Defeating the Transparency Features of Dynamic Binary Instrumentation

The detection of DynamoRIO through introspection

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About us

- Xiaoning
  - Security Researcher
- Kang
  - College Educator

What is Instrumentation

Some Random Piece of Code **(from QEMU)**

```
…

    if (size < sizeof(min_buf)) {


         iov_to_buf(iov, iovcnt, 0, min_buf, size);
         memset(&min_buf[size], 0, sizeof(min_buf) - size);

    } else if (iov->iov_len < MAXIMUM_ETHERNET_HDR_LEN) {


         /* This is very unlikely, but may happen. */
         iov_to_buf(iov, iovcnt, 0, min_buf,
                 MAXIMUM_ETHERNET_HDR_LEN);
         filter_buf = min_buf;
    }
…
```

What is Instrumentation

Some Random Piece of Code **(from QEMU)**

```
…

    if (size < sizeof(min_buf)) {

                          ←  printf("good size branch \n");

        iov_to_buf(iov, iovcnt, 0, min_buf, size);
        memset(&min_buf[size], 0, sizeof(min_buf) - size);

    } else if (iov->iov_len < MAXIMUM_ETHERNET_HDR_LEN) {

                          ←  printf("got a rare case \n");

        /* This is very unlikely, but may happen. */
        iov_to_buf(iov, iovcnt, 0, min_buf,
                   MAXIMUM_ETHERNET_HDR_LEN);
        filter_buf = min_buf;
    }
…
```

Instrumentation: inserting extra code to observe run-time behavior

Binary Instrumentation

```
mov     $0x0,%esi
mov     %rax,%rdi
mov     $0x0,%eax
```

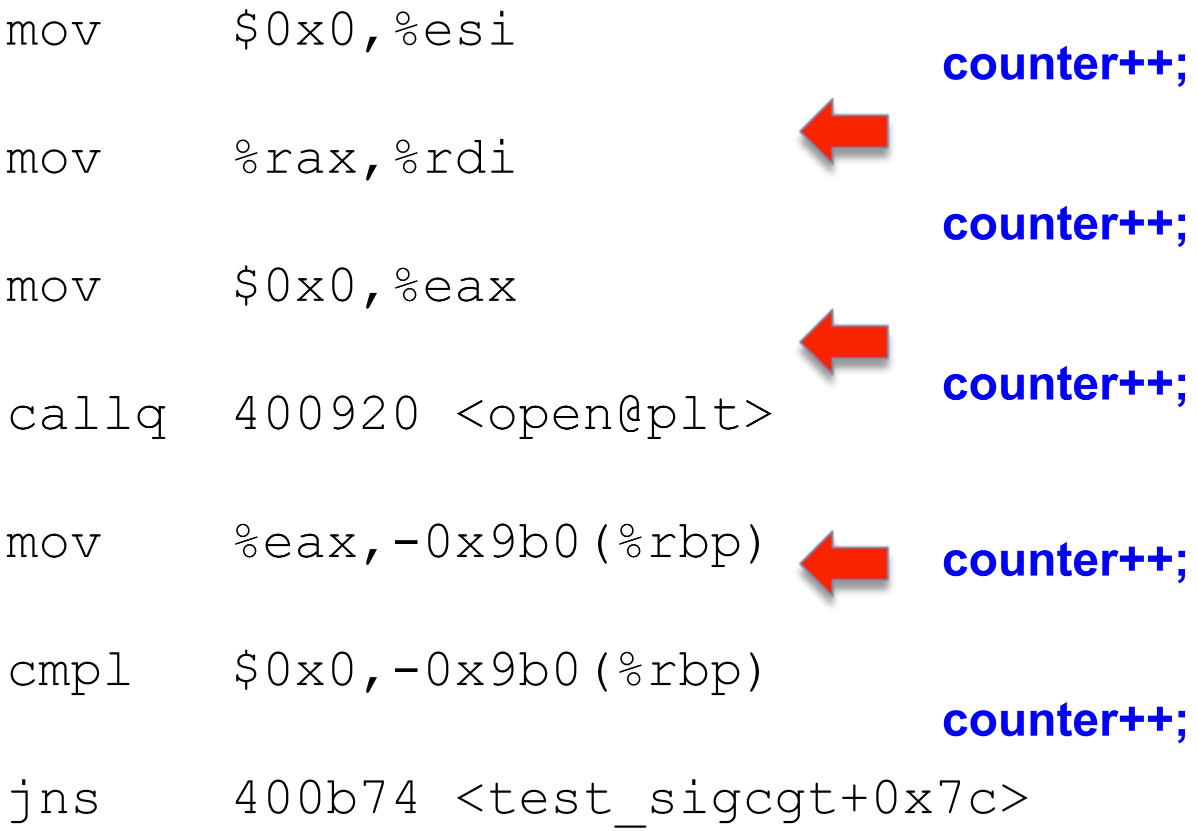
Pre-instruction Hook

```
callq   400920 <open@plt>
```

Post-instruction Hook

```
mov     %eax,-0x9b0(%rbp)
cmpl    $0x0,-0x9b0(%rbp)
jns     400b74 <test_sigcgt+0x7c>
```

Binary Instrumentation



```
mov     $0x0,%esi

mov     %rax,%rdi

mov     $0x0,%eax

callq   400920 <open@plt>

mov     %eax,-0x9b0(%rbp)

cmpl    $0x0,-0x9b0(%rbp)

jns     400b74 <test_sigcgt+0x7c>
```

counter++;

counter++;

counter++;

counter++;

counter++;

Binary Instrumentation

```
mov     $0x0,%esi

mov     %rax,%rdi

mov     $0x0,%eax

callq   400920 <open@plt>

mov     %eax,-0x9b0(%rbp)

cmpl    $0x0,-0x9b0(%rbp)

jns     400b74 <test_sigcgt+0x7c>
```

counter++;

counter++;

counter++;

