at ${$Base}
    }

    ad ${/v:$Base}
    ad ${/v:$Mod}
}
```

Useful Breakpoint Commands

Command	Description
bl	Breakpoint list
bp	Set Breakpoint
bu	Set Unresolved Breakpoint: defers the actual setting of the breakpoint until the module is loaded
ba	Break on Access
bc	Breakpoint Clear
be, bd	Breakpoint Enable, Disable

Example – Setting Simple Breakpoints

```
0:000> bu kernel32!LoadLibraryExW
0:000> bu kernel32!CreateProcessW
0:000> bu kernel32!CreateThread
0:000> ba r4 0012fe34                  → break on access (read or write); monitor 4 bytes
0:000> ba w2 0012fe38                  → break on access (write);         monitor 2 bytes

0:000> bl
 0 e 7c801af1     0001 (0001)  0:**** kernel32!LoadLibraryExW
 1 e 7c802332     0001 (0001)  0:**** kernel32!CreateProcessW
 2 e 7c810637     0001 (0001)  0:**** kernel32!CreateThread
 3 e 0012fe34 r 4 0001 (0001)  0:****
 4 e 0012fe38 2 2 0001 (0001)  0:****


0:000> bd 0,2                          → disable breakpoints 0 and 2
0:000> bc 4                            → clear breakpoint 4

0:000> bl
 0 d 7c801af1     0001 (0001)  0:**** kernel32!LoadLibraryExW
 1 e 7c802332     0001 (0001)  0:**** kernel32!CreateProcessW
 2 d 7c810637     0001 (0001)  0:**** kernel32!CreateThread
 3 e 0012fe38 r 4 0001 (0001)  0:****
```

Example – More Complex Breakpoints

- **Break at specified source code line**

```
0:000> bp `mod!source.c:12`
```

- **Breakpoint that will starts hitting after 5 passes**

```
0:000> bu kernel32!LoadLibraryExW 5
0:001> bl                       // → after 3 passes (0002=remaining count)
 0 e 7c801af1     0002 (0005)  0:**** kernel32!LoadLibraryExW
```

- **Break only if called from thread ~1**

```
0:000> ~1 bu kernel32!LoadLibraryExW
0:001> bl
 0 e 7c801af1     0001 (0001)  0:~001 kernel32!LoadLibraryExW
```

- **Break at all symbols with pattern myFunc***

```
0:000> bp mod!myFunc*
```

  - SymbolPattern is equivalent to using **x SymbolPattern**

- **Break on member methods**

```
0:000> bp @@c++( MyClass::MyMethod )
```

  - Useful if the same method is overloaded and thus present on several addresses

Example – Breakpoints With Commands

- **Skip execution of WinMain**

```
0:000> bu MyApp!WinMain "r eip = poi(@esp); r esp = @esp + 0x14; .echo WinSpy!WinMain
     entered; gc"
```

  - Right at a function's entry point the value found on the top of the stack contains the return address
    - r eip = poi(@esp) → Set EIP (instruction pointer) to the value found at offset 0x0
  - WinMain has 4x4 byte parameters = 0x10 bytes + 4 bytes for the return address = 0x14
    - r esp = @esp + 0x14 → Add 0x14 to ESP, effectively unwinding the stack pointer

- **Break only if LoadLibrary is called for MyDLL**

```
0:000> bu kernel32!LoadLibraryExW ";as /mu ${/v:MyAlias} poi(@esp+4); .if ( $spat(
     \"${MyAlias}\", \"*MYDLL*\" ) != 0 ) { kn; } .else { gc }"
```

  - The first parameter to LoadLibrary (at address ESP + 4) is a string pointer to the DLL name in question.
  - The MASM $spat operator will compare this pointer to a predefined string-wildcard, this is *MYDLL* in our example.
  - Unfortunately $spat can accept aliases or constants, but no memory pointers. This is why we store our pointer in question to an alias (MyAlias) first.
  - Our kernel32!LoadLibraryExW breakpoint will hit only if the pattern compared by $spat matches. Otherwise the application will continue executing.

Exception Analysis Commands

Command	Description
.lastevent	first-change or second-chance?
!analyze -v	Displays detailed information about the current exception
.exr -1	Display most recent exception
.exr Addr	Display exception at Addr
!cppexr	Display c++ exception at address 7c901230
g, gH	Go with Exception Handled
gN	Go with Exception Not Handled

Example - Exceptions

