DPTrace: Dual Purpose Trace for Exploitability Analysis of Program Crashes

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Disclaimer

- We don't speak for our employer(duh!). All the opinions and information presented here is our responsibility (actually no one has seen this talk before today)
  - **IMPORTANT: No, we are *not* part of the Intel Security Group (McAfee)**

Agenda

- Objectives
- Current state of Affairs or Security Today
- Taint Analysis Introduction
- Our approach – Dual Tracing
- Comparison with other ideas
- Demos
- Limitations
- Future

Objectives

- Contribute towards improving the state of the art in crash analysis
- Automate laborious/repetitive parts, but still requiring skilled exploit writer/analyst
- Discuss hybrid usage of techniques and the mixture of automation with manual analysis

Current State of Affairs

- Buggy programs deployed on critical servers
- Rapidly-evolving threats, attackers and tools (exploitation frameworks)
- Lack of developers training, resources and people to fix problems and create safe code
- **That's why we are here today, right?**

tl; dr

thnx Marcio !

Taint Analysis for Program Crashes

- Through our work we try to answer two fundamental questions:
  - Are the input operands in the attacker's control?
  - And if so, is the forward execution providing a primitive that is good for an attacker?

- Taint Analysis is one specific kind of program flow analysis and we use it to define the influence of external data (attacker's controlled data) over the analyzed application

- Since the information flows, or is copied to, or influences other data there is a need to follow this influence in order to determine the control over specific areas (registers, memory locations). This is a requirement in order to determine exploitability

History and Lore-Backward-Taint

- Original Motivation: Complex client-side vulnerability in a closed (at the time) file format
- Extended Motivation: Trying to better analyse hundreds of thousands of bugs in Microsoft Word (search for Ben Nagy, Coseinc)
- Initial version integrated with a fuzzer, only for Linux (showed in 2011 at Troopers)
- Ported version for Solaris to analyze a vulnerability released by Secunia in the same software RISE Security released a vulnerability a month before (also circa 2011)
- Thanks to Julio Auto's parallel research in the same field, a Windows version was created (extended in this research)

History and Lore- Forward-Taint

- Original Motivation: Triaging submissions in a vulnerability purchase program is hard. Many submissions lack a complete exploit but still might have real value
- Extended Motivation: Categorizing fuzzing crashes is a pain (NOT bang(!) exploitable categorizing)
- Manual process includes lots of repetitive steps
- Automation is key. Certain classes repeat themselves (such as UAF)
- 'Prototyping Exploitation' in such cases is both cost and time effective. Also a more reasonable and simpler 'automatable' problem than automating exploit writing for all classes of bugs. Prototype or GTFO!

Existing Solutions - What we aren't

- !exploitable
  - Tries to classify unique issues (crashes appearing through different code paths, machines involved in testing, and in multiple test cases). Group the crashes for analysis
  - Quickly prioritizes issues (since crashes appear in thousands, while analysis capabilities are VERY limited)
  - Classic, timeless!
- Spider Pig
  - Created by Piotr Bania
  - Not available for testing, but from the paper: It is much more advanced them the provided tool (but well, it is not available?)
    - Virtual Code Integration (or Dynamic Binary Rewriting)
    - Disputable Objects: Partially controlled data is analyzed using the parent data
- Taint Bochs
  - Used for tracking sensitive data lifecycle in memory

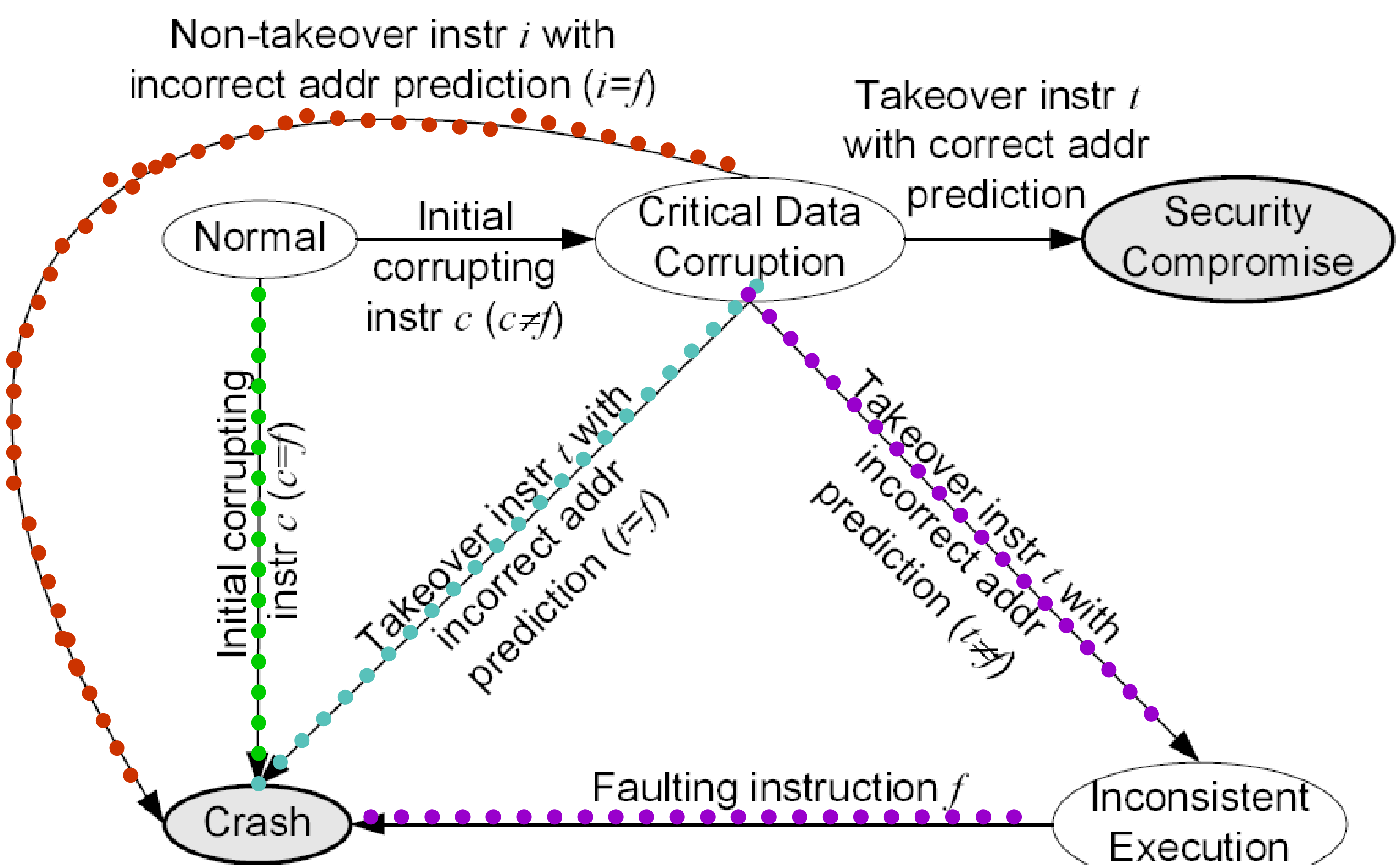
Existing Solutions - What we aren't

contd..

- Taint Check
  - Uses DynamicRIO or Valgrind
  - Taint Seed: Defining the tainted values (data comming from the network for example)
  - Taint Tracker: Tracks the propagation, Taint Assert: Alert about security violations
  - Used while testing software to detect overflow conditions, does nto really help in the exploit creation
- Bitblaze
  - An amazing platform for binary analysis
  - Provides better classification of exploitability (Charlie Miller talk in BH)
  - Can be used as base platform for the provided solution (VINE)
- Moflow Framework
  - Cisco Talos. Tools built on CMU's BAP framework.
  - sliceflow- post-crash graph back taint slicer
  - Post-crash forward symbolic emulator looking for more exploitable conditions
  - Pretty neat and advanced!

State Transition for Memory Corruption

- Case 1 (green): Format String
- Case 2 and 3 (red and blue): buffer overflow
- Case 4 (purple): unpredictable



Source:
Automatic Diagnosis and Response to Memory Corruption Vulnerabilities

c: corrupting instruction
t: takeover instruction
f: faulting instruction

Moving Backward

- Legitimate assumption:
  - To change the execution of a program illegitimately we need to have a value being derived from the attacker's input (which we call: controlled by the attacker)
- String sizes and format strings should usually be supplied by the code itself, not from external, un-trusted inputs
- Any data originated from or arithmetically derived from un-trusted source must be inspected

Analyzing Taint

- Tainted data: Data from un-trusted source
- Keeps track of tainted data (from un-trusted source)
- Monitors program execution to track how tainted attribute propagates
- Detect when tainted data is used in sensitive way

Taint Propagation

- When a tainted location is used in such a way that a value of other data is derived from the tainted data (like in mathematical operations, move instructions and others) we mark the other location as tainted as well

- The transitive relation is:
  - If information A is used to derive information B:
    - A->t(B) -> Direct flow
  - If B is used to derive information C:
    - B->t(C) -> Direct flow
    - Thus: A->t(C) -> Indirect flow

- Due to the transitive nature, you can analyze individual transitions or the whole block (A->t(C))

Location

- A location is defined as:
  - Memory address and size
  - Register name (we use the register entirely, not partially -> thus %al and %eax are the same)
    - When setting a register, we set it higher (setting %al as tainted will also taint %eax)
    - When clearing a register, we clear it lower
- To keep track over bit operations in a register it is important to taint the code-block level of a control flow graph
  - This create extra complexity due to the existence of the flow graph and data flow dependencies graph
  - The dependencies graph represents the influence of a source data in the operation been performed

Flows

- Explicit flow:
  - mov %eax, A
- Implicit flow:
  - If (x == 1) y=0;
- Conditional statements require a special analysis approach:
  - In our case, we are analyzing the trace of a program (not the program itself, but only what was executed during the debugging section)
  - We have two different analysis step: tracing and analysis

Special Considerations

- Partial Tainting: When the untrusted source does not completely control the tainted data
- Tainting Merge: When there are two different untrusted sources being used to derive some data
- Data
  - In Use: when it is referenced by an operation
  - Defined: when the data is modified

Inheritance problems

<u>Problem:</u> state explosion for binary operations !

Application	Propagation Tracking	Inheritance Tracking
`mov %eax ← A` `mov B ← %eax`	*taint(%eax) = taint(A)* *taint(B) = taint(%eax)*	**%eax inherits from A** **B inherits from %eax**
`add %ebx ← D`	*taint(%ebx) |= taint(D)*	**insert D into %ebx's inherit-from list**

Events

Rare
e.g., malloc/free, system calls

Frequent
e.g., memory access,
data movement

Tracking Instructions

- Pure assignments: Easy to track
  - If a tainted location is used to define another location, this new location will be tainted
- Operations over strings are tainted when:
  - They are used to calculate string sizes using a tained location
    - a = strlen(tainted(string));
    - Since the ‘string’ is tainted, we assume the attacker controls ‘a’
  - Search for some specific char using a tainted location, defining a flag if found or not found
    - pointer = strchr(tainted(string), some_char);
    - If (pointer) flag=1;
    - ‘flag’ is tainted if the attacker controls ‘string’ or ‘some_char’

Tracking Instructions contd..

- Arithmetic instructions with at least one tainted data usually define tainted results
- Those arithmetic instructions can be simplified to map to boolean operations and then the following rules applies

Eflags and Flow Information

- The eflags register can also be tainted to monitor flags conditions influencing in operations (and flow)
- In the presented approach, conditional branches are taken care due to the trace generated by the WinDBG plugin (single-stepping)

Backward Taint Analysis

- Divide the analysis process in two parts:
  - A trace from a good state to the crash (incrementally dumped to a file) -> Gather substantial information about the target application when it receives the input data, which is formally named 'analysis'
  - Analysis of the trace file -> Formally defined as 'verification' step, where the conclusive analysis is done

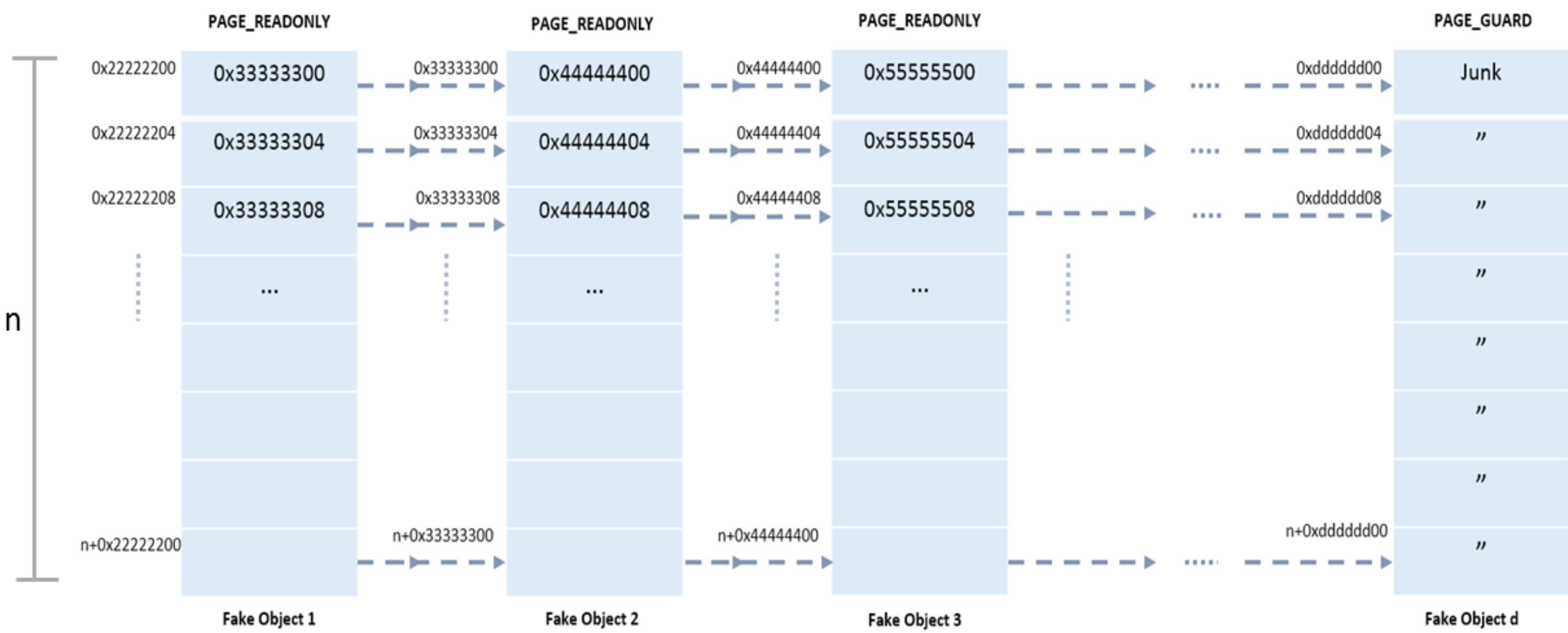
Forward Taint Analysis

- To see what kind of primitives (read/write/calls) are available we 'prototype' input control and allocate a fake object structure in memory such that the program can continue from the point of the crash to other code paths.

- The property of such fake memory structure should guarantee to a reasonable extent that any memory references (like virtual function tables or other object pointers) will be resolved including memory address references that are additive or subtractive to the faulting address(which is already assumed controllable).

- In essence one could imagine it as simulating the reallocation of a fake object 'within' the debugger in a use-after-free situation and continuing the exception. Or allocating an adjacent object in an out of bounds access violation, etc.

Fake Memory Structure Sample



n- size of each object in bytes
d- depth/number of fake objects in the linked list chain

Forward Logic

- In the debugger you see a seemingly non exploitable read AV (access violation).
  - Example: mov eax ,[ecx] ; (ecx is supposed here to be a pointer to attacker controlled memory.)
  - You allocate a chunk of memory within the process (preferably the size of the memory pointed to by ecx to mimic an accurate freed block control using heap massaging,feng-shui)
- The permissions of all memory blocks in a linked list chain are read-only. So any attempt to write/execute on any of the values within the memory blocks would cause an exception later and that shows evidence of exploitability
- Now manually change the ecx value in the crash to point to the address of the root of this linked list which is the root of the chain of memory blocks pointing to one another
- Continue the program execution and it will continue from the point of crash with the modified value of ecx.