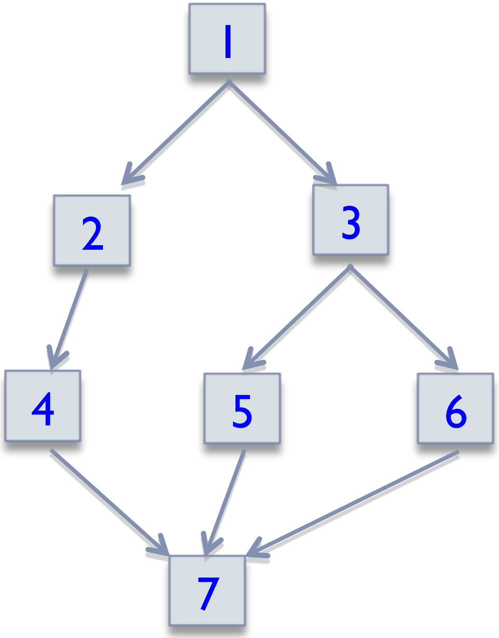
counter++;

counter++;

Concept Similar to Source Level Instrumentation

Binary Instrumentation

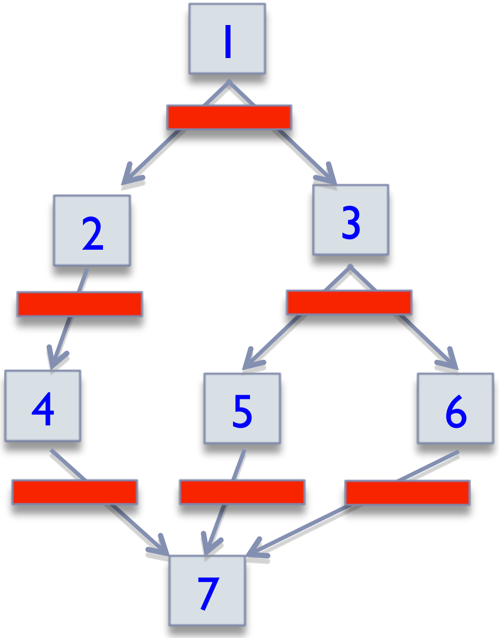
Call Graph



Instrumentation can be done at the Code Block level

Binary Instrumentation

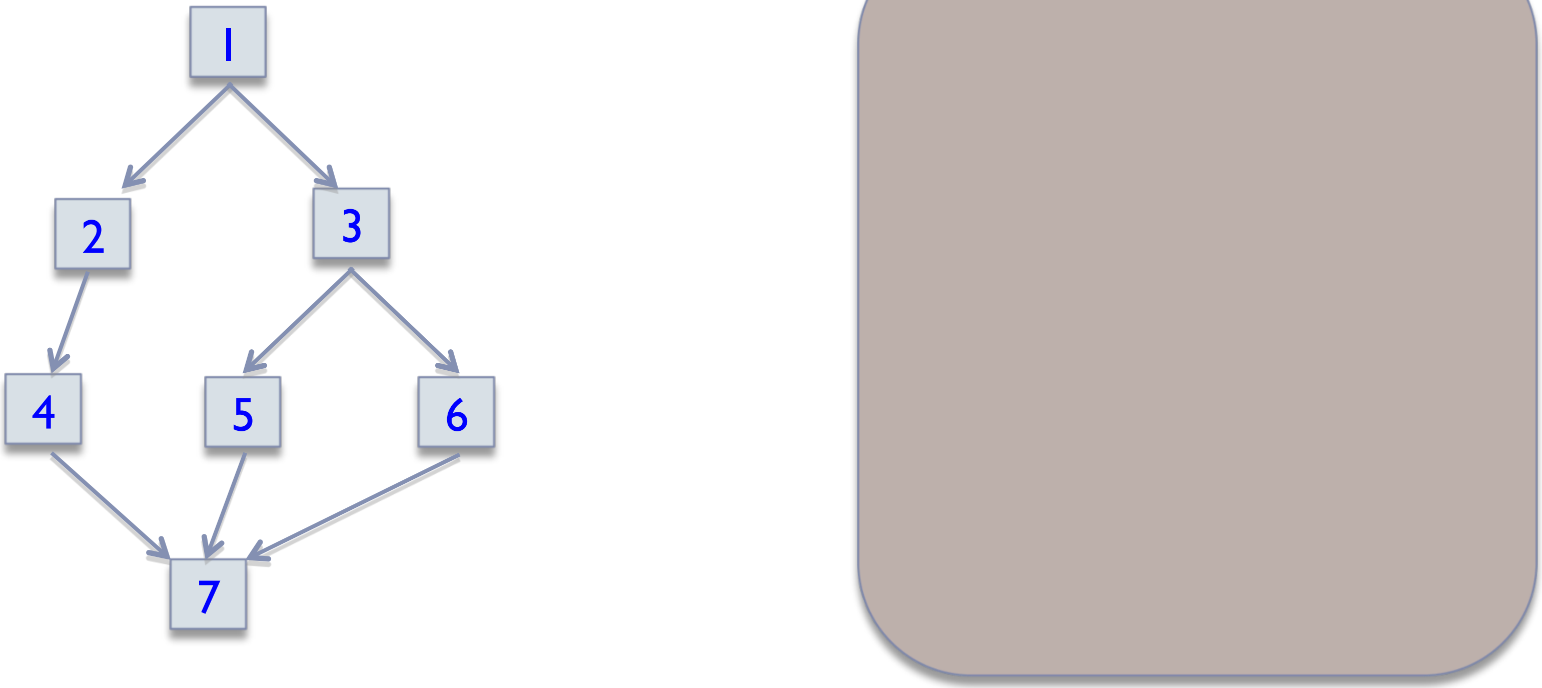
Call Graph



Instrumentation can be done at the Code Block level

Dynamic Binary Instrumentation (DBI)