```
0:000> .lastevent
Last event: dac.154c: Stack overflow - code c00000fd (first chance)
  debugger time: Wed Aug 29 16:04:15.367 2007 (GMT+2)


0:000> .exr -1
ExceptionAddress: 00413fb7 (TestApp!_chkstk+0x00000027)
   ExceptionCode: c00000fd (Stack overflow)
  ExceptionFlags: 00000000
NumberParameters: 2
   Parameter[0]: 00000000
   Parameter[1]: 001e2000

0:000> !analyze -v
FAULTING_IP:
TestApp!_chkstk+27 [F:\SP\vctools\crt_bld\SELF_X86\crt\src\intel\chkstk.asm @ 99]
00413fb7 8500            test    dword ptr [eax],eax
...
```

Remote Debugging with WinDbg

- Target computer (server)
  - Copy dbgsrv.exe, dbgeng.dll and dbghelp.dll to the remote computer
  - Disable the firewall for "dbgsrv.exe“
  - Run → *dbgsrv.exe -t tcp:port=1025*

Windows Vista: Start dbgsrv.exe with admin privileges to see all processes.

- Host computer (client)
  - Run → *WinDbg.exe -premote tcp:server=TargetIP_or_Name,port=1025*
  - File (Menu) → Attach to Process → Select Process on Target Computer that you would like to debug

WinDbg Commands for Remote Debugging

Command	Description
Cdb.exe –QR server(IP or Name)	Lists all debugging servers running on the specified network server.
.detach	Detach from Process
.endpsrv	End dbgsrv.exe on remote computer. This command will kill the debugged process if you don't detach first.
.tlist	lists all processes running on the (remote) system

Monitoring Events

- The debugger engine provides facilities for monitoring and responding to events in the target application

- Events are generally divided into:
  - Exception events

    Breakpoint, Access Violation, Stack Overflow, division-by-zero, etc.

    For a full list see: Specific Exceptions.

  - Non-exception events

    Create Process, Create Thread, Load Module, Unload Module.

    For a full list see DEBUG_FILTER_*XXX*.

- Whenever a debugging session is accessible, there is a last event
  - Command: .lastevent

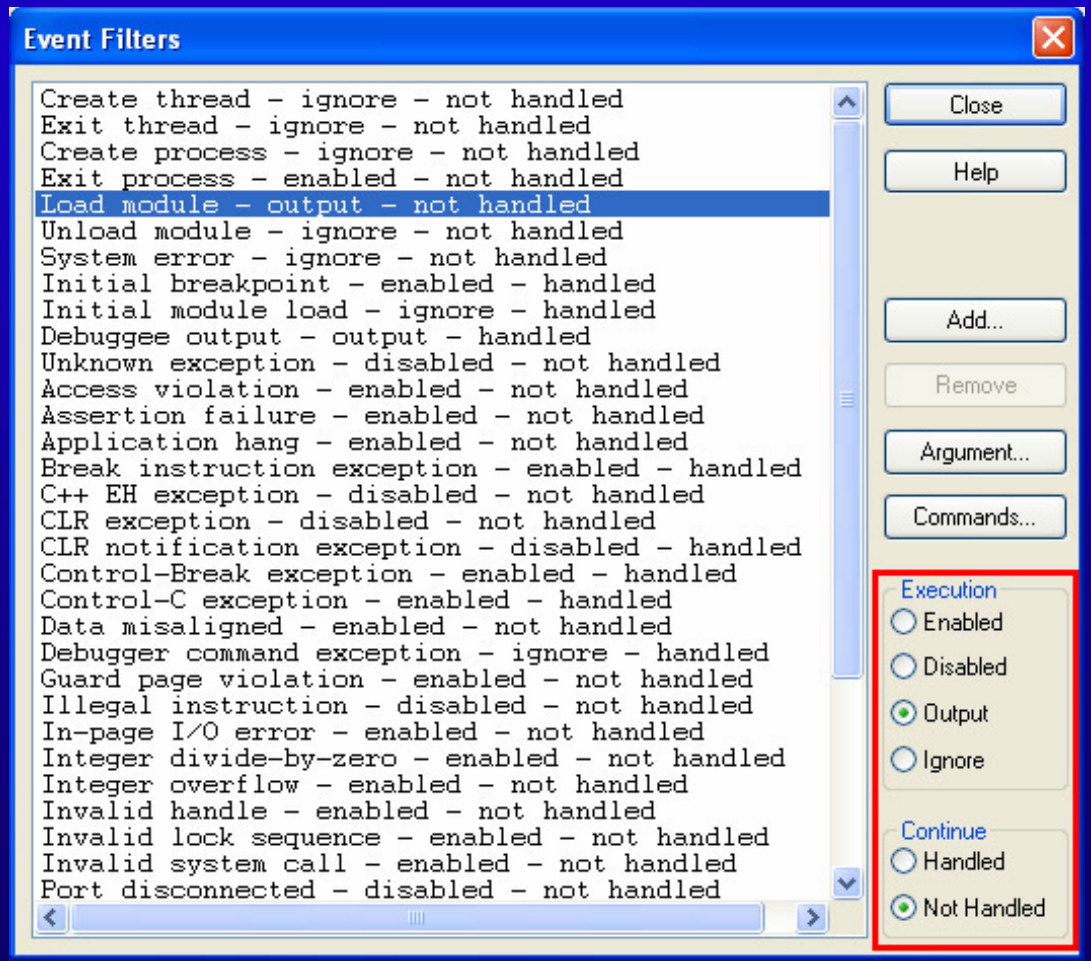
Events Filters in WinDbg

- Provide simple event filtering
- Influence how the debugger engine proceeds after an event occurs in a target
- To list all events: sx

- Break or execution status:
  - Influences whether the debugger will break into the target
    - First-chance break on event (sxe)
    - Second-chance break event (sxd)
    - Debugger message output on event (sxn)
    - Ignore event (sxi)

- Handling or Continue status:
  - Determines whether an exception event should be considered handled (gH) or not-handled (gN) in the target

Events Filters Dialog



Execution:

- → Enabled - first-chance break (sxe)
- → Disabled - second-chance break (sxd)
- → Output - message output on event (sxn)
- → Ignore - ignore event (sxi)

Continue:

- → Handled - Consider event handled when execution resumes
- → Not-Handled - Consider event not-handled when execution resumes

Event Arguments

- Some filters take arguments that restrict which events they match
- No arguments → No restriction

Event	Match criteria
Create Process	The name of the created process must match the argument.
Exit Process	The name of the exited process must match the argument.
Load Module	The name of the loaded module must match the argument.
Target Output	The debug output from the target must match the argument.
Unload Module	The base address of the unloaded module must be the same as the argument.

String wildcard syntax

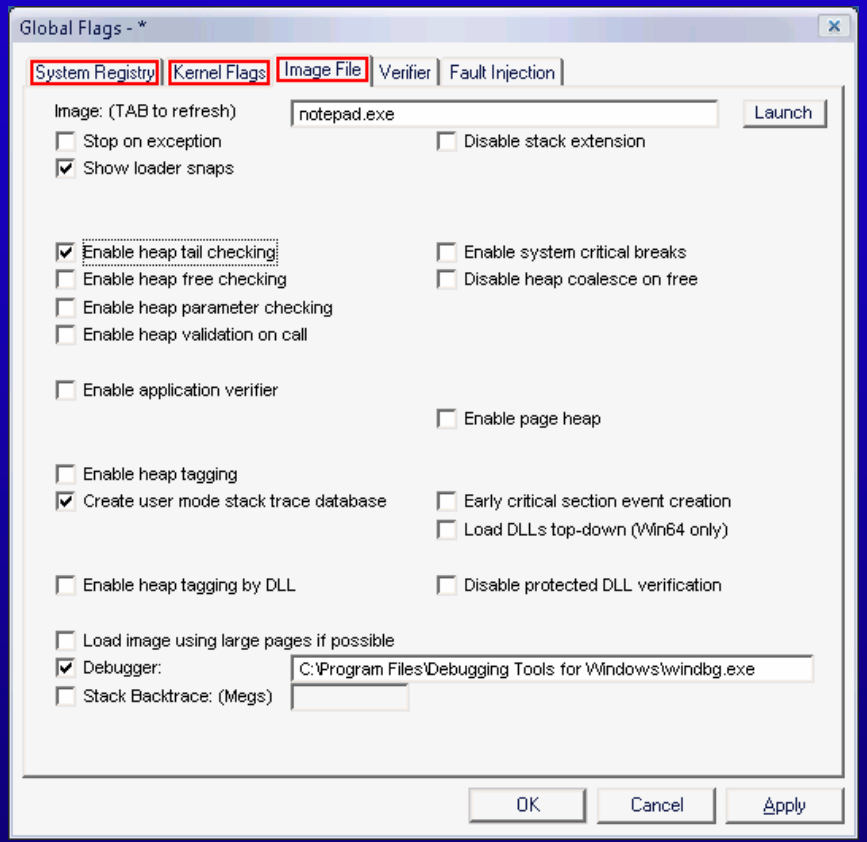
Table of Contents - Roadmap

- ✓ Behind the Scenes
- ✓ Using WinDbg
- → **Global Flags**
- Application Verifier
- Process Dumps

Flags? GFlags? Global Flags!

- GFlags enables and disables features by editing the Windows registry
- GFlags can set system-wide or image-specific settings
- Image specific settings are stored in:
  - HKLM\SOFTWARE\Microsoft\Windows NT\CurrentVersion**Image File Execution Options*****ImageFileName*****GlobalFlag**
- The OS reads these settings and adopts its functionality accordingly
- GFlags can be run from the command line or by using a dialog box
- We can also use !gflags in WinDbg to set or display the global flags
- With GFlags we can enable:
  - heap checking
  - heap tagging
  - Loader snaps
  - Debugger for an Image (automatically attached each time an Image is started)
  - Application verifier
  - Etc.

GFlags Dialog



- System Registry: System-wide settings that affect all processes running on Windows. They remain effective until you change them. Restart Windows to make the changes effective.
- Kernel Flags: Run-time settings that affect the entire system. They take effect immediately without rebooting, but they are lost if you shut down or restart the system.
- Image File: They affect instances of the specified program that start after the command completes. They are saved in the registry and remain effective until you change them.

GFlags: “Show loader snaps” Enabled

WinDbg Output:

```
LDR: LdrLoadDll, loading samlib.dll from
     C:\WINDOWS\system32;C:\WINDOWS\system;C:\WINDOWS;.;C:\WINDOWS\System32\Wbem;C:\WINDOWS\system32\kktools
LDR: Loading (DYNAMIC, NON_REDIRECTED) C:\WINDOWS\system32\samlib.dll
ModLoad: 71bf0000 71c03000   C:\WINDOWS\system32\samlib.dll
LDR: samlib.dll bound to ntdll.dll
LDR: samlib.dll has correct binding to ntdll.dll
LDR: samlib.dll bound to ADVAPI32.dll
LDR: samlib.dll has correct binding to ADVAPI32.dll
LDR: samlib.dll bound to RPCRT4.dll
LDR: samlib.dll has correct binding to RPCRT4.dll
LDR: samlib.dll bound to KERNEL32.dll
LDR: samlib.dll has stale binding to KERNEL32.dll
LDR: samlib.dll bound to ntdll.dll via forwarder(s) from kernel32.dll
LDR: samlib.dll has correct binding to ntdll.dll
LDR: Stale Bind KERNEL32.dll from samlib.dll
LDR: LdrGetProcedureAddress by NAME - RtlAllocateHeap
LDR: LdrGetProcedureAddress by NAME - RtlFreeHeap
LDR: LdrGetProcedureAddress by NAME - RtlGetLastWin32Error
LDR: LdrGetProcedureAddress by NAME - RtlReAllocateHeap
LDR: samlib.dll bound to USER32.dll
LDR: samlib.dll has stale binding to USER32.dll
LDR: Stale Bind USER32.dll from samlib.dll
[d58,690] LDR: Real INIT LIST for process C:\Development\Sources\TestApp\Release\TestApp.exe pid 3416 0xd58
[d58,690]    C:\WINDOWS\system32\samlib.dll init routine 003A0F30
[d58,690] LDR: samlib.dll loaded - Calling init routine at 003A0F30
```

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- → **Application Verifier**
- • Process Dumps

Get Even More: Enable Application Verifier

- Application Verifier:
  - is a runtime verification tool for Windows applications
  - is monitoring an application's interaction with the OS
  - profiles and tracks:
    - Microsoft Win32 APIs (heap, handles, locks, threads, DLL load/unload, and more)
    - Exceptions
    - Kernel objects
    - Registry
    - File system
  - with **!avrf** we get access to this tracking information

Note: Under the hood Application Verifier injects a number of DLLs (verifier.dll, vrfcore.dll, vfbasics.dll, vfcompat.dll, and more) into the target application. More precisely: It sets a registry key according to the selected tests for the image in question. The windows loader reads this registry key and loads the specified DLLs into the applications address space while starting it.