Need for Intermediate Languages

- Assembly instructions have explicit operands, which are easy to deal with, and sometimes implicit operands:
  - Instruction: push eax
  - Explicit operand: eax
  - What it really does?
    - ESP = ESP – 4 (a substraction)
    - SS:[ESP] = EAX (a move)
    - Here we have ESP and SS as implicit operands
      - Tks to Edgar Barbose for this great example!

Implementing the Tracer

- Instead of using an intermediate language, we play straight with the debugger interfaces (WinDBG). Windbg or GTFO!
- The tracer stores some useful information, like effective addresses and data values and also simplifies the instructions for easy parsing:
  - CMPXCHG r/m32, r32 -> 'Compare EAX with r/m32. If equal, ZF is set and r32 is loaded into r/m32. Else, clear ZF and load r/m32 into AL'
    - Such an instruction creates the need for conditional taints, since by controlling %eax and r32 the attacker controls r/m32 too.

Implementation Details

- Instead of using an intermediate language, we play straight with the debugger interfaces (WinDBG). Windbg or GTFO!
- Trace File Contains:
  - Mnemonic of the instruction and operands
  - Dependences for the source operand
    - Eg: Elements of an indirectly addressed memory
    - This creates a tree of the dataflow, with a root in the crash instruction
- The verification (GUI and cmdline program) step reads this file and:
  - Search this tree using a BFS algorithm
- Forward step uses the debugger interfaces for the memory allocation and forward execution

ICE CREAM ICE
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Program Execution Timeline

Program start

Trace! Check Taint! Forward Execution → Initial Crash, AV

Trace! Check Taint! Forward Execution → Exception → Constraint 1

… …

… …

… …

Trace! Check Taint! Forward Execution → Exception → Constraint n

…

…

Trace! Check Taint! ⇢ Exploitable Primitive?! Profit!

…

…

OR march on, down to hell ☹

Theoretical Example

- 1-) mov edi, 0x1234 ; dst=edi, src=0x1234
- 2-) mov eax, [0xABCD] ; dst=eax, src=ptr 0xABCD ; Note 0xABCD is evil addr
- 3-) lea ebx, [eax+ecx*8] ; dst=ebx, src=eax, srcdep1=ecx
- 4-) mov [edi], ebx ; dst=ptr 0x1234, src=ebx
- 5-) mov esi, [edi] ; dst=esi, src=ptr 0x1234, srcdep1=edi
- 6-) mov edx, [esi] ; Crash!!!

Theoretical Example contd..

- 6-) Where does [esi] come from?
- 5-) [edi] is moved to esi, where edi comes from and what does exist in [edi]?
- 4-) [edi] receives ebx and edi is defined in 1-) from a fixed value
- 3-) ebx comes from a lea instruction that uses eax and ecx
- 2-) eax receives a value controlled by the attacker
- ... ecx is out of the scope here :)

Assumptions & Challenges

- Since we only use the trace information, if the crash input data does not force a flow, we can't see the influence of the input over this specific flow data
- To solve that:
  - If a jmp is dependent of a flag, the attacker controls branch decision
  - Control over a branch means tainted EIP
  - To define the value of EIP, consider:
    - The address if the jump is taken
    - The address of the next instruction (if the jump is not taken)
    - The value of the interesting flag register (0 or 1)
    - Then: %eip <- (address of the next instruction) + value of the register flag * (|address if jump is taken – address of the next instruction|)

Forward Analysis

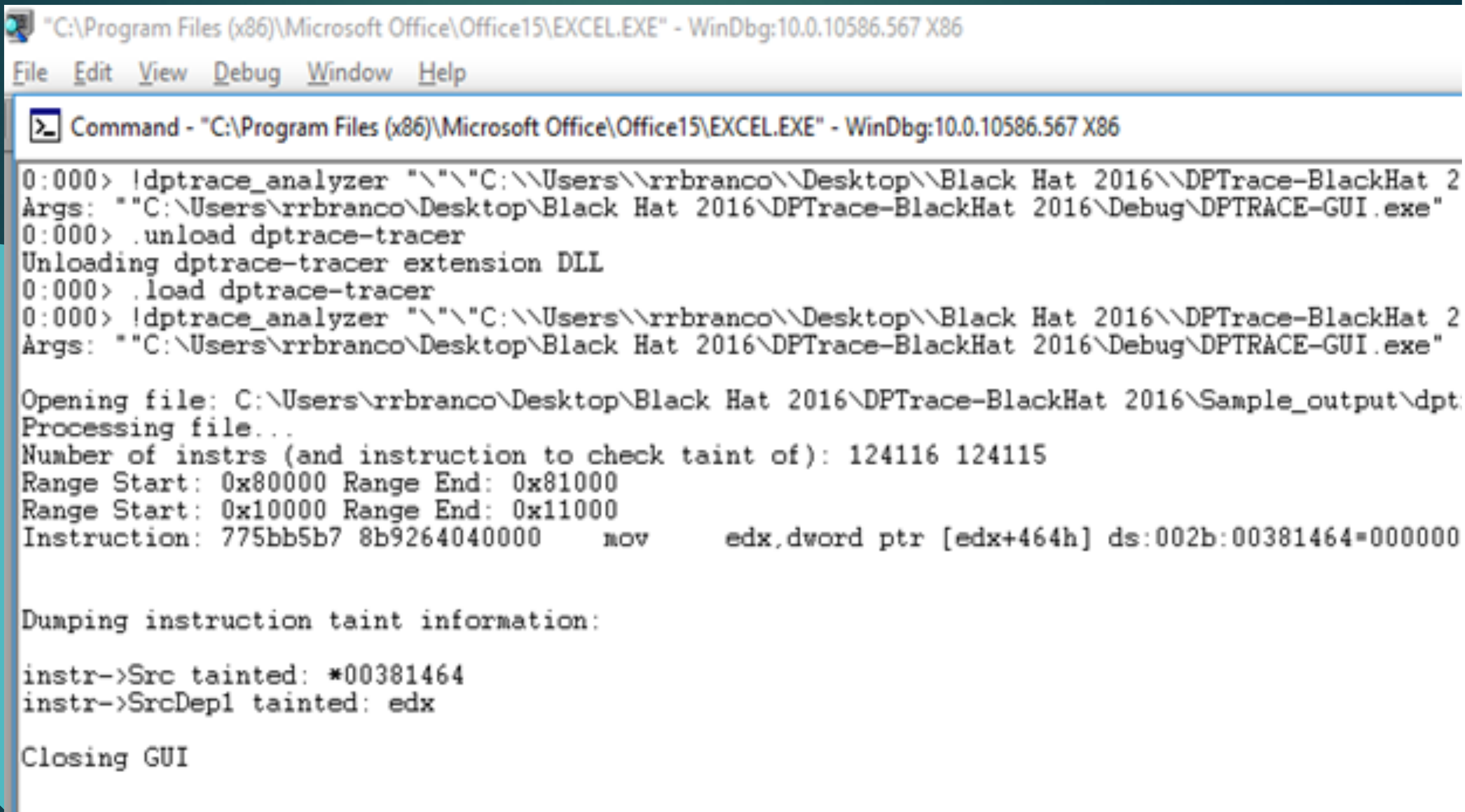
- The method here was conceived originally to help determine whether crashes for potential UAF (Use-After-Free) bugs in browsers are exploitable or not
- UAFs in browsers or any significantly large programs for that matter are often hard to analyze for exploitability and typically involve following varied code paths in the control flow to find a write access violation/potential code redirection using indirect calls
- The idea is not just limited to UAFs though
- After input control(first part of the problem) has been determined, the next logical step is to gauge what can be done with it.

Command-line options

```
0:018> .load dptracer
0:018> !dptrace_help
Dual Purpose Tracer v1.0 Alpha - Copyright (C) 2008-2016
License: This software was created as companion to a Black Hat Presentation.
Developed by Rodrigo Rubira Branco (BSDaemon) <rodrigo@kernelhacking.com> and Rohit Mothe <rohitwas@gmail.com> (alphabetical order of names)
Heavily based on VDT-Tracer by Julio Auto and Rodrigo Branco

!dptrace_trace <filename>  - trace the program until a breakpoint or exception and save the trace
          in a file to be later consumed by the Visual Data Tracer GUI.
!dptrace_forward <n(required) - s(required) - p(OPTIONAL)>              - forward analysis, either no arguments or all mandatory
!dptrace_analyzer <analyzer_filepath> <trace_filepath> <close_gui> <controlled_ranges> <instr_index>
!dptrace_analyzer_help      - help to the !dptrace_run_analyzer command
!dptrace_forward_help       - help to the !dptrace_forward command
!dptrace_help - this help screen
```

```
*** ERROR: Symbol file could not be found.  Defaulted to export symbols for C:\Windows\SYSTEM32\ntdll.dll -
ntdll!DbgBreakPoint:
77c140f0 cc              int     3
0:016> .load dptracer

0:016> !dptrace_trace C:\Desktop\LogFiles\Log.vdt
```

Analyzer



"C:\Program Files (x86)\Microsoft Office\Office15\EXCEL.EXE" - WinDbg:10.0.10586.567 X86

File Edit View Debug Window Help

Command - "C:\Program Files (x86)\Microsoft Office\Office15\EXCEL.EXE" - WinDbg:10.0.10586.567 X86

```
0:000> !dptrace_analyzer "\"\"C:\\Users\\rrbranco\\Desktop\\Black Hat 2016\\DPTrace-BlackHat 2
Args: ""C:\Users\rrbranco\Desktop\Black Hat 2016\DPTrace-BlackHat 2016\Debug\DPTRACE-GUI.exe"
0:000> .unload dptrace-tracer
Unloading dptrace-tracer extension DLL
0:000> .load dptrace-tracer
0:000> !dptrace_analyzer "\"\"C:\\Users\\rrbranco\\Desktop\\Black Hat 2016\\DPTrace-BlackHat 2
Args: ""C:\Users\rrbranco\Desktop\Black Hat 2016\DPTrace-BlackHat 2016\Debug\DPTRACE-GUI.exe"

Opening file: C:\Users\rrbranco\Desktop\Black Hat 2016\DPTrace-BlackHat 2016\Sample_output\dpt
Processing file...
Number of instrs (and instruction to check taint of): 124116 124115
Range Start: 0x80000 Range End: 0x81000
Range Start: 0x10000 Range End: 0x11000
Instruction: 775bb5b7 8b9264040000     mov     edx,dword ptr [edx+464h] ds:002b:00381464=000000


Dumping instruction taint information:

instr->Src tainted: *00381464
instr->SrcDep1 tainted: edx

Closing GUI
```

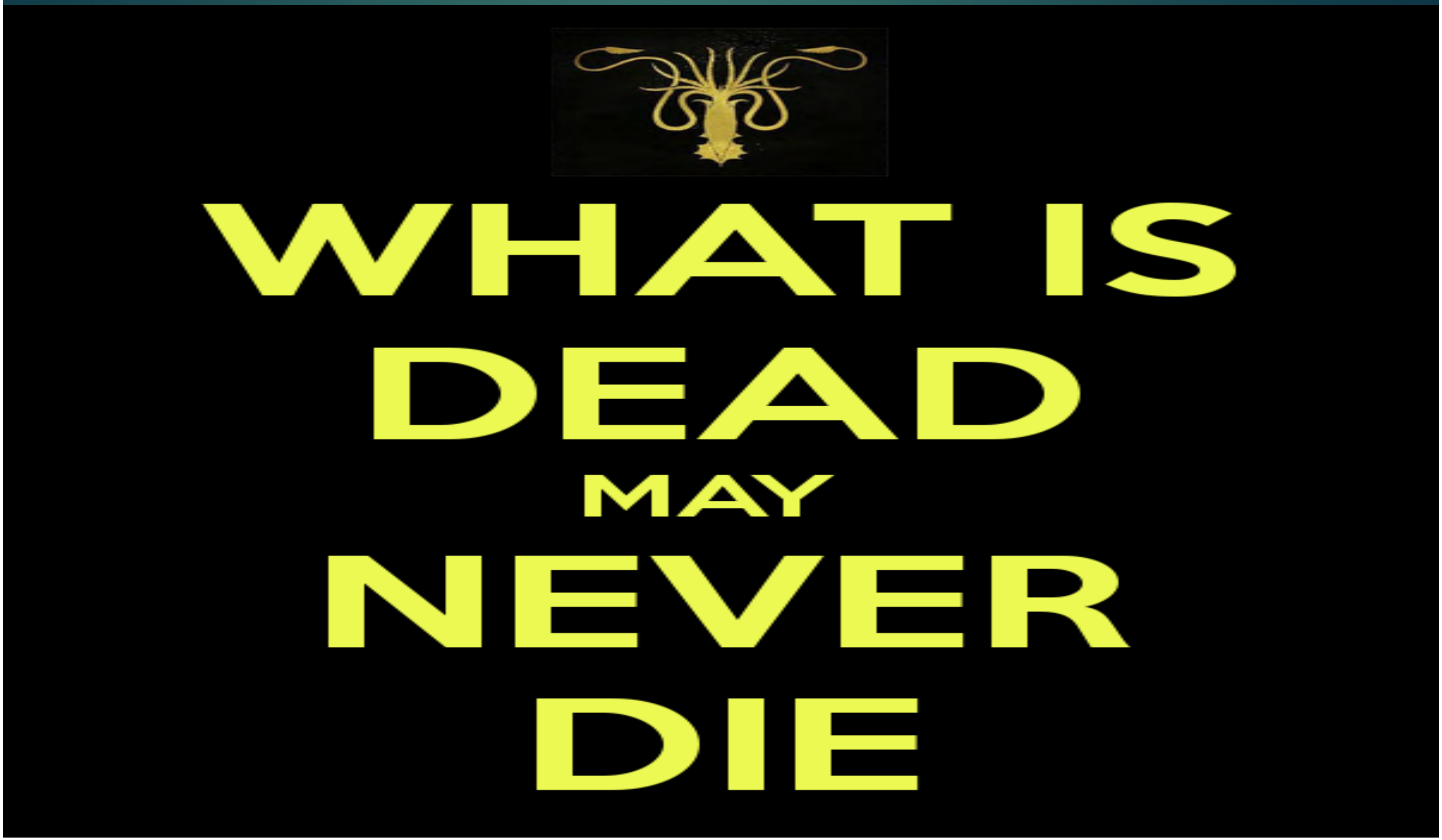
Forward

```
0:009> !dptrace_forward help
!dptrace_forward:

[*] Two options of running-

        a) Simple Run with no arguments
                    !dptrace_forward
                    = > default number of objects n = 2, size s= 40, permissions are RW for first object, READONLY for all other

        b) If running with arguments to configure the run following rules apply -
                    !dptrace_forward - n(required) - s(required) - p(OPTIONAL)
                     = > number of fake objects(required), size of each object in bytes(required), page permissions(OPTIONAL)(0x

                    Parameters n and s are parsed in decimal(base 10). however, if passing the 3rd parameter p, specify the cons

        <Optional>For passing 'p' use the following map -
                    PAGE_EXECUTE  0x10
                    PAGE_EXECUTE_READ  0x20
                    PAGE_EXECUTE_READWRITE  0x40
                    PAGE_EXECUTE_WRITECOPY  0x80
                    PAGE_NOACCESS  0x01
                    PAGE_READONLY  0x02 // defualt protection if run with no arguments.
                    PAGE_READWRITE  0x04
                    PAGE_WRITECOPY  0x08
        </Optional>

0:009> !dptrace_forward 3 100 0x2


 Allocated range is
3da0000-3da1000,3db0000-3db1000,3dc0000-3dc1000
```