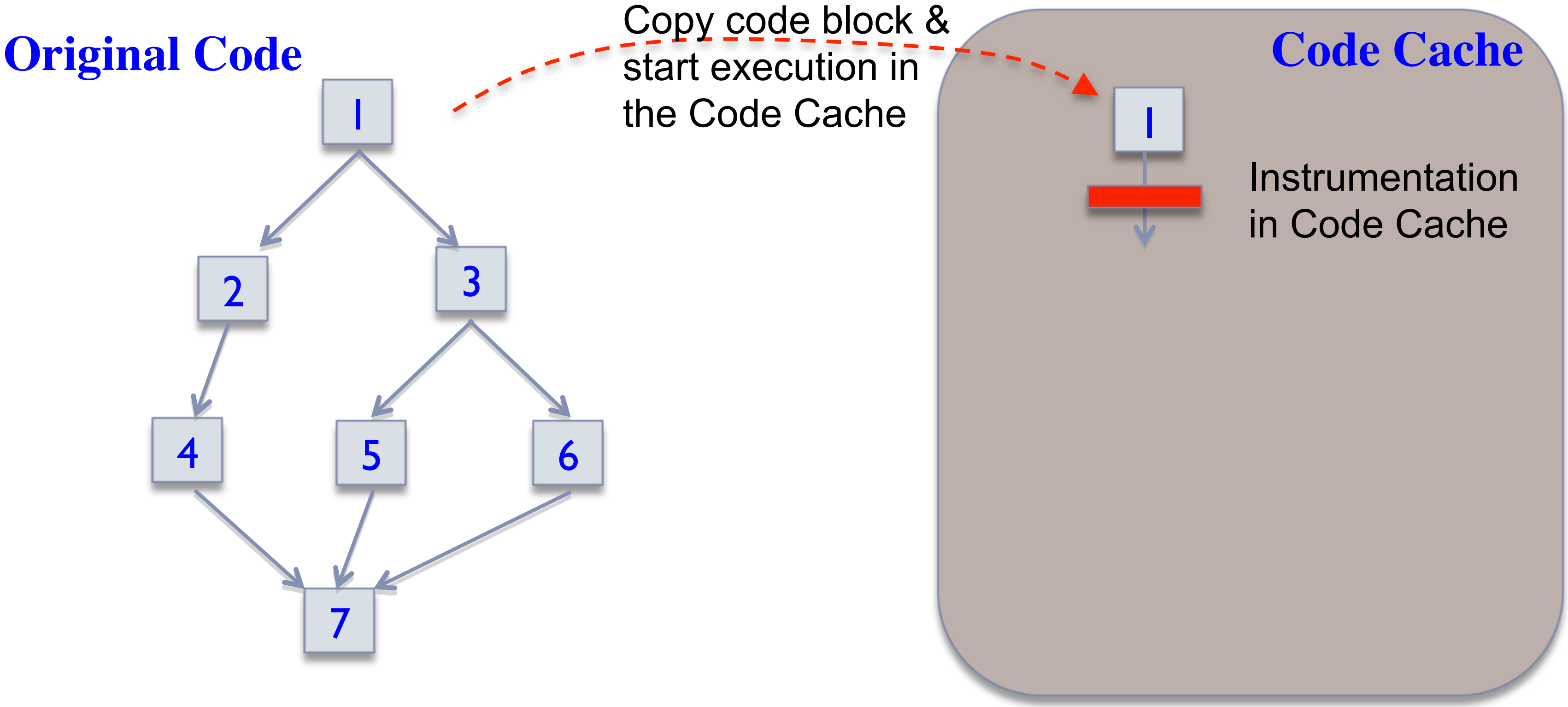
Original Code



Code Cache

Dynamic Instrumentation via Code Cache

Dynamic Binary Instrumentation (DBI)