Application Verifier Variants

GFlags *Application Verifier*

- Only verifier.dll is injected into the target process
- verifier.dll is installed with Windows XP
- Offers a very limited subset of Application Verifier options
- Probably this option in GFlags is obsolete and will eventually be removed (?)

Application Verifier

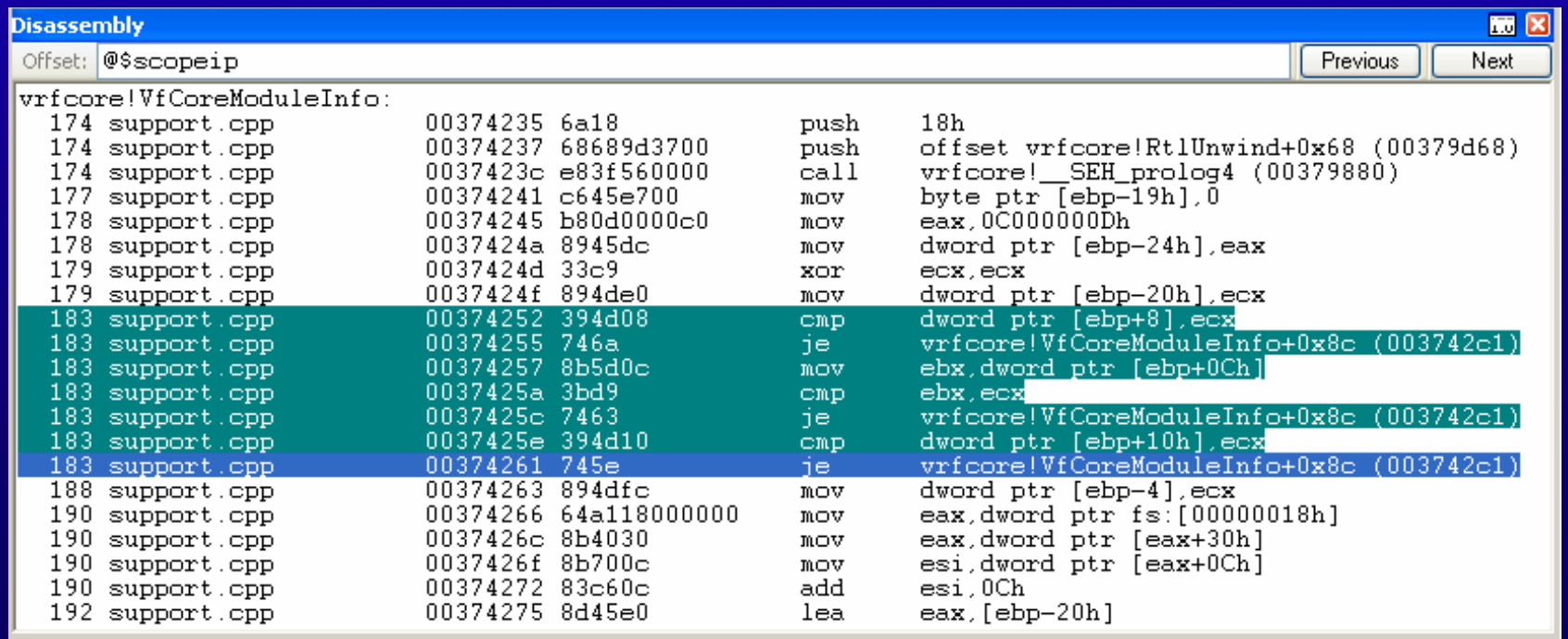
- Can freely be downloaded and installed from the MS website
- Additionally installs vrfcore.dll, vfbasics.dll, vfcompat.dll, and more into Windows\System32
- Enables much more test options and full functionality of the !avrf extension

Application Verifier Symbols

Application Verifier is installed with PDB's with full symbol information

- Note the source information included in the disassembly
- These are the only modules from Microsoft that I've seen delivered with full symbol information
- In fact, WinDbg must use these symbols rather than the public ones from the server. Otherwise the !avrf extension will not work

.reload /f @"C:\Windows\System32\verifier.pdb"



Common !avrf Parameters

Command	Description
!avrf	Displays current Application Verifier options. If an Application Verifier Stop has occurred, reveal the nature of the stop and what caused it.
!avrf -cs	Displays the critical section delete* log. * DeleteCriticalSection API. ~CCriticalSection calls this implicitly.
!avrf -hp 5	Displays the heap operation log (last 5 entries). * HeapAlloc, HeapFree, new, delete
!avrf -dlls	Displays the DLL load/unload log.
!avrf -ex	Displays the exception log.
!avrf -cnt	Displays a list of global counters (WaitForSingleObject calls, CreateEvent calls, HeapAllocation calls, ..).
!avrf -threads	Displays information about threads in the target process. For child threads, the stack size and the CreateThread flags specified by the parent are displayed as well.
!avrf -trm	Displays a log of all terminated* and suspended threads. * TerminateThread API

Example – !avrf