Forward

```
0:012> dd 3eb0000
03eb0000  03ec0000 03ec0004 03ec0008 03ec000c
03eb0010  03ec0010 03ec0014 03ec0018 03ec001c
03eb0020  03ec0020 03ec0024 03ec0028 03ec002c
03eb0030  03ec0030 03ec0034 03ec0038 03ec003c
03eb0040  03ec0040 03ec0044 03ec0048 03ec004c
03eb0050  03ec0050 03ec0054 03ec0058 03ec005c
03eb0060  03ec0060 41414141 41414141 41414141
03eb0070  41414141 41414141 41414141 41414141
0:012> dd 03ec0000
03ec0000  03ed0000 03ed0004 03ed0008 03ed000c
03ec0010  03ed0010 03ed0014 03ed0018 03ed001c
03ec0020  03ed0020 03ed0024 03ed0028 03ed002c
03ec0030  03ed0030 03ed0034 03ed0038 03ed003c
03ec0040  03ed0040 03ed0044 03ed0048 03ed004c
03ec0050  03ed0050 03ed0054 03ed0058 03ed005c
03ec0060  03ed0060 41414141 41414141 41414141
03ec0070  41414141 41414141 41414141 41414141
0:012> dd 03ed0000
03ed0000  cccccccc cccccccc cccccccc cccccccc
03ed0010  cccccccc cccccccc cccccccc cccccccc
03ed0020  cccccccc cccccccc cccccccc cccccccc
03ed0030  cccccccc cccccccc cccccccc cccccccc
03ed0040  cccccccc cccccccc cccccccc cccccccc
03ed0050  cccccccc cccccccc cccccccc cccccccc
03ed0060  cccccccc cccccccc cccccccc cccccccc
03ed0070  cccccccc cccccccc cccccccc cccccccc
0:012> !vprot 3eb0000
BaseAddress:       03eb0000
AllocationBase:    03eb0000
AllocationProtect: 00000004  PAGE_READWRITE
RegionSize:        00001000
State:             00001000  MEM_COMMIT
Protect:           00000004  PAGE_READWRITE
Type:              00020000  MEM_PRIVATE
0:012>
BaseAddress:       03eb0000
AllocationBase:    03eb0000
AllocationProtect: 00000004  PAGE_READWRITE
RegionSize:        00001000
State:             00001000  MEM_COMMIT
Protect:           00000004  PAGE_READWRITE
Type:              00020000  MEM_PRIVATE
0:012> !vprot 03ec0000
BaseAddress:       03ec0000
AllocationBase:    03ec0000
AllocationProtect: 00000004  PAGE_READWRITE
RegionSize:        00001000
State:             00001000  MEM_COMMIT
Protect:           00000002  PAGE_READONLY
Type:              00020000  MEM_PRIVATE
0:012> !vprot 03ed0000
BaseAddress:       03ed0000
AllocationBase:    03ed0000
AllocationProtect: 00000004  PAGE_READWRITE
RegionSize:        00001000
State:             00001000  MEM_COMMIT
Protect:           00000002  PAGE_READONLY
Type:              00020000  MEM_PRIVATE
```

Sample Analysis on dead bugs



Sample Analysis 1


```
Breakpoint 0 hit
eax=05bf3c38 ebx=00000400 ecx=05db7260 edx=05bf3c33 esi=002be28c edi=00000000
eip=638038d5 esp=002be174 ebp=002be1a4 iopl=0         nv up ei pl nz na po nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00200202
AcroForm!DllUnregisterServer+0x1bd752:
638038d5 8b01            mov     eax,dword ptr [ecx]  ds:0023:05db7260=63bd8d68
```

We did a bit of cheating to avoid huge traces (from that point on til the crash, we would have traced more than 10 million instructions)

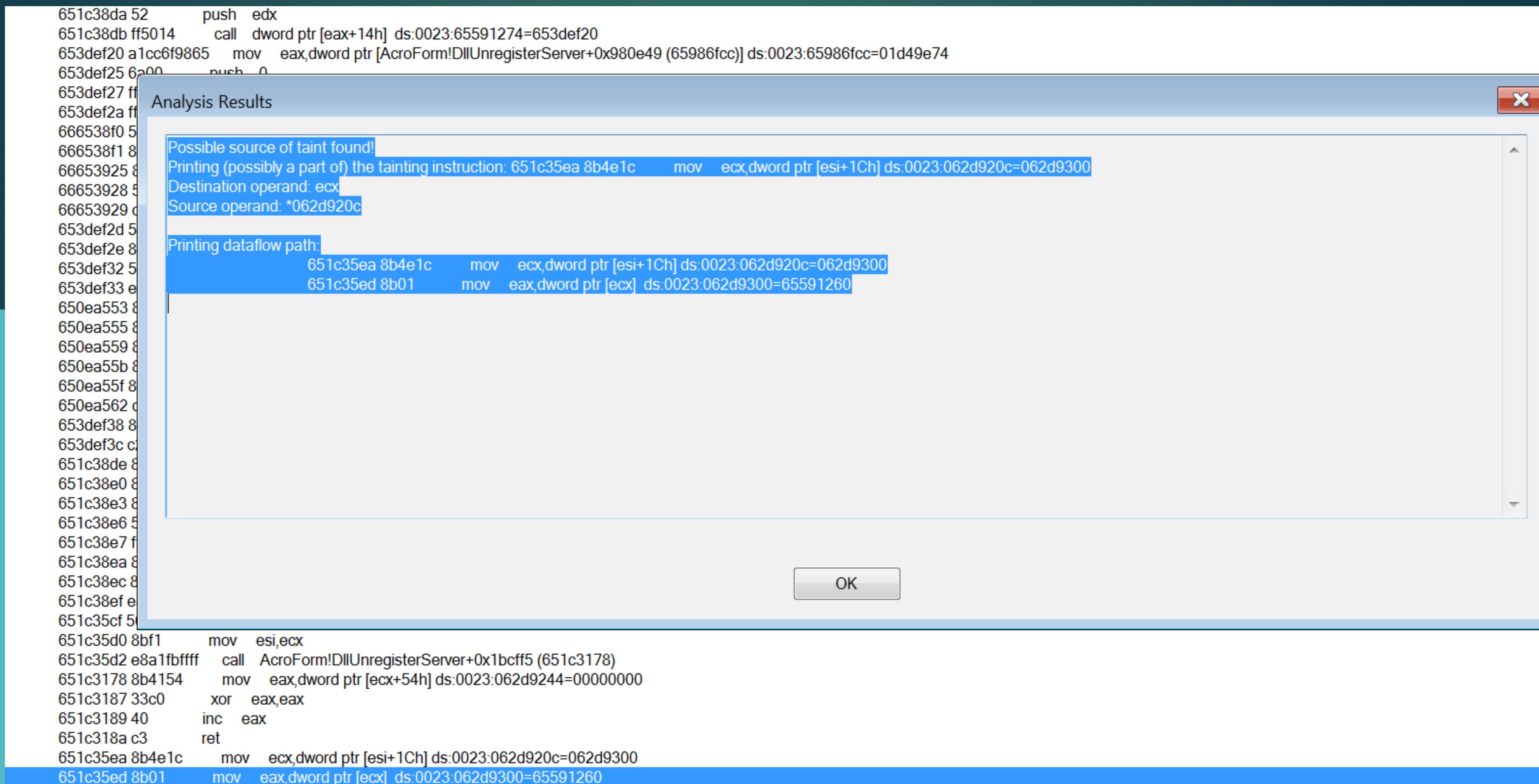
- CVE-2010-0188 – Adobe Reader Libtiff TIFFFetchShortPair Stack-based Buffer Overflow
- TIFF file embedded in a PDF were the IFD Entry has Tag ID (0x0129, 0x0141, 0x0212 or **0x0150**) and Tag Type 3 (short)
- The field data count of the TIFF file will be used as size (dc*2) to copy to a fixed buffer in stack

Contd…


```
0:000> !dptrace_analyzer "\"\"C:\\Users\\rrbranco\\Desktop\\Black Hat 2016\\DPTrace-BlackHat 2016\\Debug\\DPTRACE-GUI.exe\" \"C:\\Users\\rrbranco\\Desktop\\Blac
Args: ""C:\Users\rrbranco\Desktop\Black Hat 2016\DPTrace-BlackHat 2016\Debug\DPTRACE-GUI.exe" "C:\Users\rrbranco\Desktop\Black Hat 2016\DPTrace-BlackHat 2016\Sa

Opening file: C:\Users\rrbranco\Desktop\Black Hat 2016\DPTrace-BlackHat 2016\Sample_output\dptrace-test2.vdt
Processing file...



Instruction: 651c35ed 8b01          mov     eax,dword ptr [ecx]  ds:0023:062d9300=65591260


Dumping instruction taint information:

instr->Src tainted: *062d9300
instr->SrcDep1 tainted: ecx
```

At the crash point, we check the trace to see if the pointer is
Indeed controlled

Contd…



Dataflow information can be visualized in the GUI

Contd…

```
0:000> g
(62c.180): Access violation - code c0000005 (first chance)
First chance exceptions are reported before any exception handling.
This exception may be expected and handled.
eax=424144b7 ebx=00000400 ecx=42414241 edx=00000002 esi=002be28c edi=00000276
eip=638038d5 esp=002be044 ebp=002be074 iopl=0         nv up ei pl nz na pe nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00210206
AcroForm!DllUnregisterServer+0x1bd752:
638038d5 8b01            mov     eax,dword ptr [ecx]  ds:0023:42414241=????????
```

"C:\Program Files\Adobe\Reader 9.0\Reader\AcroRd32.exe" - WinDbg:6.11.0001.404 X86

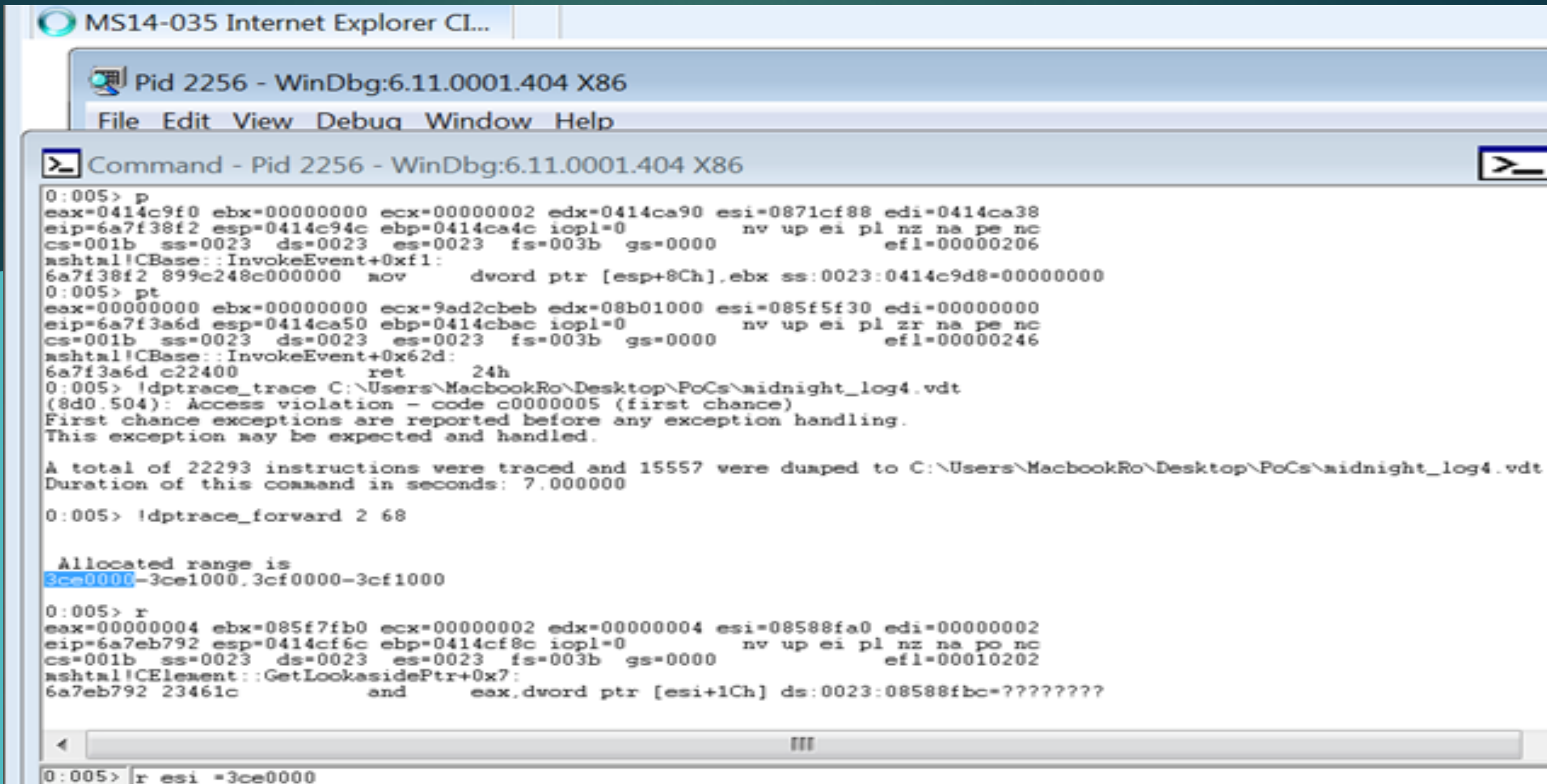
File Edit View Debug Window Help

Command - "C:\Program Files\Adobe\Reader 9.0\Reader\AcroRd32.exe" - WinDbg:6.11.0001.4

```
ModLoad: 10000000 10095000   C:\Program Files\Adobe\Reader 9.0\Reader\cryptocme2.dll
ModLoad: 03760000 037d6000   C:\Program Files\Adobe\Reader 9.0\Reader\ccme_base.dll
ModLoad: 733d0000 733d7000   C:\Program Files\Adobe\Reader 9.0\Reader\viewerps.dll
(274.7b4): C++ EH exception - code e06d7363 (first chance)
ModLoad: 65730000 65dd7000   C:\Program Files\Adobe\Reader 9.0\Reader\plug_ins\PPKLite.api
ModLoad: 6faa0000 6faa7000   C:\Windows\system32\WSOCK32.dll
ModLoad: 768d0000 76905000   C:\Windows\system32\WS2_32.dll
ModLoad: 77350000 77356000   C:\Windows\system32\NSI.dll
ModLoad: 4a800000 4a8a7000   C:\Program Files\Adobe\Reader 9.0\Reader\icucnv36.dll
ModLoad: 4ad00000 4ad17000   C:\Program Files\Adobe\Reader 9.0\Reader\icudt36.dll
ModLoad: 72890000 7289c000   C:\Windows\system32\ATMLIB.dll
ModLoad: 6bea0000 6bf11000   C:\Program Files\Adobe\Reader 9.0\Reader\plug_ins\Accessibility.api
ModLoad: 69660000 696cc000   C:\Program Files\Adobe\Reader 9.0\Reader\AdobeXMP.dll
ModLoad: 686a0000 68707000   C:\Program Files\Adobe\Reader 9.0\Reader\plug_ins\PDDom.api
(274.7b4): Access violation - code c0000005 (first chance)
First chance exceptions are reported before any exception handling.
This exception may be expected and handled.
eax=00000001 ebx=03beb658 ecx=00000001 edx=00000000 esi=004eff60 edi=03beb658
eip=45454443 esp=0030dfec ebp=42414241 iopl=0         nv up ei pl nz na po nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00210202
45454443 ??              ???
```

We indeed control the values (coming from our input file)

Sample Analysis 2



MS14-035 Internet Explorer Cl...