Original Code

Copy code block & start execution in the Code Cache

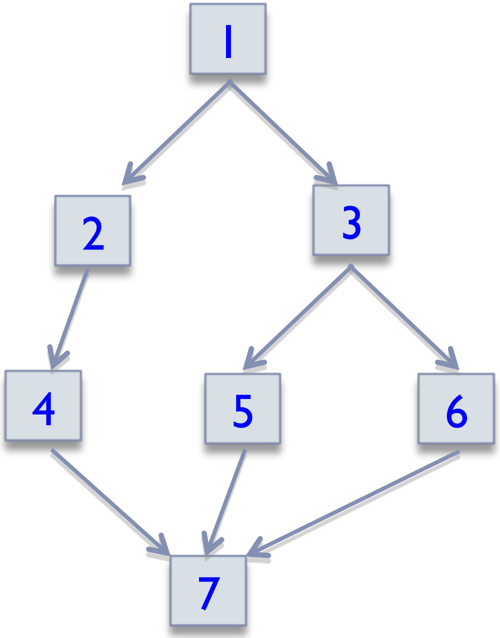
Code Cache

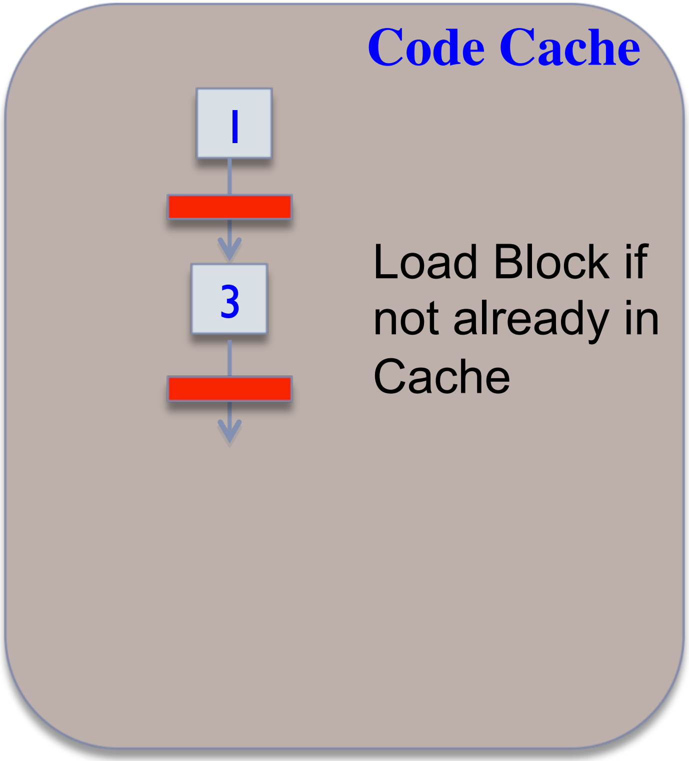
Instrumentation in Code Cache

Dynamic Instrumentation via Code Cache

Dynamic Binary Instrumentation (DBI)

Original Code





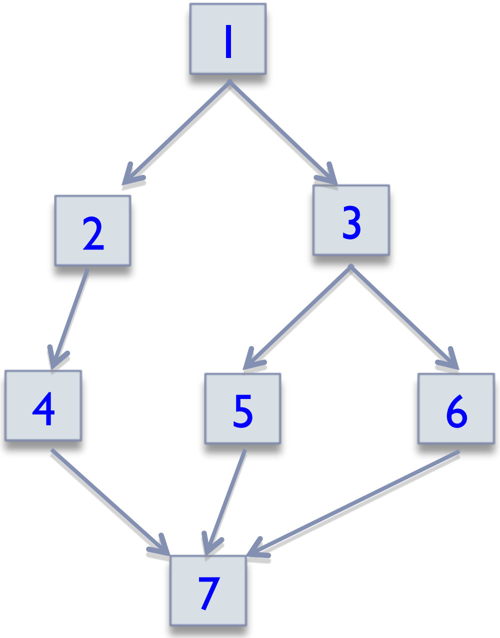
Code Cache

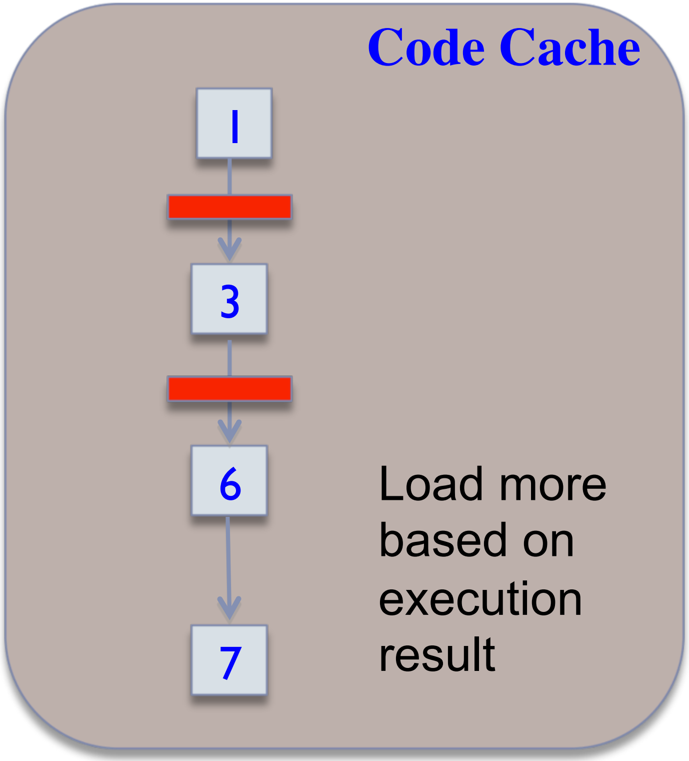
Load Block if not already in Cache

Dynamic Instrumentation via Code Cache

Dynamic Binary Instrumentation (DBI)

Original Code




Code Cache

Load more based on execution result

Dynamic Instrumentation via Code Cache

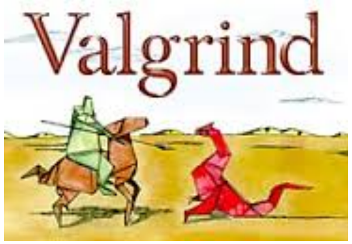
The Increasing Use of DBI

- Function:
  - Observing execution
  - Hardening and protection

- Useful for
  - Profiling and optimization
  - Reverse engineering
  - Malware analysis

Popular DBI Tools

- Process level:



Demand of Transparency!

- Matching the native behavior
  - E.g.
    - No change to program execution flow
    - No obvious overhead

- Special effort towards transparency
  - E.g.
    - Making no assumptions about memory usage
    - Hide code cache management and instrumentation code

Example of Preserving Transparency

- Library Transparency in DynamoRIO
  - Execution in code cache needs DynamoRIO library calls

    E.g.

    □ for the start of app from code cache

    □ for translation between code cache and app addresses
  - DynamoRIO uses a custom loader for its libraries

    E.g.

    □ DLL is loaded to App process space, but "invisible" from App.

    □ EnumProcessModules ( ) shows no DLLs from DynamoRIO.