```
// Right after our application executes:
// HeapAlloc( 0x00140000, 8, dwBytes =0x00A00000 ) -->> 0x033D1000;

0:000> !avrf -hp 1
Verifier package version >= 3.00
Dumping last 1 entries from tracker @ 01690fd8 with 1291 valid entries ...
------------------------------------------------------------
HeapAlloc: 33D1000 A00000 0 0
     004019cf: TestApp!CMyDialog::OnBnClicked_HeapAlloc+0x4F
     0041a0c1: TestApp!_AfxDispatchCmdMsg+0x3D
     0041a2a6: TestApp!CCmdTarget::OnCmdMsg+0x10A
     0041a76c: TestApp!CDialog::OnCmdMsg+0x1B
     0041d05c: TestApp!CWnd::OnCommand+0x51
     0041d92b: TestApp!CWnd::OnWndMsg+0x2F
     0041b2eb: TestApp!CWnd::WindowProc+0x22
     …

0:000> !avrf -threads
================================================
Thread ID = 0xDE4
Parent thread ID = 0xE3C
Start address = 0x004a7d82: TestApp!ILT+11645(?ThreadProcYGKPAXZ)
Parameter = 0x0061833c
================================================
Thread ID = 0xE3C
Initial thread
================================================
Number of threads displayed: 0x2
```

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- ✓ Behind the Scenes
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- → **Process Dumps**

Process Dumps

- A Process's dump
  - is quite similar to a non-invasive attach
  - represents a snapshot of a process at a given time
  - varies in size, depending on what contents and information it includes