Pid 2256 - WinDbg:6.11.0001.404 X86

File Edit View Debug Window Help

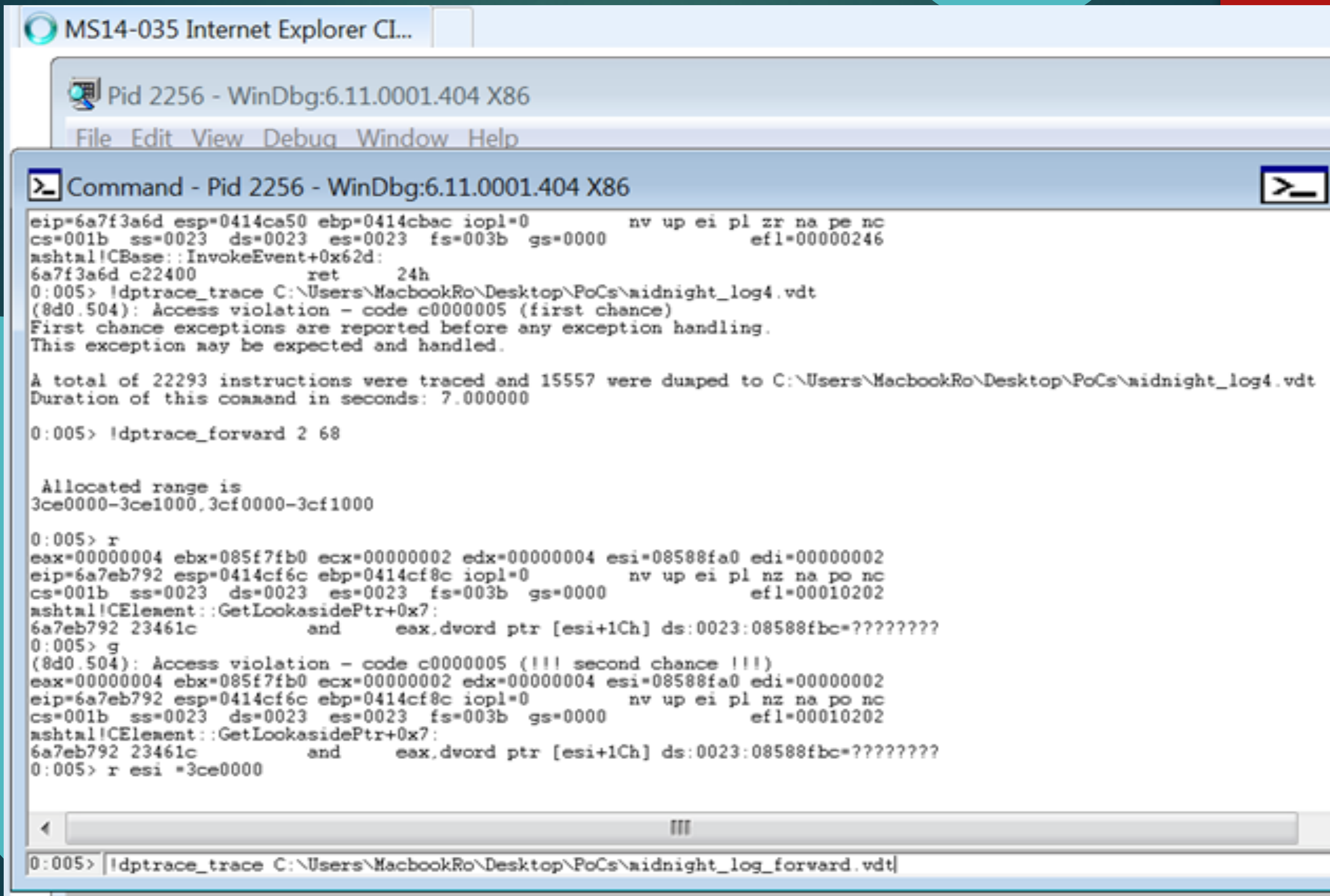
Command - Pid 2256 - WinDbg:6.11.0001.404 X86

```
0:005> p
eax=0414c9f0 ebx=00000000 ecx=00000002 edx=0414ca90 esi=0871cf88 edi=0414ca38
eip=6a7f38f2 esp=0414c94c ebp=0414ca4c iopl=0         nv up ei pl nz na pe nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00000206
mshtml!CBase::InvokeEvent+0xf1:
6a7f38f2 899c248c000000  mov     dword ptr [esp+8Ch],ebx ss:0023:0414c9d8=00000000
0:005> pt
eax=00000000 ebx=00000000 ecx=9ad2cbeb edx=08b01000 esi=085f5f30 edi=00000000
eip=6a7f3a6d esp=0414ca50 ebp=0414cbac iopl=0         nv up ei pl zr na pe nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00000246
mshtml!CBase::InvokeEvent+0x62d:
6a7f3a6d c22400          ret     24h
0:005> !dptrace_trace C:\Users\MacbookRo\Desktop\PoCs\midnight_log4.vdt
(8d0.504): Access violation - code c0000005 (first chance)
First chance exceptions are reported before any exception handling.
This exception may be expected and handled.

A total of 22293 instructions were traced and 15557 were dumped to C:\Users\MacbookRo\Desktop\PoCs\midnight_log4.vdt
Duration of this command in seconds: 7.000000

0:005> !dptrace_forward 2 68


 Allocated range is
3ce0000-3ce1000,3cf0000-3cf1000

0:005> r
eax=00000004 ebx=085f7fb0 ecx=00000002 edx=00000004 esi=08588fa0 edi=00000002
eip=6a7eb792 esp=0414cf6c ebp=0414cf8c iopl=0         nv up ei pl nz na po nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00010202
mshtml!CElement::GetLookasidePtr+0x7:
6a7eb792 23461c          and     eax,dword ptr [esi+1Ch] ds:0023:08588fbc=????????
```

```
0:005> r esi =3ce0000
```

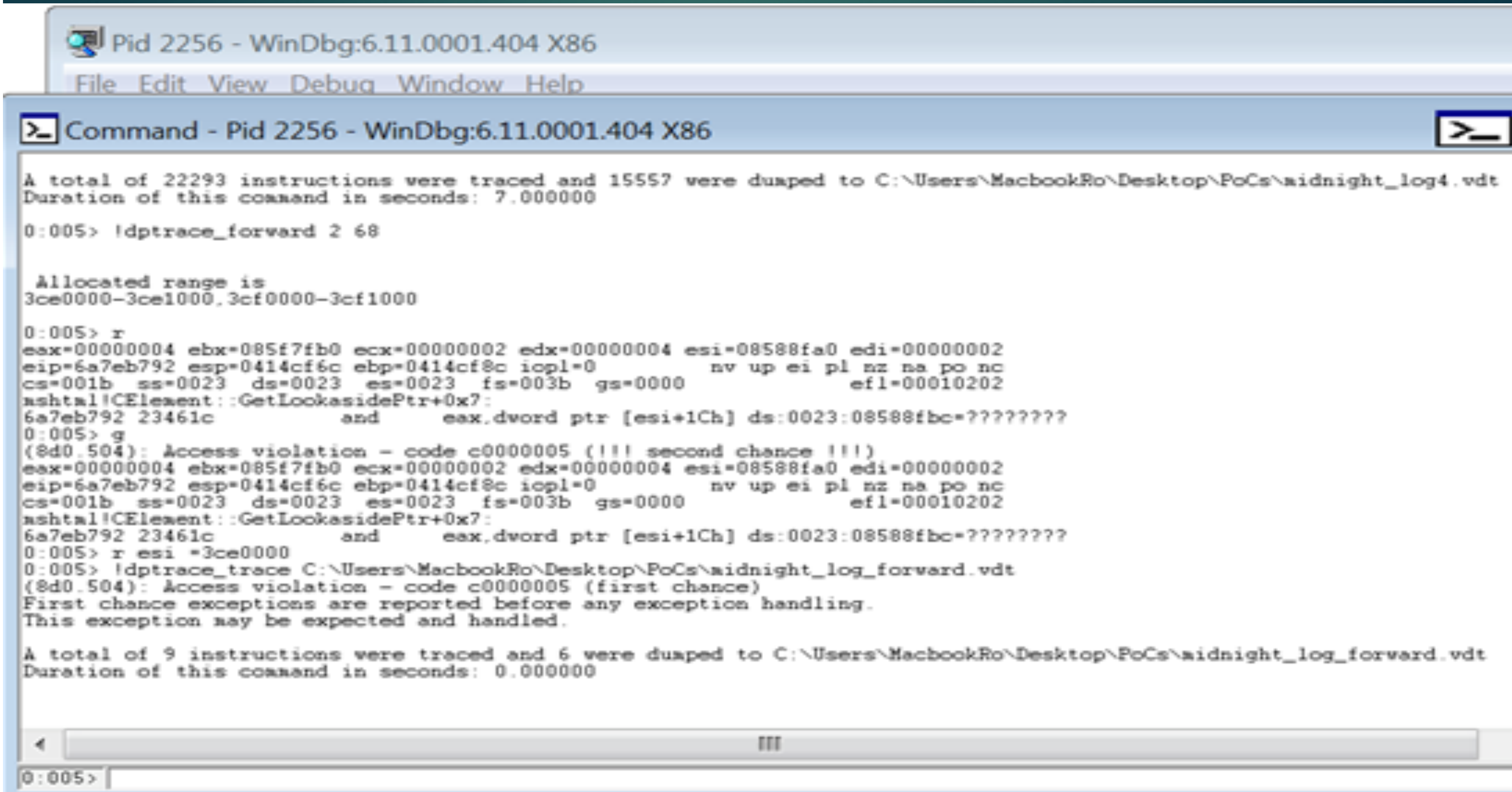
CVE-2014-0282 IE8/9/10/11 ‘Cinput’ Use-After-Free (MS14-035)

Contd...



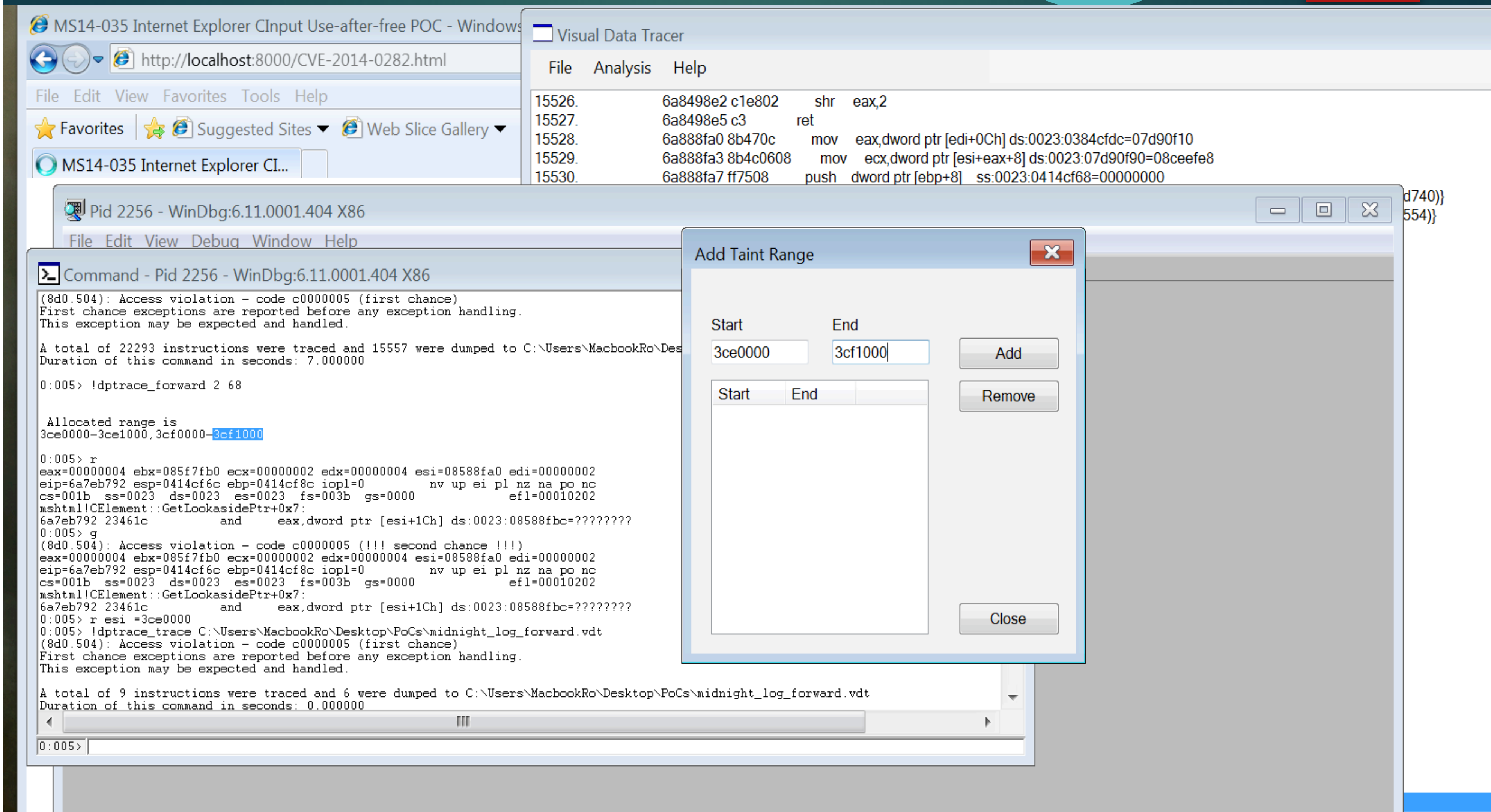
Replace Freed object with the root of the fake object chain

Contd...



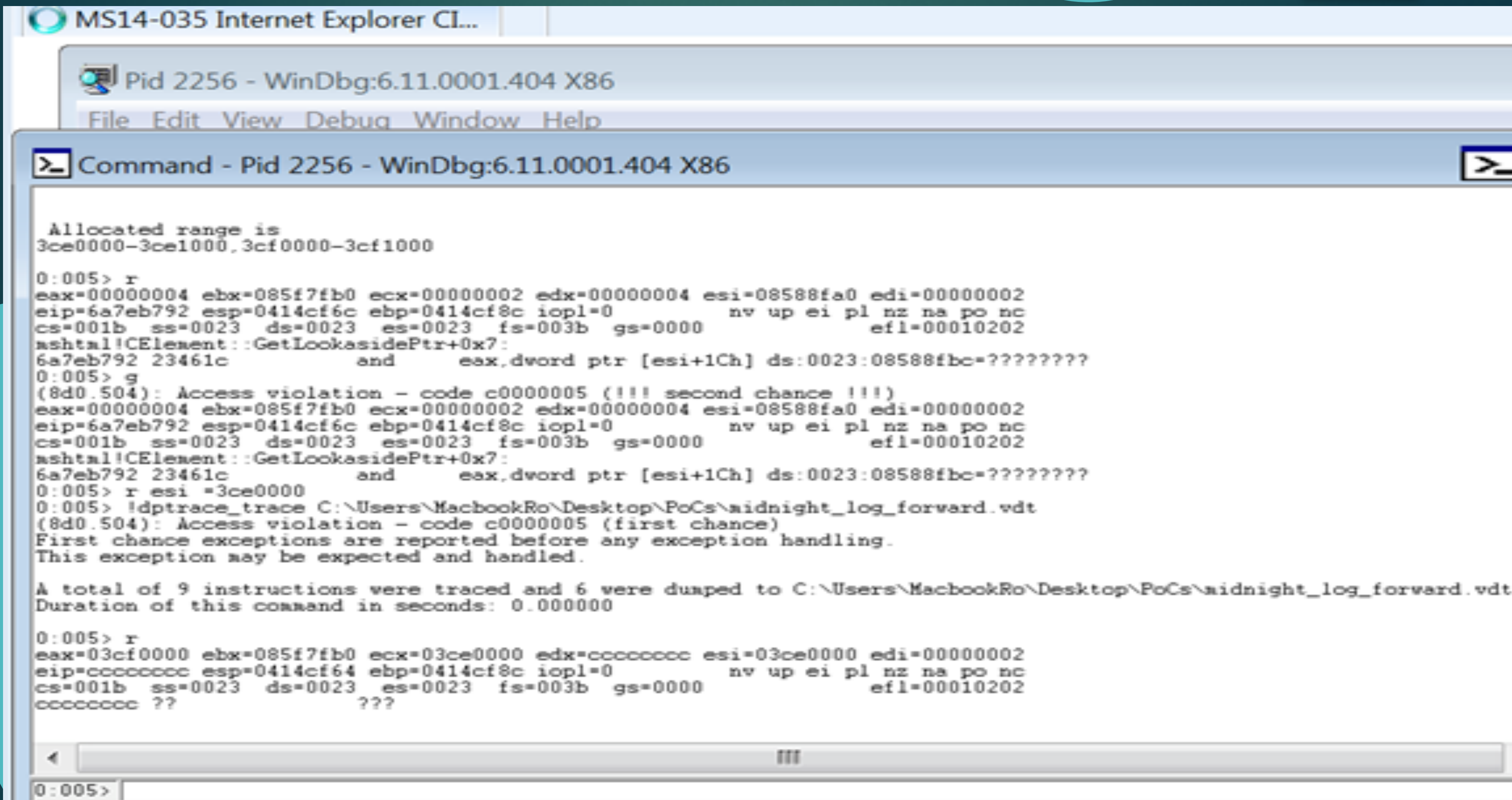
Continue from initial crash and trace each subsequent breakpoint/access violation

Contd...