Transparency Features in DynamoRIO

I/O Transparency

Error Transparency

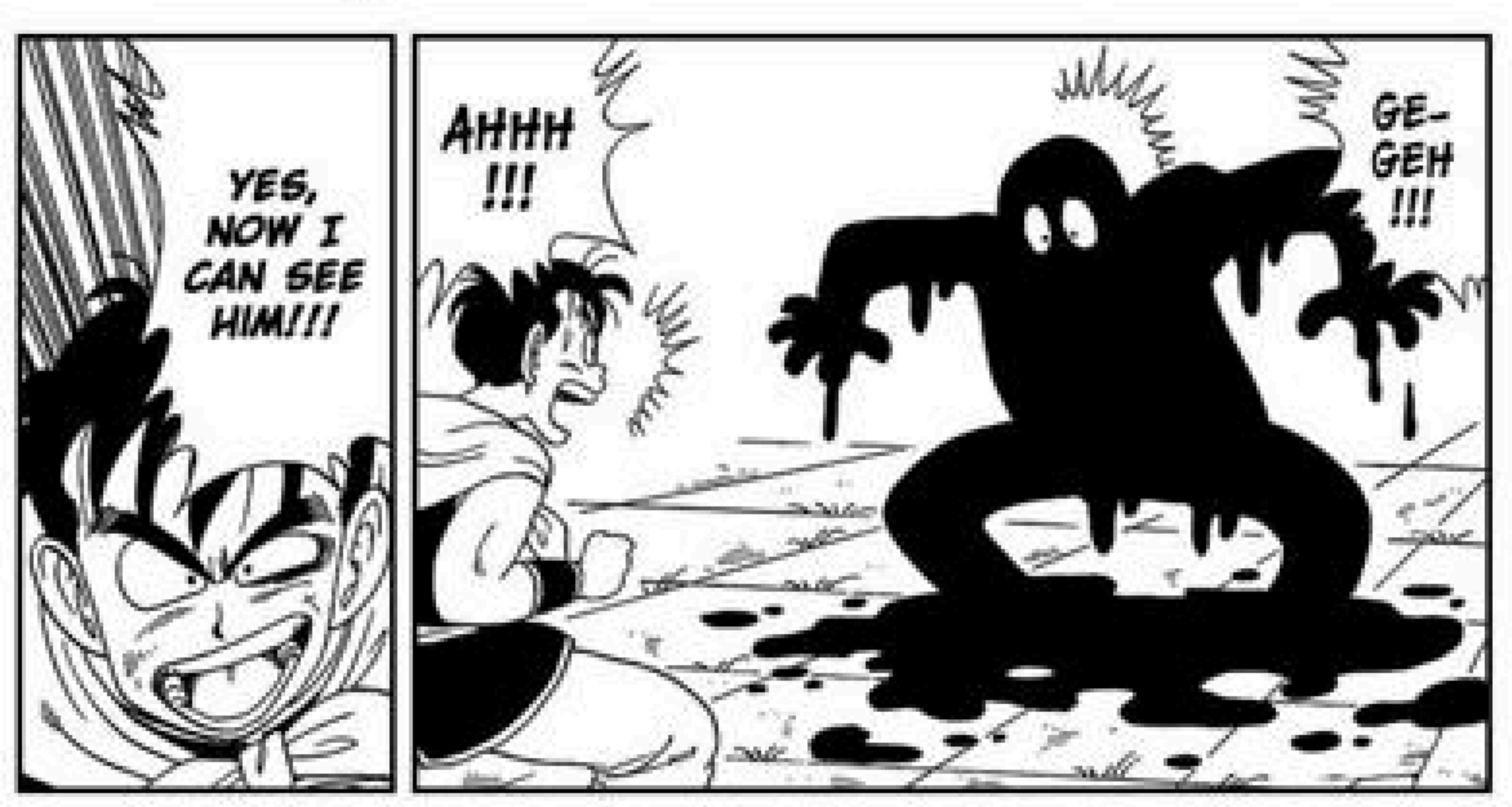
Memory Transparency

Library Transparency

Resource Transparency

Address Transparency

Debugging Transparency



Exposing DBI

DBI detection case studies based on DynamoRIO

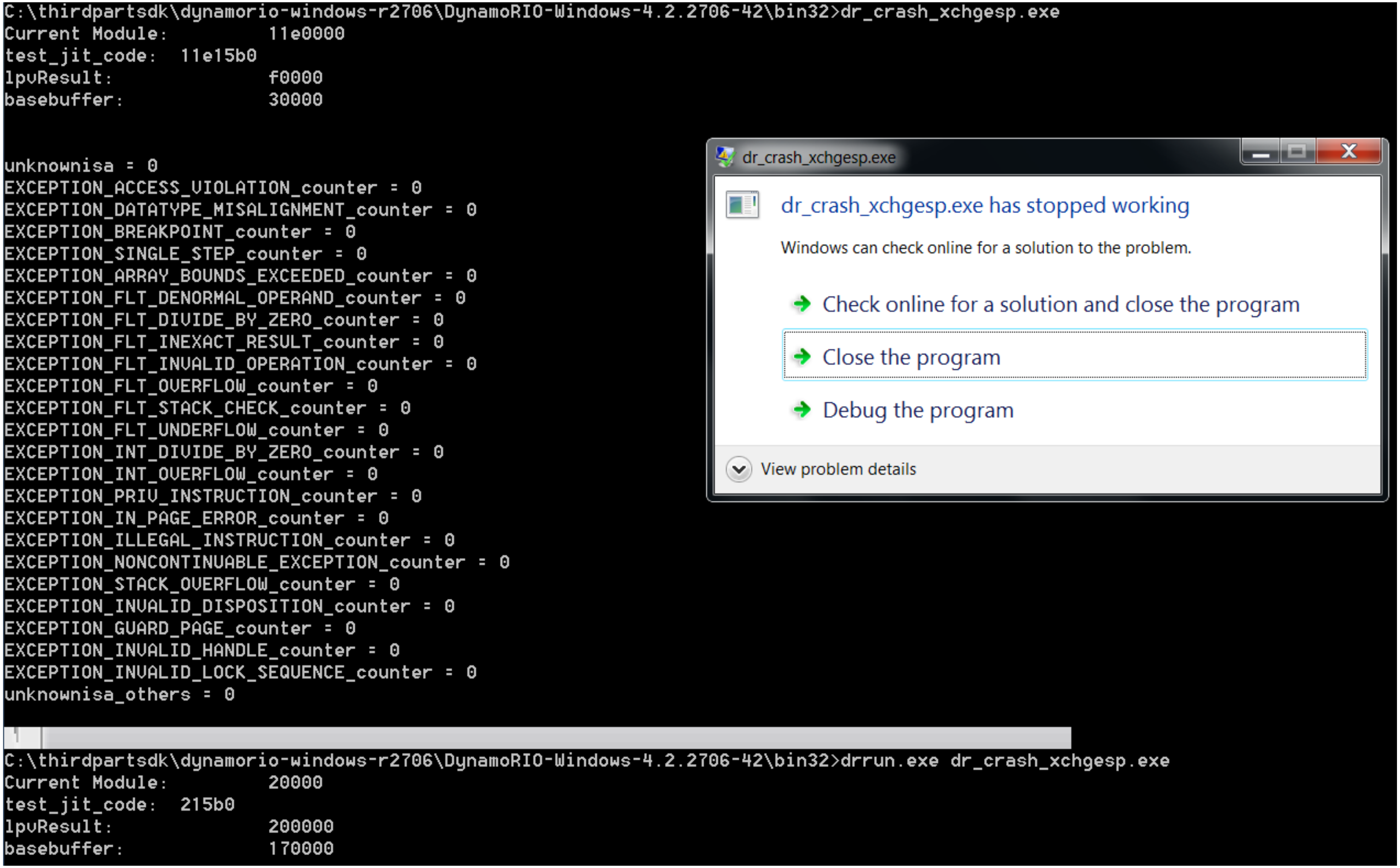
Image Source: http://dragonball.wikia.com