- With a dump
  - we can examine memory as well as other internal structures of a process
  - we cannot set breakpoints or step through the program execution
- Dump a dump
  - we can always "shrink" a dump with more information to a dump with less information
  - use the .dump command as you would with a live process

Types of Dumps

1) Kernel-mode dumps

Variants: Complete Memory Dump, Kernel Memory Dump, Small Memory Dump

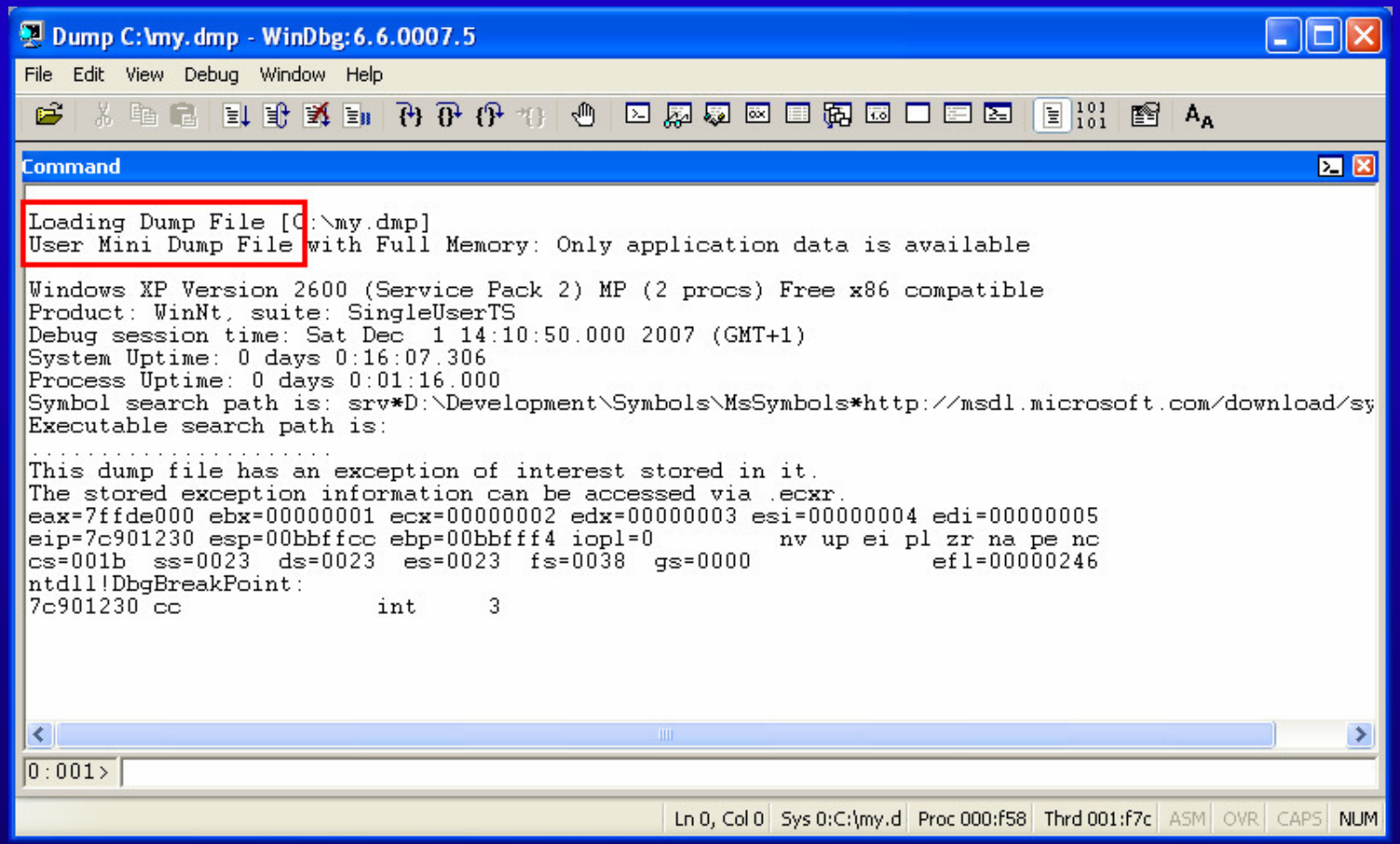
2) Full User-mode dumps

- Generated by WinDbg with ".dump /f" or by Dr. Watson on Windows 2000
- Includes the entire memory space of a process, the program's executable image itself, the handle table
- Widely used in the past, MS is slowly dropping support for it

3) Minidumps

- .dump /m??
- The modern dump format
- Fine-grained control about what is included in the dump (see MSDN: MINIDUMP_TYPE)
- Despite their names, the largest minidump file actually contains more information than a full user-mode dump. For example, .dump /mf or .dump /ma creates a larger and more complete file than ".dump /f"

Determine Type of a Dump

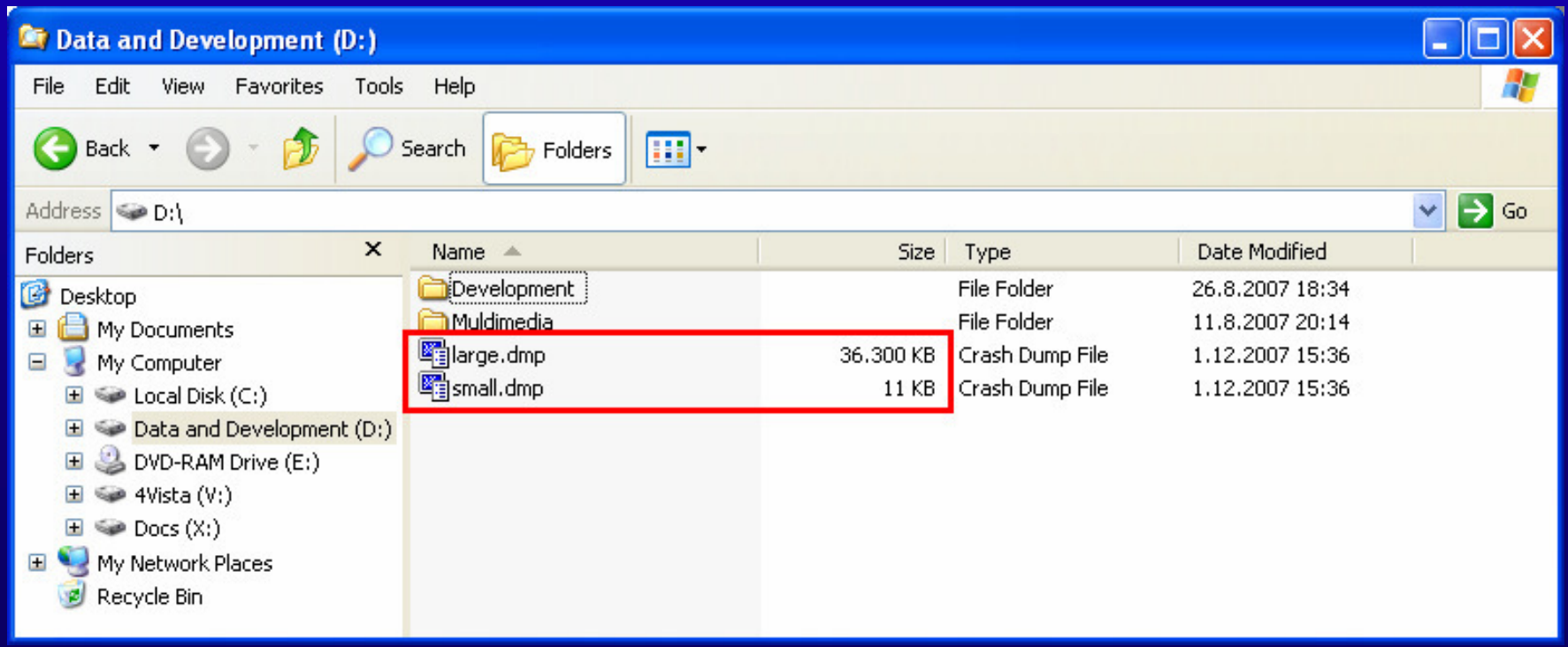


You can load the dump in question into WinDbg. WinDbg will call a minidump a "User Mini Dump File," and the old style crash dump will be called a "User Dump File."

Example – ".dump" Command