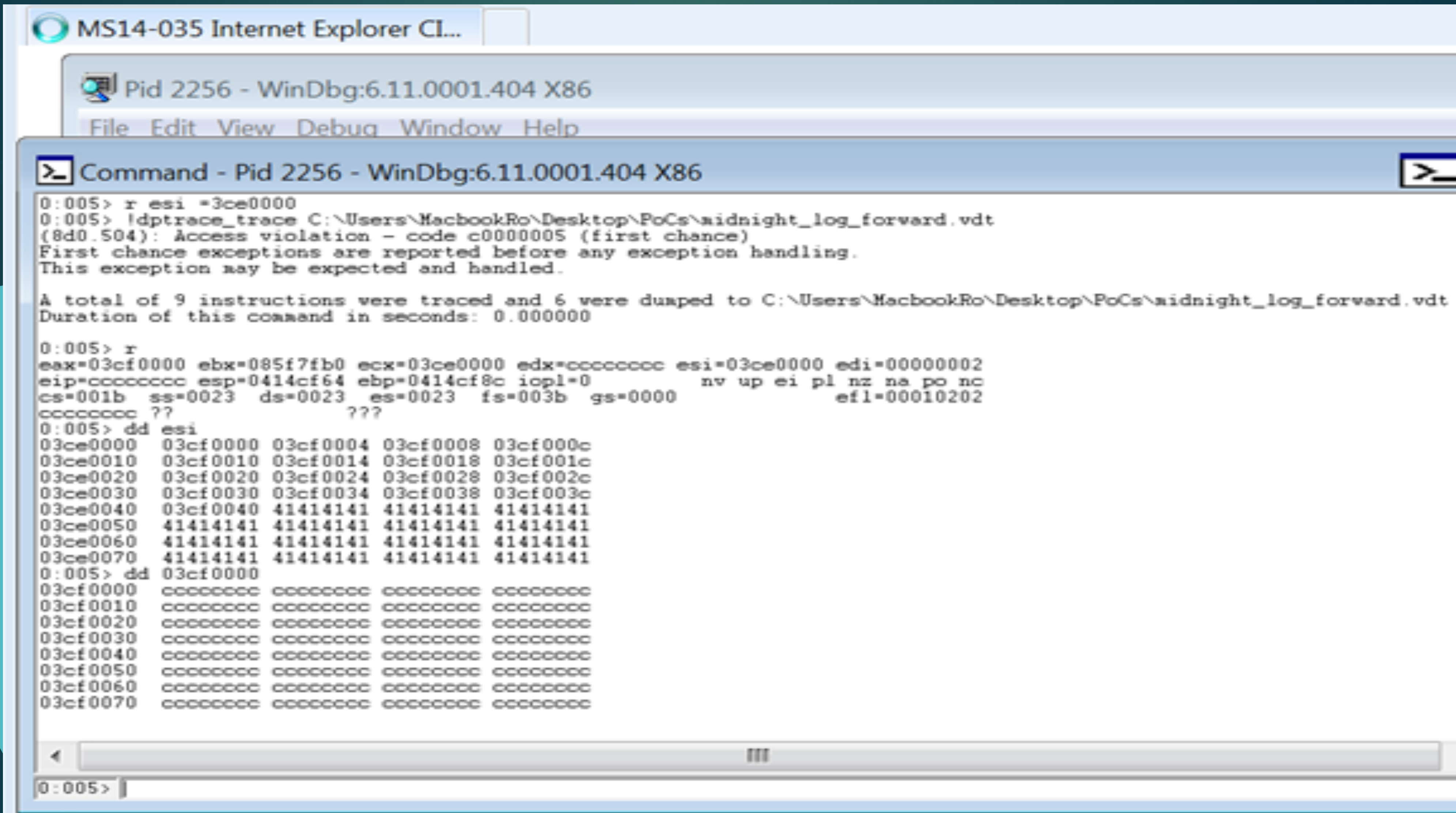
Add the range of the fake allocated objects, so when we look for the taint information on the instruction of interest, we can confirm it is mapped to our controlled memory areas

Contd…



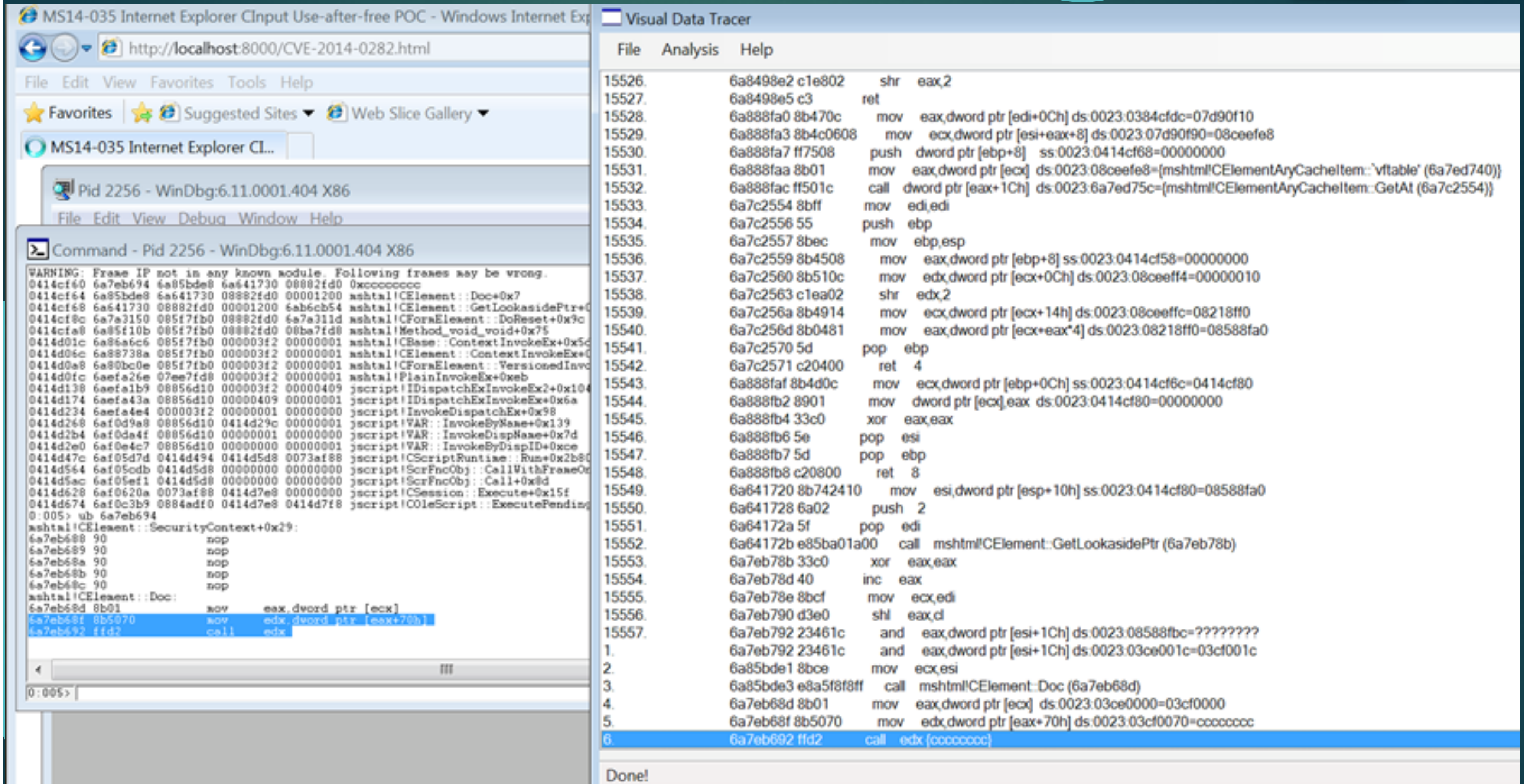
Program Control Immediately evident. We just need to make sure we can point indeed it to our fake structure

Contd...



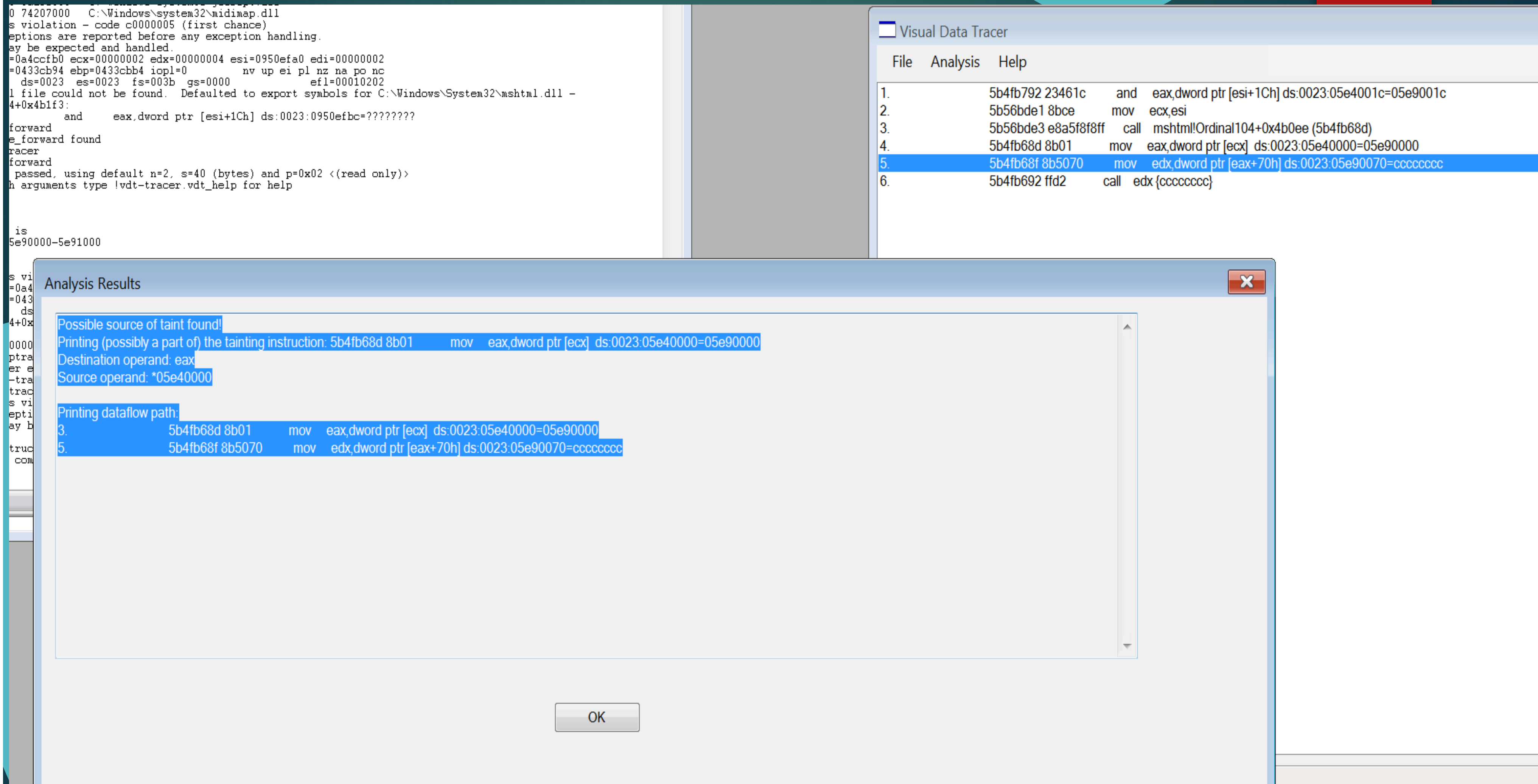
We see that the EIP value at time of crash comes from our fake object allocated at the previous crash

Contd…



Visualize it in the tracer and trace the program control (or directly in the command line of the debugger, shown later)

Contd...



Taint source is confirmed also in the analyzer (visual here). Same thing can be obtained in the command line by !dptrace_analyzer <analyzer_binary> <trace_file> <keep GUI open> <ranges> <index of instruction to check the taint of>

Contd...


```
Unloading dptracer extension DLL
0:004> !dptrace_trace C:\Users\MacbookRo\Desktop\PoCs\log_again4.vdt
WARNING: This break is not a step/trace completion.
The last command has been cleared to prevent
accidental continuation of this unrelated event.
Check the event, location and thread before resuming.
(f54.e4): Break instruction exception - code 80000003 (first chance)

A total of 677415 instructions were traced and 455209 were dumped to C:\Users\MacbookRo\Desktop\PoCs\log_again4.vdt
Duration of this command in seconds: 205.000000

0:012> r
eax=7ffdc000 ebx=00000000 ecx=00000000 edx=77c7f125 esi=00000000 edi=00000000
eip=77c140f0 esp=051dfa5c ebp=051dfa88 iopl=0         nv up ei pl zr na pe nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00000246
ntdll!DbgBreakPoint:
77c140f0 cc               int     3
0:012> g
eax=00000000 ebx=0c05af20 ecx=00000003 edx=0a85af78 esi=5b50fbec edi=5b505164
eip=5b50fc19 esp=0439c964 ebp=0439c96c iopl=0         ov up ei pl nz ac pe nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00000a16
mshtml!PlainQueryInterface+0x1f:
5b50fc19 8b4508           mov     eax,dword ptr [ebp+8] ss:0023:0439c974=05a2afd8
0:004> g
Breakpoint 0 hit
eax=5b498bb8 ebx=0a2c0fb0 ecx=00000002 edx=00000004 esi=08310f88 edi=00000002
eip=5b35173a esp=0439cae0 ebp=0439cafc iopl=0         nv up ei pl zr na pe nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00000246
mshtml!CFormElement::DoReset+0xe2:
5b35173a 8bce             mov     ecx,esi
0:004> !dptrace_trace C:\Users\MacbookRo\Desktop\PoCs\log_again5.vdt
(f54.918): Access violation - code c0000005 (first chance)
First chance exceptions are reported before any exception handling.
This exception may be expected and handled.

A total of 891392 instructions were traced and 618734 were dumped to C:\Users\MacbookRo\Desktop\PoCs\log_again5.vdt
Duration of this command in seconds: 266.000000

0:004> r
eax=00000004 ebx=0a2c0fb0 ecx=00000002 edx=00000004 esi=0b491fa0 edi=00000002
eip=5b4fb792 esp=0439cadc ebp=0439cafc iopl=0         nv up ei pl nz na po nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00010202
mshtml!CElement::GetLookasidePtr+0x7:
5b4fb792 23461c           and     eax,dword ptr [esi+1Ch] ds:0023:0b491fbc=????????
```

Because the backward taint analysis demand tracing the process, so we can later construct the BFS analysis, it is important to use intelligently/diligently. In the case of this issue, we use to analyze a part of the execution, instead of the initial crash.

Contd…

Pid 1896 - WinDbg:6.11.0001.404 X86

File Edit View Debug Window Help

Command

```
ModLoad: 743e0000 743e7000   C:\Windows\system32\AVRT.dll
ModLoad: 73500000 73536000   C:\Windows\system32\AUDIOSES.DLL
ModLoad: 734f0000 734f8000   C:\Windows\system32\msacm32.drv
ModLoad: 734d0000 734e4000   C:\Windows\system32\MSACM32.dll
ModLoad: 734c0000 734c7000   C:\Windows\system32\midimap.dll
ModLoad: 5d920000 5d9d2000   C:\Windows\System32\jscript.dll
(768.988): Access violation - code c0000005 (first chance)
First chance exceptions are reported before any exception handling.
This exception may be expected and handled.
eax=00000004 ebx=0aac5fb0 ecx=00000002 edx=00000004 esi=0a844fa0 edi=00000002
eip=08a3b792 esp=043dcb4c ebp=043dcb6c iopl=0         nv up ei pl nz na po nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00010202
*** ERROR: Symbol file could not be found.  Defaulted to export symbols for C:\Windows\System32\mshtml.dll -
mshtml!Ordinal104+0x4b1f3:
08a3b792 23461c          and     eax,dword ptr [esi+1Ch] ds:0023:0a844fbc=????????
0:005> g
(768.988): Access violation - code c0000005 (!!! second chance !!!)
eax=00000004 ebx=0aac5fb0 ecx=00000002 edx=00000004 esi=0a844fa0 edi=00000002
eip=08a3b792 esp=043dcb4c ebp=043dcb6c iopl=0         nv up ei pl nz na po nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00010202
mshtml!Ordinal104+0x4b1f3:
08a3b792 23461c          and     eax,dword ptr [esi+1Ch] ds:0023:0a844fbc=????????
0:005> !dptrace_forward 4 200
No export dptrace_forward found
0:005> .load dptracer
0:005> !dptrace_forward 4 200


 Allocated range is
5880000-5881000,5890000-5891000,58a0000-58a1000,58b0000-58b1000

0:005> r esi=5880000
0:005> r
eax=00000004 ebx=0aac5fb0 ecx=00000002 edx=00000004 esi=05880000 edi=00000002
eip=08a3b792 esp=043dcb4c ebp=043dcb6c iopl=0         nv up ei pl nz na po nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00010202
mshtml!Ordinal104+0x4b1f3:
08a3b792 23461c          and     eax,dword ptr [esi+1Ch] ds:0023:0588001c=0589001c
0:005> !dptrace_trace C:\Users\MacbookRo\Desktop\PoCs\log_final2.vdt
(768.988): Access violation - code c0000005 (first chance)
First chance exceptions are reported before any exception handling.
This exception may be expected and handled.

A total of 9 instructions were traced and 6 were dumped to C:\Users\MacbookRo\Desktop\PoCs\log_final2.vdt
Duration of this command in seconds: 0.000000
```

Contd...