Example #1: Cause DynamoRIO to crash

DynamoRIO Crash Code

- Code pieces
  - Works correctly on Native
  - But crashes DynamoRIO if running with it

- For example: Heap as stack



```
C:\thirdpartsdk\dynamorio-windows-r2706\DynamoRIO-Windows-4.2.2706-42\bin32>dr_crash_xchgesp.exe
Current Module:         11e0000
test_jit_code:  11e15b0
lpvResult:              f0000
basebuffer:             30000


unknownisa = 0
EXCEPTION_ACCESS_VIOLATION_counter = 0
EXCEPTION_DATATYPE_MISALIGNMENT_counter = 0
EXCEPTION_BREAKPOINT_counter = 0
EXCEPTION_SINGLE_STEP_counter = 0
EXCEPTION_ARRAY_BOUNDS_EXCEEDED_counter = 0
EXCEPTION_FLT_DENORMAL_OPERAND_counter = 0
EXCEPTION_FLT_DIVIDE_BY_ZERO_counter = 0
EXCEPTION_FLT_INEXACT_RESULT_counter = 0
EXCEPTION_FLT_INVALID_OPERATION_counter = 0
EXCEPTION_FLT_OVERFLOW_counter = 0
EXCEPTION_FLT_STACK_CHECK_counter = 0
EXCEPTION_FLT_UNDERFLOW_counter = 0
EXCEPTION_INT_DIVIDE_BY_ZERO_counter = 0
EXCEPTION_INT_OVERFLOW_counter = 0
EXCEPTION_PRIV_INSTRUCTION_counter = 0
EXCEPTION_IN_PAGE_ERROR_counter = 0
EXCEPTION_ILLEGAL_INSTRUCTION_counter = 0
EXCEPTION_NONCONTINUABLE_EXCEPTION_counter = 0
EXCEPTION_STACK_OVERFLOW_counter = 0
EXCEPTION_INVALID_DISPOSITION_counter = 0
EXCEPTION_GUARD_PAGE_counter = 0
EXCEPTION_INVALID_HANDLE_counter = 0
EXCEPTION_INVALID_LOCK_SEQUENCE_counter = 0
unknownisa_others = 0

C:\thirdpartsdk\dynamorio-windows-r2706\DynamoRIO-Windows-4.2.2706-42\bin32>drrun.exe dr_crash_xchgesp.exe
Current Module:         20000
test_jit_code:  215b0
lpvResult:              200000
basebuffer:             170000
```

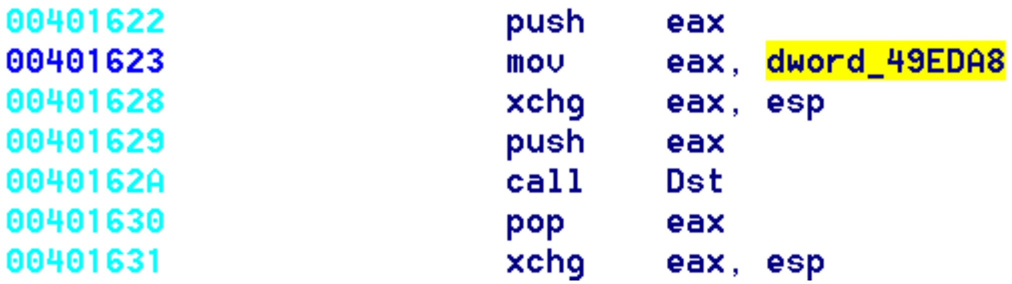
dr_crash_xchgesp.exe

dr_crash_xchgesp.exe has stopped working

Windows can check online for a solution to the problem.