```
0:000> .dump /ma   d:\large.dmp          → all possible data: full memory, code sections, PEB and TEB's,
Creating d:\large.dmp - mini user dump      handle data, thread time information, unloaded module lists, and more
Dump successfully written

0:000> .dump /m   d:\small.dmp           → only basic information: module information (signatures),
Creating d:\small.dmp - mini user dump      thread and stack information
Dump successfully written
```



Choosing the Best Tool

Scenario / Options	ADPlus	Dr. Watson	CDB and WinDbg	UserDump
Application crash (postmortem debugging)	Yes	Yes	Yes	Yes
Application "hang" (stops responding but does not actually crash)	Yes	No	Yes	Yes
Application encounters an exception	Yes	Yes	Yes	Yes
Application is running normally	No	No	Yes	Yes
Application that fails during startup (i.e. missing DLL dependency)	No	No	Yes	Yes
Shrinking an existing dump file	No	No	Yes	No
Dump all running applications with the same image name at once	No	No	No	Yes
Control what information is included in the dump file	No	No[1]	Yes	No[2]

1: Always creates a small Minidump --MiniDumpNormal -- with basic information only. It is usually less than 20KB in size.

2: Always creates a Minidump with Full Memory information. It is usually 20-200MB in size.

Your Homework

- Read WinDbg's documentation
  - Memory leaks, handles, deadlocks, breakpoints with conditions, and more. Everything is explained there.
- Learn assembly
  - It will greatly improve your debugging skills
  - Besides WinDbg assembly will be your best friend when it comes to debugging situations

Questions? Suggestions?

- You have a question about WinDbg?
- You are interested in a WinDbg lab or seminar?
- You think that something in *“WinDbg. From A to Z!”* could be improved?
- Or you would just like to say WOW, this presentation was really useful?

- Feel free to drop a line at: **mailwindbg@rkuster.com**
  The actual email address does not contain the word “mail“ – spam prevention.

References

- WinDbg's Documentation, MSDN
- Common WinDbg Commands (Thematically Grouped)
  http://software.rkuster.com/windbg/printcmd.htm
- Matching Debug Information
  http://www.debuginfo.com/articles/debuginfomatch.html
- Generating Debug Information with Visual C++
  http://www.debuginfo.com/articles/gendebuginfo.html
- Microsoft Windows Internals, Fourth Edition
  M.E. Russinovich, D.A. Solomon, ISBN 0-7356-1917-4
- Advanced Kernel Debugging
  Andre Vachon, PowerPoint, WinHec 2004
- Application Verifier's Documentation