Pid 1896 - WinDbg:6.11.0001.404 X86

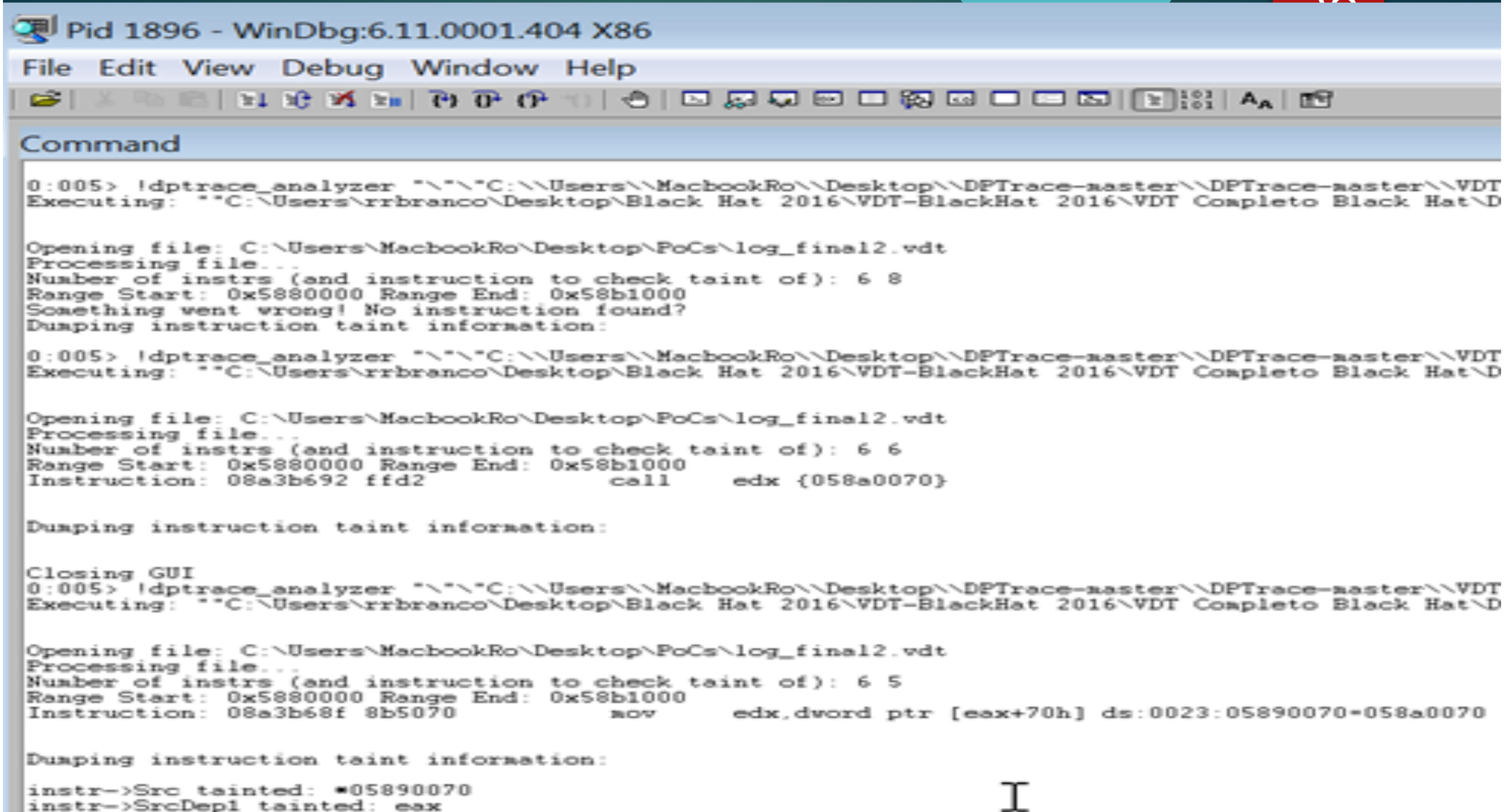
File Edit View Debug Window Help

Command

```
ModLoad: 743e0000 743e7000   C:\Windows\system32\AVRT.dll
ModLoad: 73500000 73536000   C:\Windows\system32\AUDIOSES.DLL
ModLoad: 734f0000 734f8000   C:\Windows\system32\msacm32.drv
ModLoad: 734d0000 734e4000   C:\Windows\system32\MSACM32.dll
ModLoad: 734c0000 734c7000   C:\Windows\system32\midimap.dll
ModLoad: 5d920000 5d9d2000   C:\Windows\System32\jscript.dll
(768.988): Access violation - code c0000005 (first chance)
First chance exceptions are reported before any exception handling.
This exception may be expected and handled.
eax=00000004 ebx=0aac5fb0 ecx=00000002 edx=00000004 esi=0a844fa0 edi=00000002
eip=08a3b792 esp=043dcb4c ebp=043dcb6c iopl=0         nv up ei pl nz na po nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00010202
*** ERROR: Symbol file could not be found.  Defaulted to export symbols for C:\Windows\System32\mshtml.dll -
mshtml!Ordinal104+0x4b1f3:
08a3b792 23461c          and     eax,dword ptr [esi+1Ch] ds:0023:0a844fbc=????????
0:005> g
(768.988): Access violation - code c0000005 (!!! second chance !!!)
eax=00000004 ebx=0aac5fb0 ecx=00000002 edx=00000004 esi=0a844fa0 edi=00000002
eip=08a3b792 esp=043dcb4c ebp=043dcb6c iopl=0         nv up ei pl nz na po nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00010202
mshtml!Ordinal104+0x4b1f3:
08a3b792 23461c          and     eax,dword ptr [esi+1Ch] ds:0023:0a844fbc=????????
0:005> !dptrace_forward 4 200
No export dptrace_forward found
0:005> .load dptracer
0:005> !dptrace_forward 4 200


 Allocated range is
5880000-5881000,5890000-5891000,58a0000-58a1000,58b0000-58b1000

0:005> r esi=5880000
0:005> r
eax=00000004 ebx=0aac5fb0 ecx=00000002 edx=00000004 esi=05880000 edi=00000002
eip=08a3b792 esp=043dcb4c ebp=043dcb6c iopl=0         nv up ei pl nz na po nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00010202
mshtml!Ordinal104+0x4b1f3:
08a3b792 23461c          and     eax,dword ptr [esi+1Ch] ds:0023:0588001c=0589001c
0:005> !dptrace_trace C:\Users\MacbookRo\Desktop\PoCs\log_final2.vdt
(768.988): Access violation - code c0000005 (first chance)
First chance exceptions are reported before any exception handling.
This exception may be expected and handled.

A total of 9 instructions were traced and 6 were dumped to C:\Users\MacbookRo\Desktop\PoCs\log_final2.vdt
Duration of this command in seconds: 0.000000

0:005> !dptrace_analyzer "\"\"C:\\Users\\MacbookRo\\Desktop\\DPTrace-master\\DPTrace-master\\VDT Completo Black Hat2\\Debug\ \DPTRACE-GUI.exe\" \"C:\\Users\\MacbookRo\\Desktop\\PoCs
```

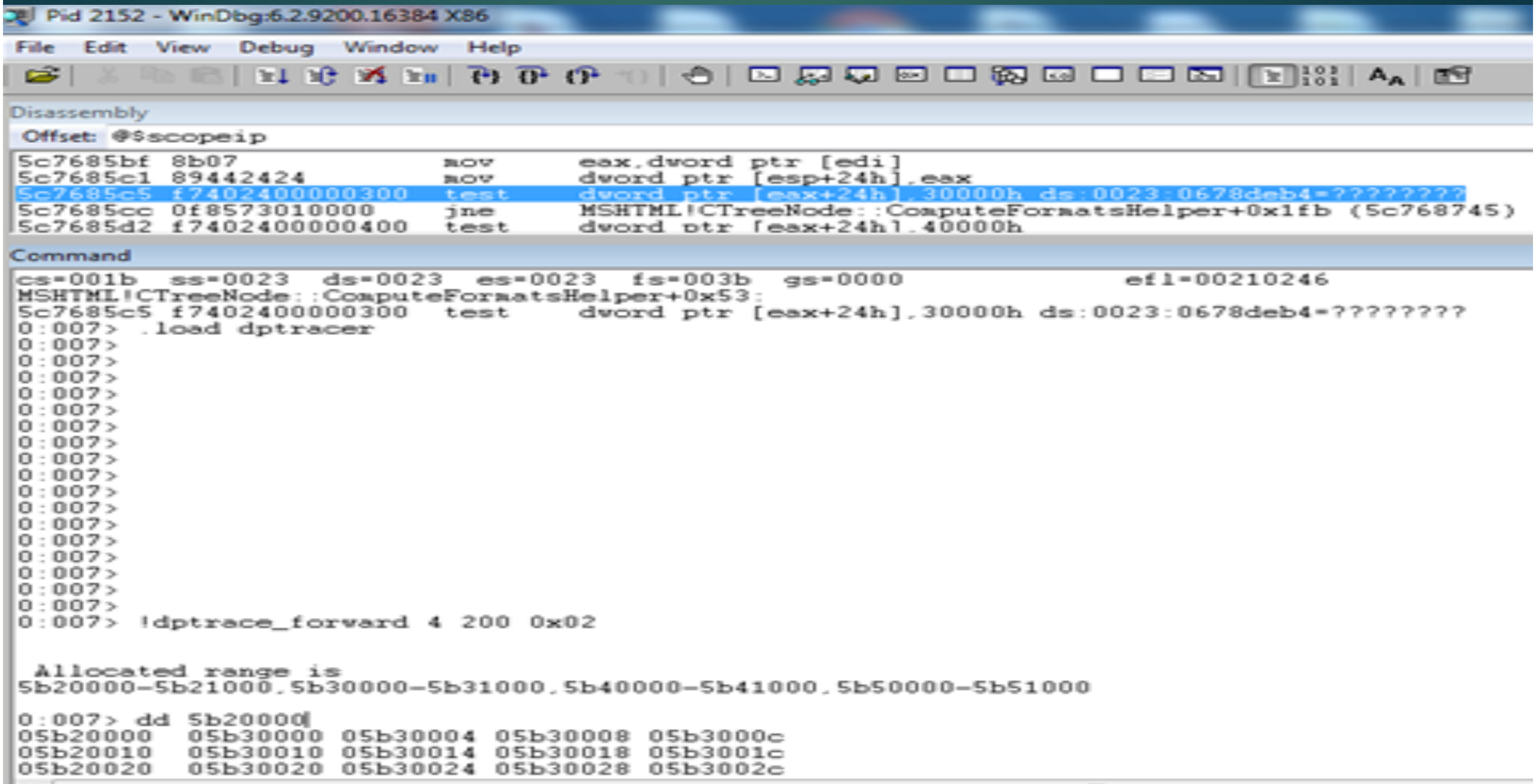
Ln 0, Col 0 | Sys 0:<Local> | Proc 000:768 | Thrd 005:988 | ASM | OVR | CAPS | NUM

Contd...



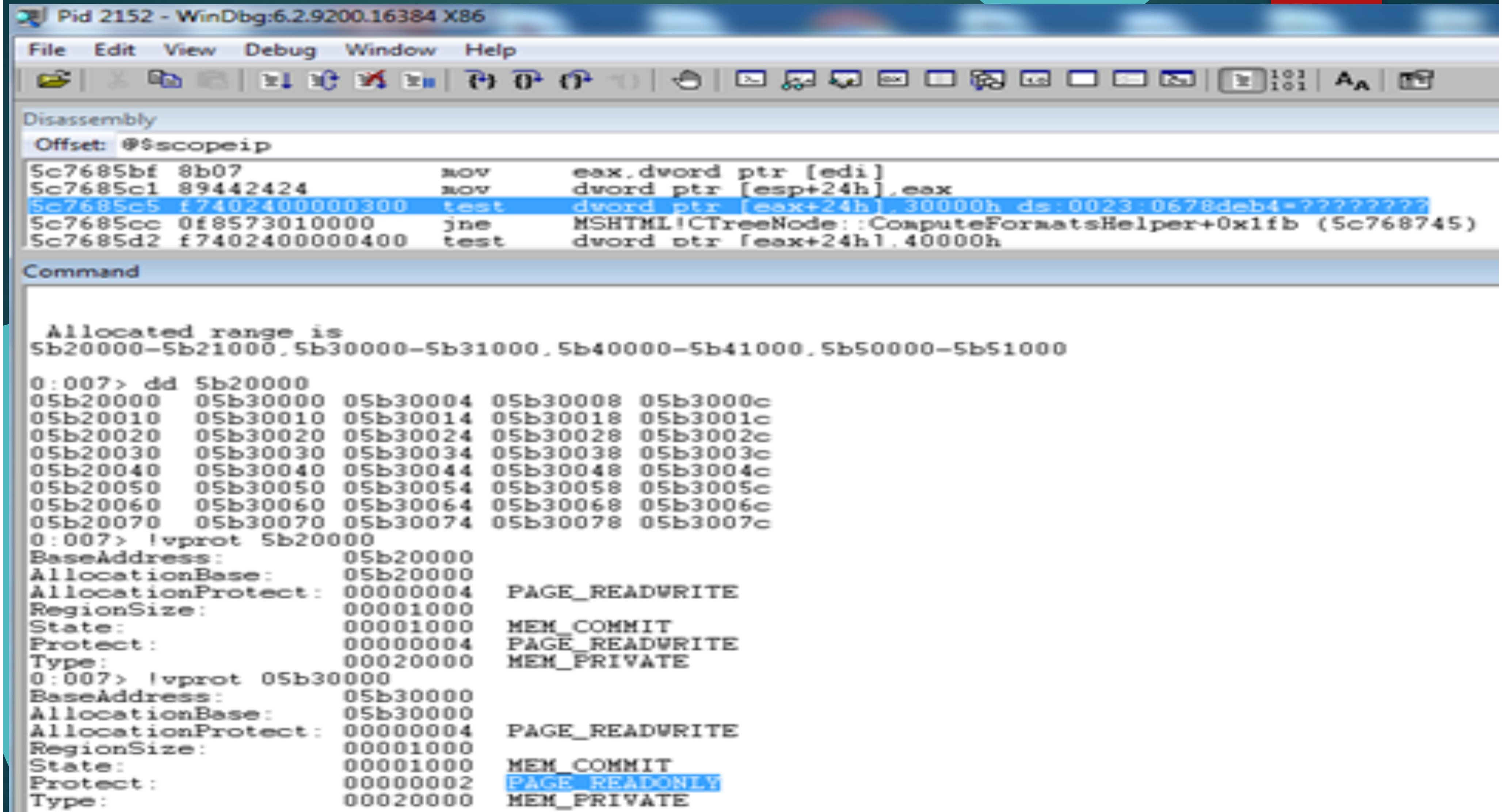
Everything that was done using the GUI (setting the taint ranges, defining the instruction of interest and analyzing its taint information) is possible to do via the command-line of the debugger, as shown here