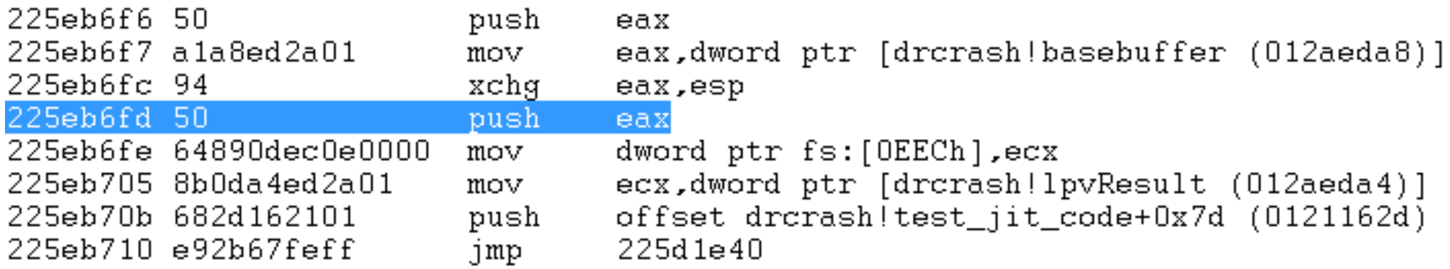
Comparing Code

Original Code



```
00401622                push    eax
00401623                mov     eax, dword_49EDA8
00401628                xchg    eax, esp
00401629                push    eax
0040162A                call    Dst
00401630                pop     eax
00401631                xchg    eax, esp
```

Code in Code cache



```
225eb6f6 50               push    eax
225eb6f7 a1a8ed2a01       mov     eax,dword ptr [drcrash!basebuffer (012aeda8)]
225eb6fc 94               xchg    eax,esp
225eb6fd 50               push    eax
225eb6fe 64890dec0e0000   mov     dword ptr fs:[0EECh],ecx
225eb705 8b0da4ed2a01     mov     ecx,dword ptr [drcrash!lpvResult (012aeda4)]
225eb70b 682d162101       push    offset drcrash!test_jit_code+0x7d (0121162d)
225eb710 e92b67feff       jmp     225d1e40
```

Example #2: Simple Implementation Artifact

Simple Heuristics for DBI Detection

- Implementation Artifact
  - Parent Process Name
    - Detection by checking who is the parent!
    - InheritedFromUniqueProcessId shows the father is drrun.exe
  - "File" Handler Number
    - Handler Count
      - □ DynamoRIO: 0x17 Native: 0x0d
  - Max Open File Handlers
    - 4000 vs. 4096 (on Linux)

Detection by Abnormal Resource Usage

- Peak Memory Usage
  - PeakVirtualSize (on our sample program)
    - With DynamoRIO: 0x8e7c000 bytes
    - Without: 0x0d73000 bytes

- Other Anomaly Behavior
    - E.g. Setting Max Open File handler (on Linux)

setrlimit(**RLIMIT_NOFILE**, 1024) fails even when current limit is 1024

Detecting DynamoRIO by Signal Masks

- DynamoRIO capture all signals and relays them
  - To observe all signals while avoiding modify signal handlers
  - To preserve transparency
  - Consequence (on Linux):
    - Application with DynamoRIO :

      SIGCGT mask: 0x0FFFFFFFFFFC1FEF
    - Native Application:

      SIGCGT mask: 0x0000000000001000

Example #3: Detecting DynamoRIO Library

Detecting DynamoRIO Library

- Library Transparency
  - DynamoRIO library needs to be in the App process
  - DynamoRIO hides its DLL from the Process

- However, the code cache management code has to be in process memory!

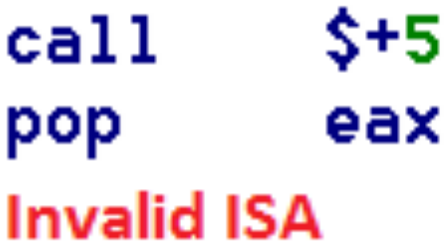
Detecting DynamoRIO Library

- Scanning for all PE/DLLs in process memory
- Identify hidden DLLs by comparing with the list from EnumProcessModules()
- Identifying DynamoRIO library
  - Searching hidden library for DynamoRIO data
  - Searching for DynamoRIO code
  - GetProcAddress for DynamoRIO DLL APIs