Sample Analysis 3



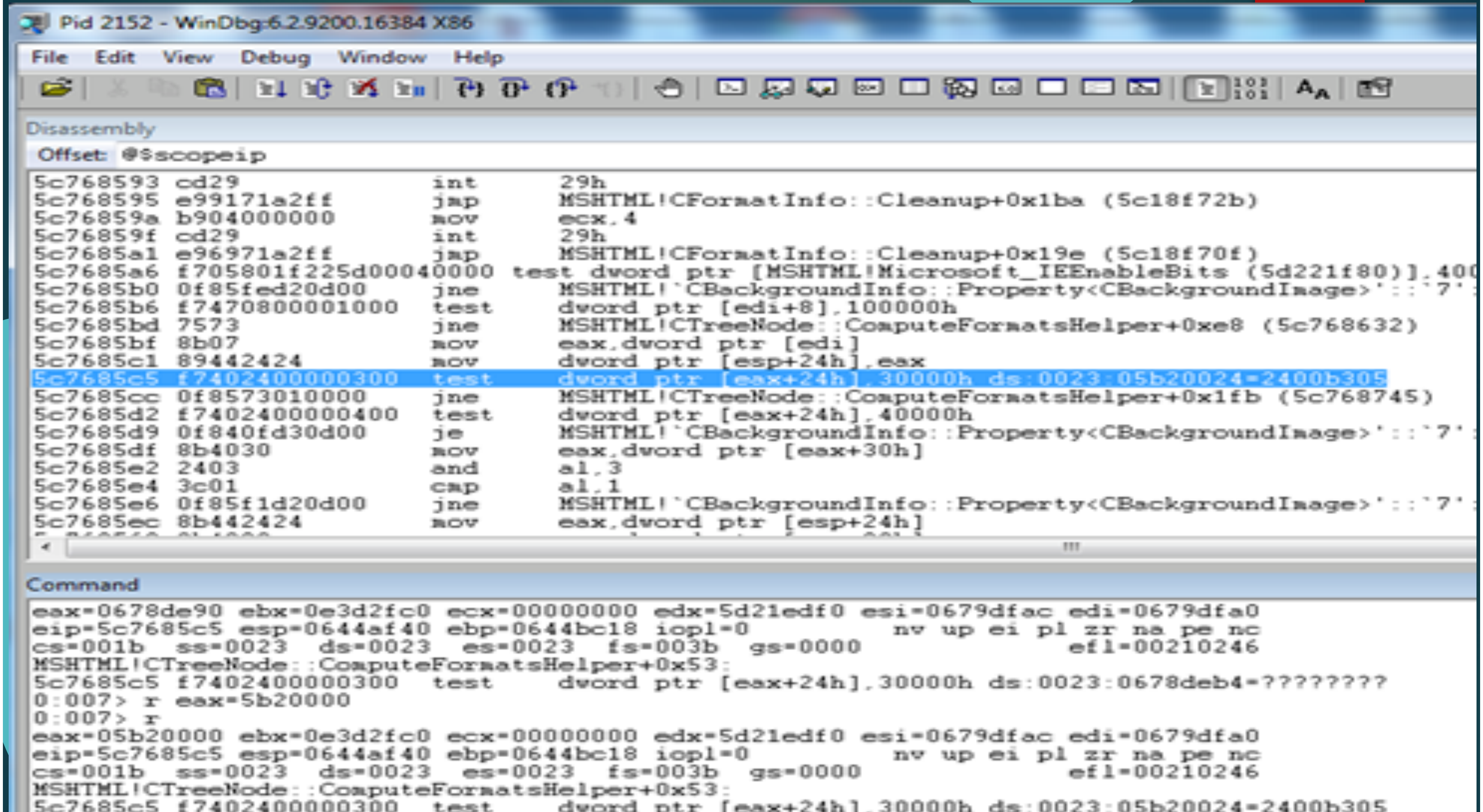
CVE-2015-6152 IE 11 CObjectElement Use-After-Free . Initial Crash on IE 11 without patches.

Contd...



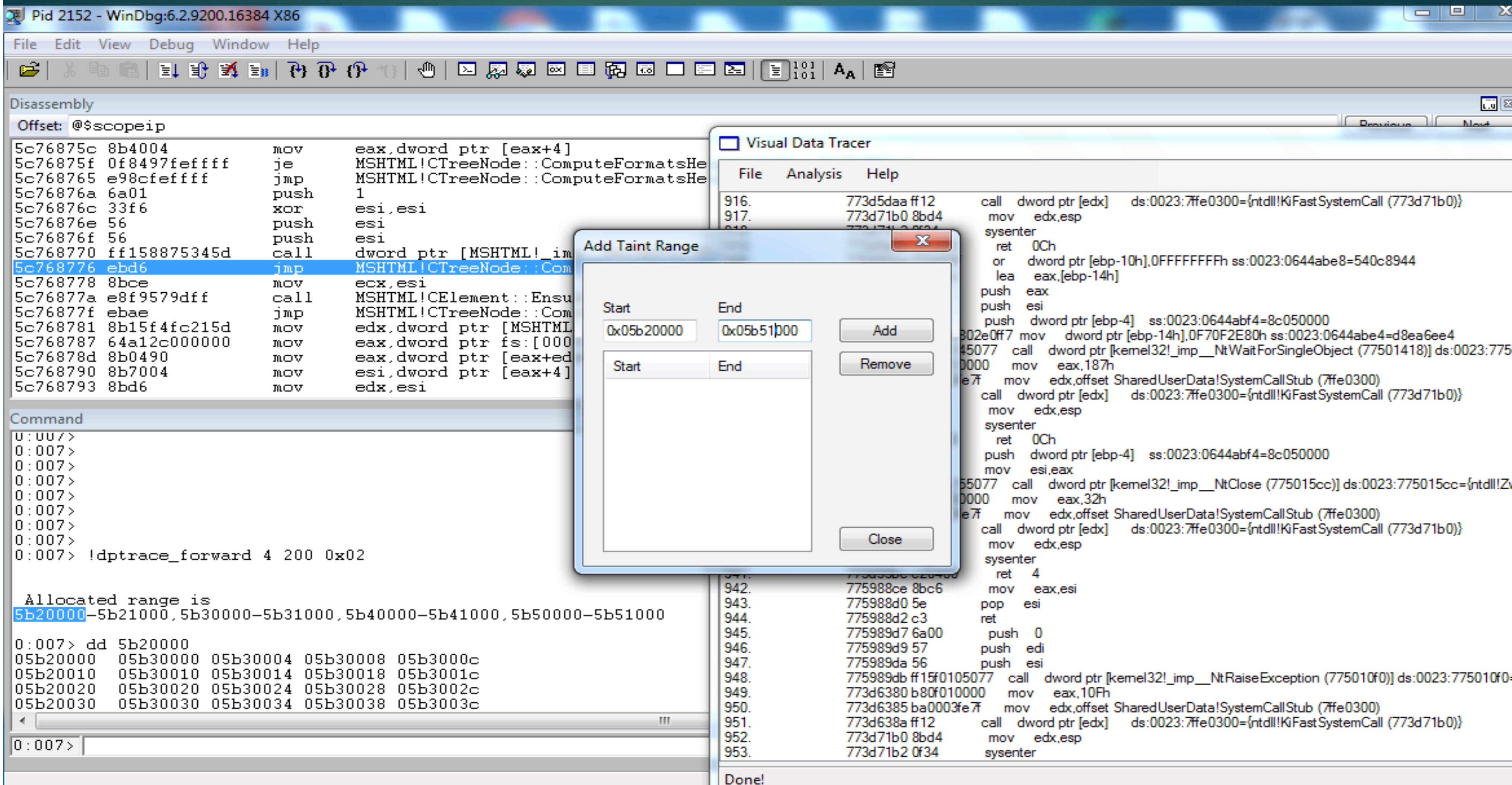
Fake object chain of 4 objects of size 200. Precise size can be determined by manual analysis to figure out the freed/alloc'd function and checking the size of the root object.

Contd…



'Redefine' the reference to freed reference (eax) with the first fake object . Continue the execution with !dptrace_trace and monitor the forward trace .

Contd...



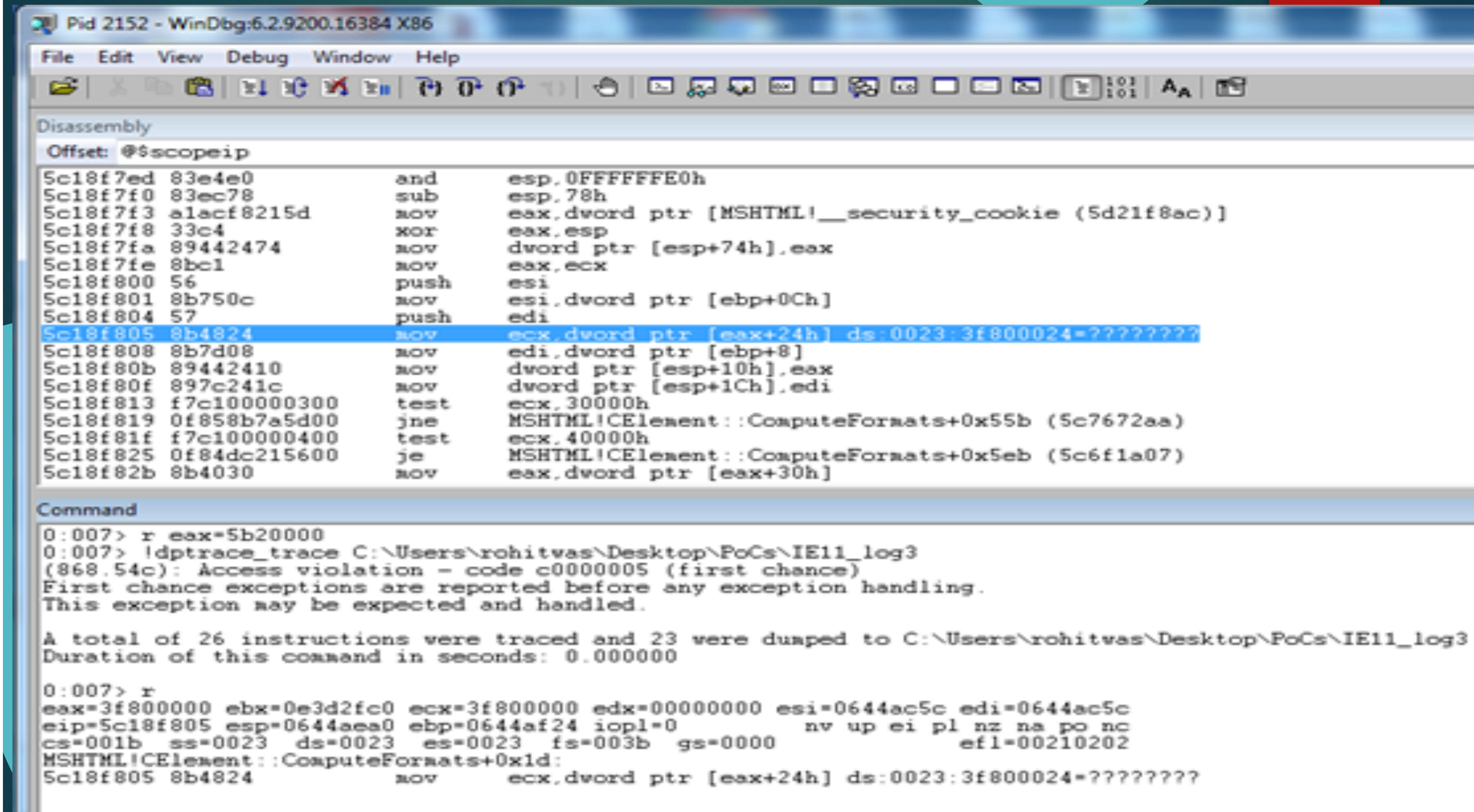
Add taint range and check to see if the source of an access violation can be traced back to controlled input

Contd...

```
0:007> ed eax+24 300
0:007> r
eax=05ba0000 ebx=0ea4bfc0 ecx=00000000 edx=5d36edf0 esi=0616ffac edi=0616ffa0
eip=5c8b85c5 esp=05e1b320 ebp=05e1bfe8 iopl=0         nv up ei pl zr na pe nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00010246
MSHTML!CTreeNode::ComputeFormatsHelper+0x53:
5c8b85c5 f7402400000300  test    dword ptr [eax+24h],30000h ds:0023:05ba0024=00030000
```

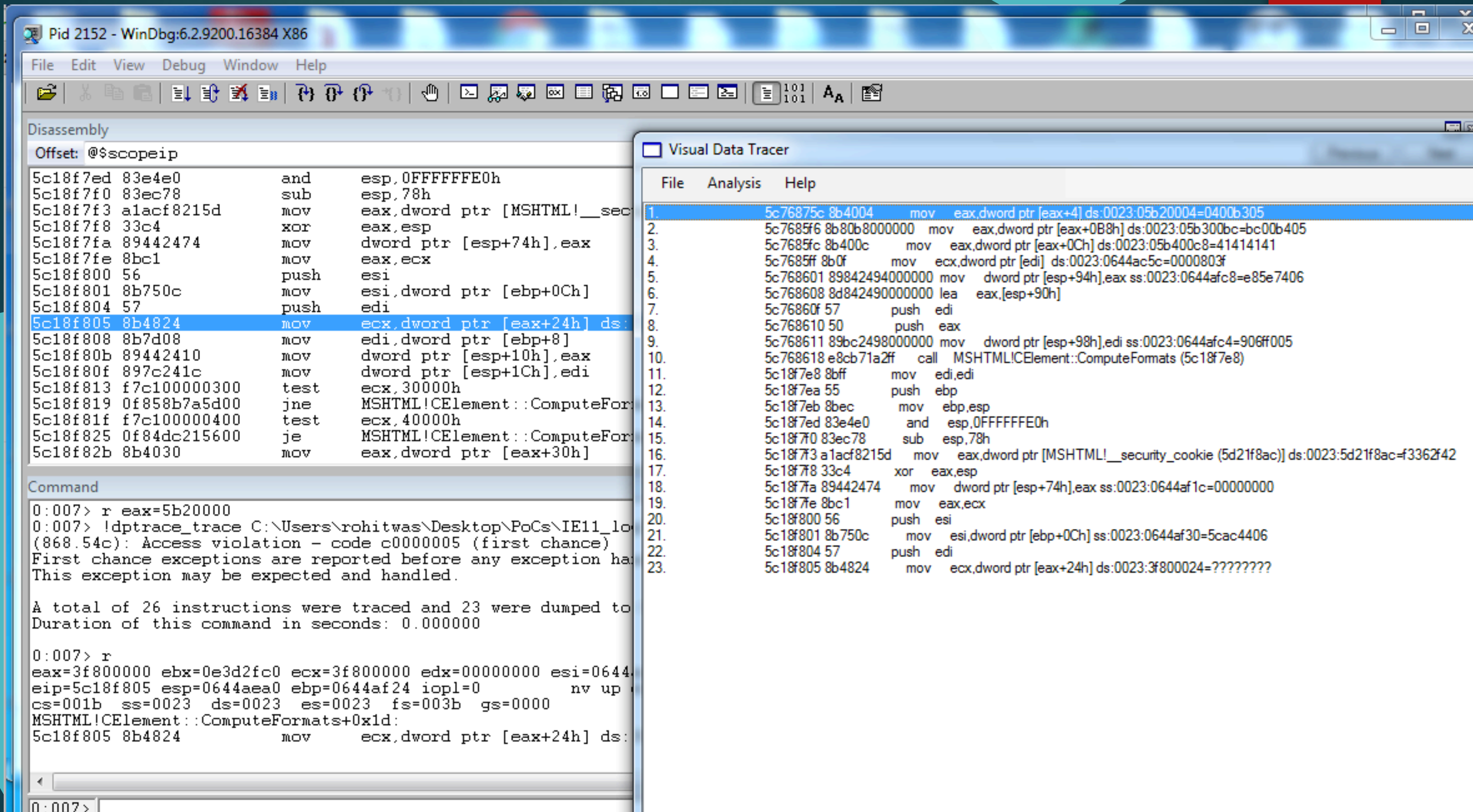
Following another path by meeting a new constraint

Contd...



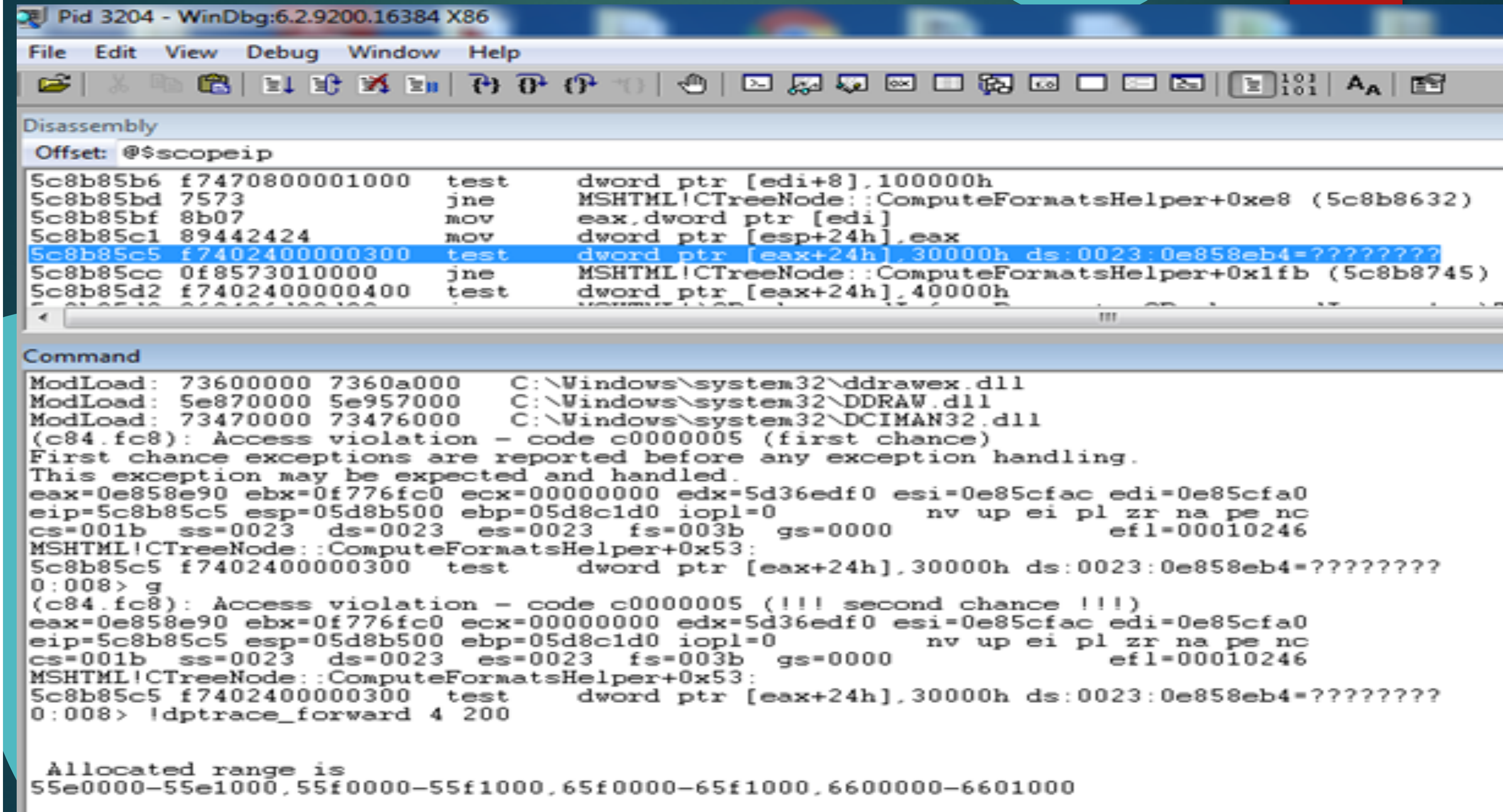
More constraints

Contd…



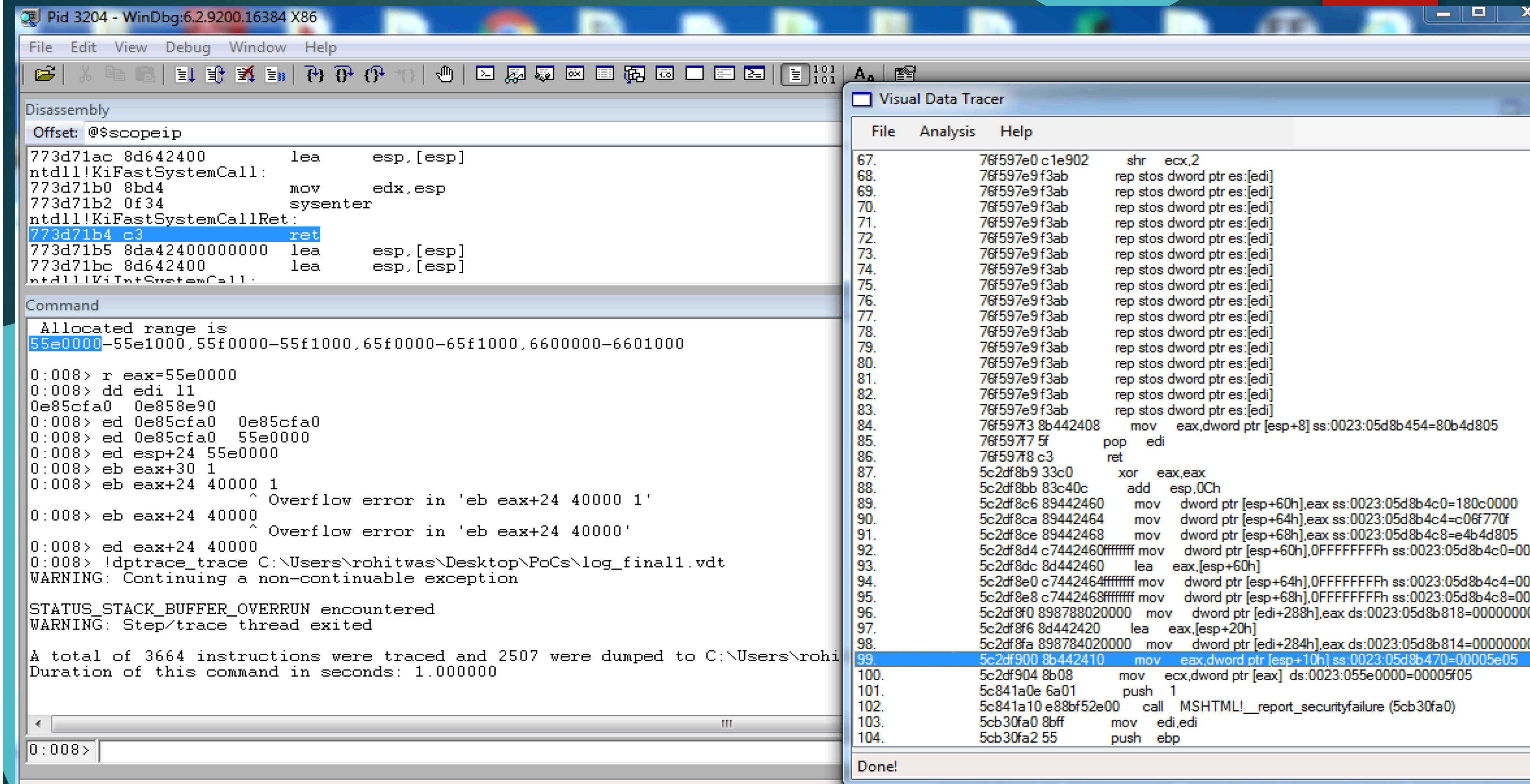
Checking the taint source again. This particular execution run leads us to uncertainty and we aren't sure of an exploitable primitive yet.

Contd...



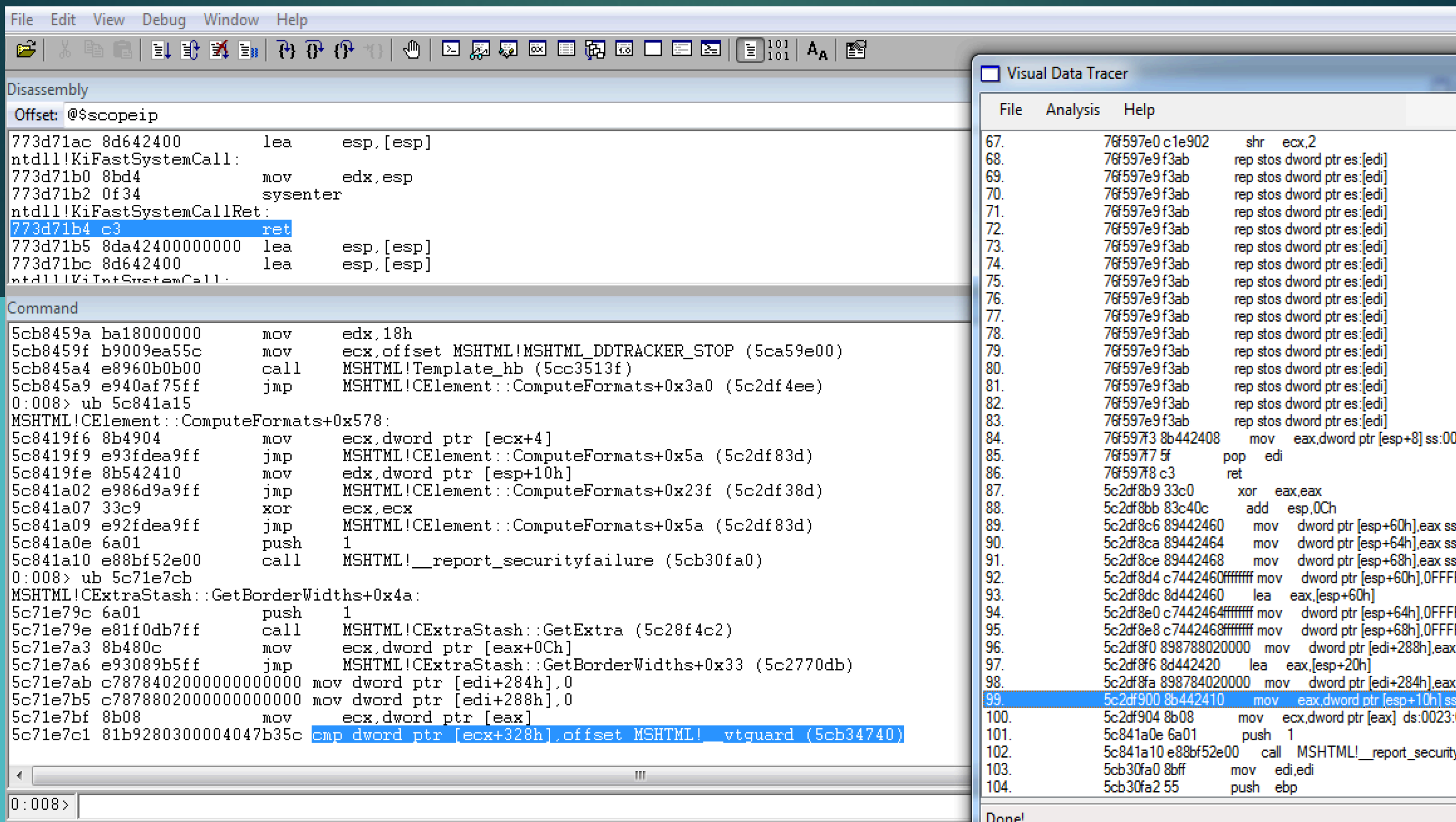
So we carry on another execution while trying to meet some other constraints and hit an alternate code path this time.

Contd…



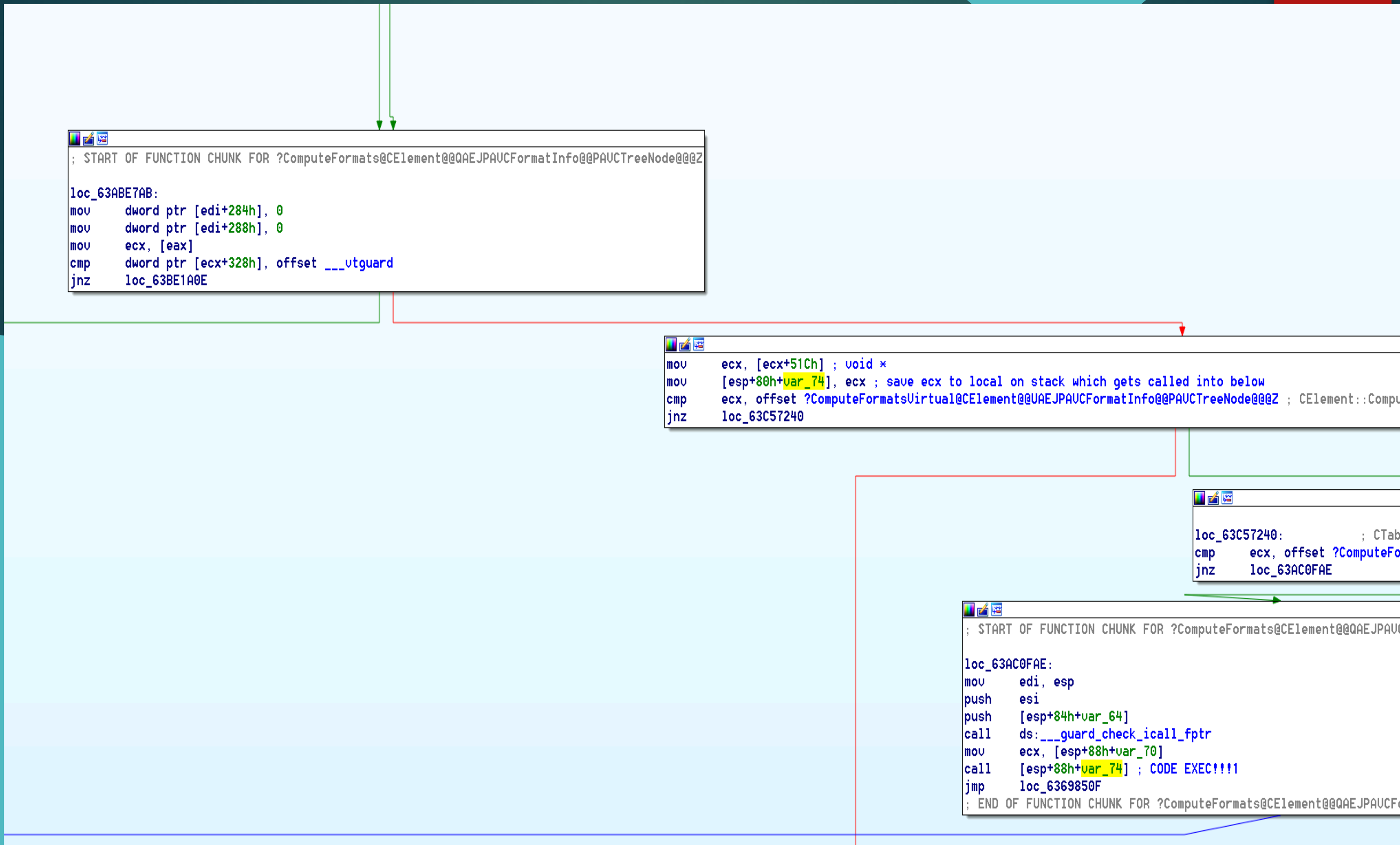
We try another path this time by crafting some different values within the fake object, notably the value of 0x40000 in the dword @ fake_object+0x24. We also modify references to the same fake object in edi (CTreeNode *) and on the stack (esp+24). Hit a more interesting exception!

Contd...



Preliminary analysis shows us that the MSHTML!!report_securityfailure call was triggered due to a failed VTguard_check (next figure)

Contd...



Confirm taint control and we influence the pointer which is dereferenced to do the vtguard check. That there is code execution right after the vtguard_check can either be looked into the debugger or within IDA for more clarity as shown above

Challenges & Limitations

- Determining the actual range of memory which needs to be traced. Determining this is easier for some cases (like file format bugs) whereas for browser based bugs this can be difficult (and sometimes unnecessary)
- Explosion and partial tainting (we assume full control when merging taint)
- Because the tracer outputs instruction information, it needs to understand the semantics of it (for example, source and destination operands):
  - It only supports the most basic x86 subset (no x87, MMX, XMM, etc) (future versions , also, helping is caring!)

Challenges & Limitations

- Another limitation of the approach is covering conditional code paths that hit only on certain values expected to be in the memory address (checking of reference counters, object type tag or some other metadata that affects the control flow of the program after the crash point)
  - Branch Explosion! Similar problems can arise with symbolic execution approach

- Manual analysis involves knowing where to break , where to start tracing, etc. The closer to the exception the better because of smaller traces and faster processing time by the analyzer

- Not a magic solution that works on its own without a skilled analyst. Not a one size fits all solution either. Meant to augment crash analysis.

Future

- We aren’t soothsayers. More like sooth-slayers \,,/
- Please, read TODO.txt in the code trunk and send pull requests :p

Latest version of this presentation, paper, code and demos available at:

- https://github.com/rrbranco/blackhat2016

Acknowledgments

- Julio Auto for his previous work alongside one of the authors of this work (Rodrigo Branco) in implementing VDT (Vulnerability Data tracer) which was the original implementation of the backward taint tracing plugin
- David D. Rude(@bannedit) and Kiran Bandla(@kb) for ideas and feedback regarding the initial prototype of the forward trace
  - **All of the other researchers who contributed to this field!**

Thanks!

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