Example #4: Measuring Error Transparency Behavior

Error Transparency Detection

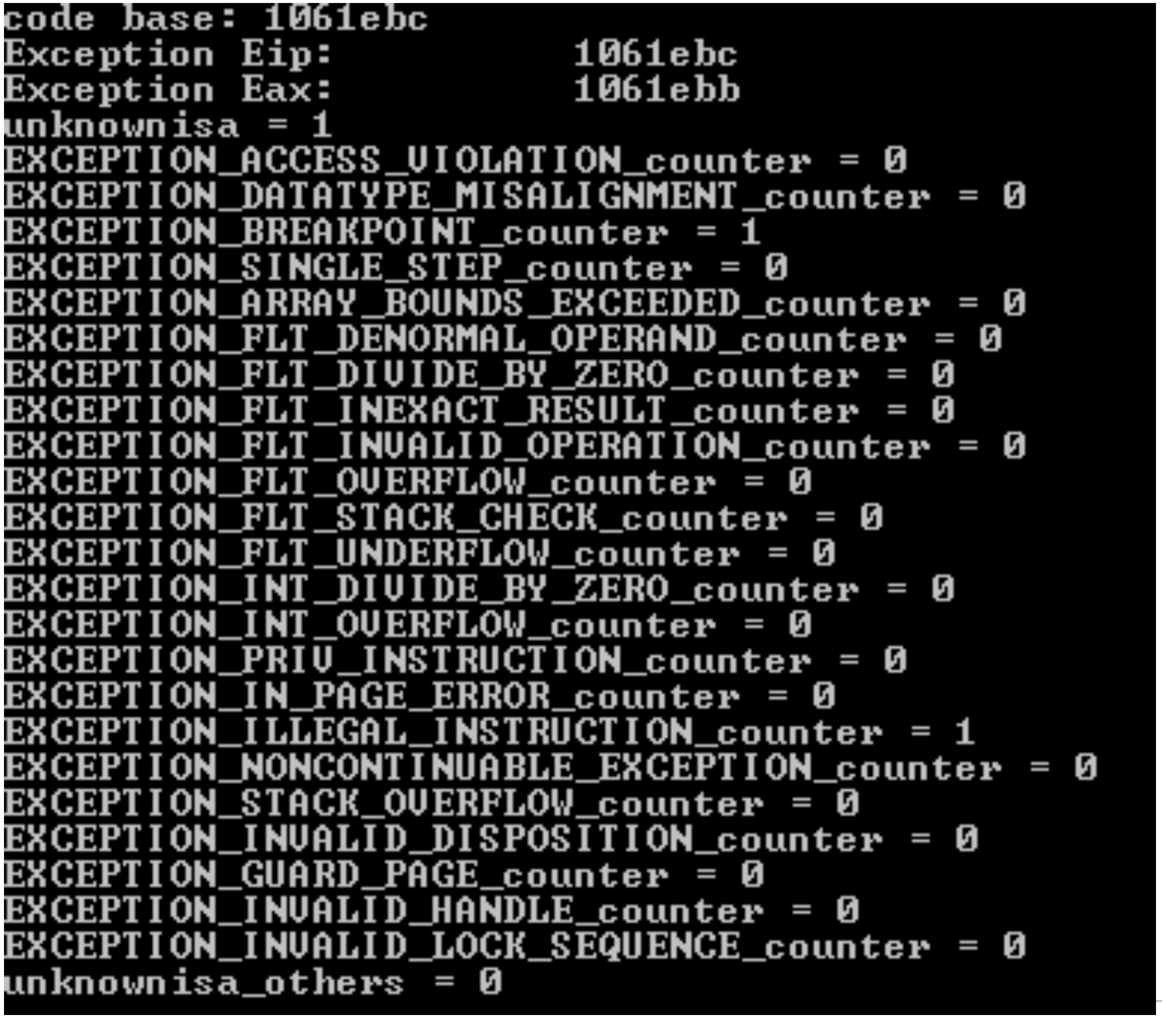
- Designed code to trigger exception



```
call    $+5
pop     eax
Invalid ISA
```

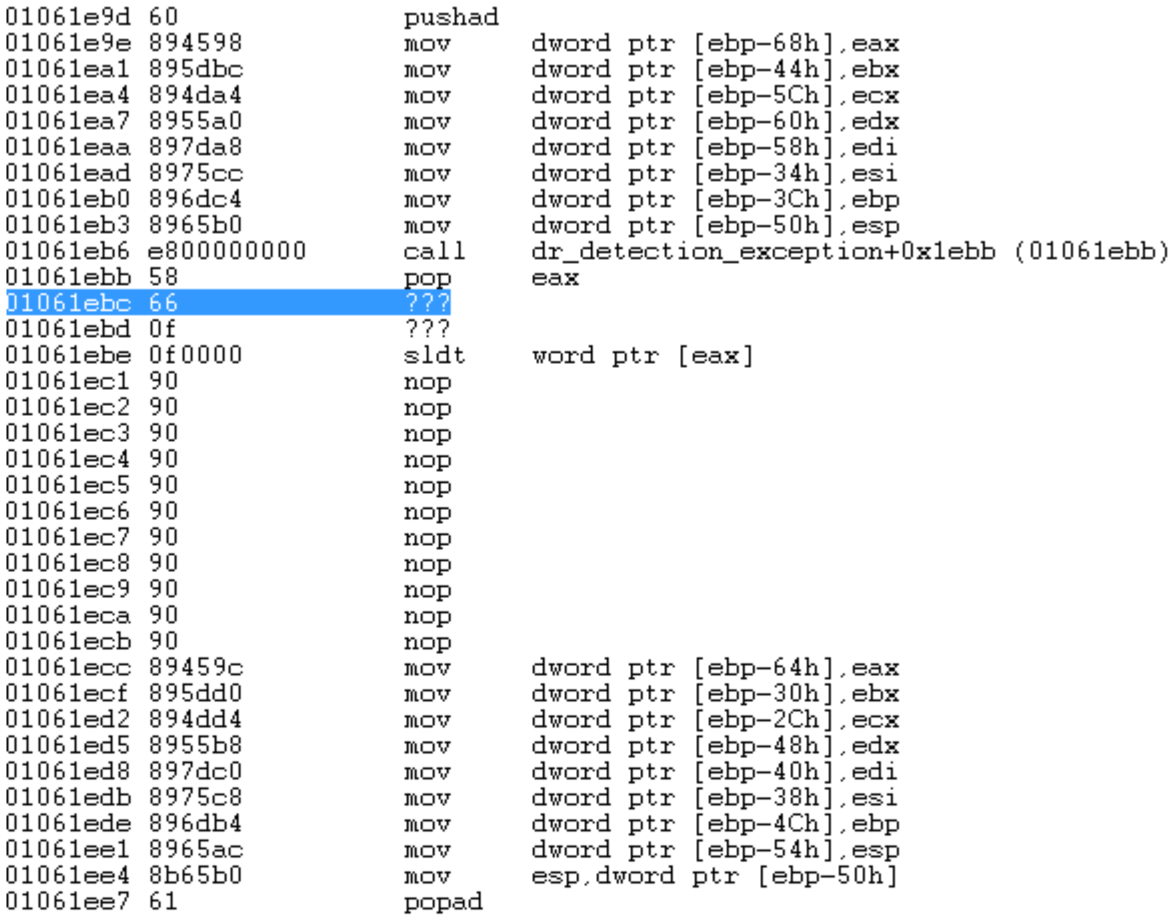
- In exception handler, exception record eax/eip distance should be one
- Trigger this code via self modified code

On Native Windows 7 32-bits



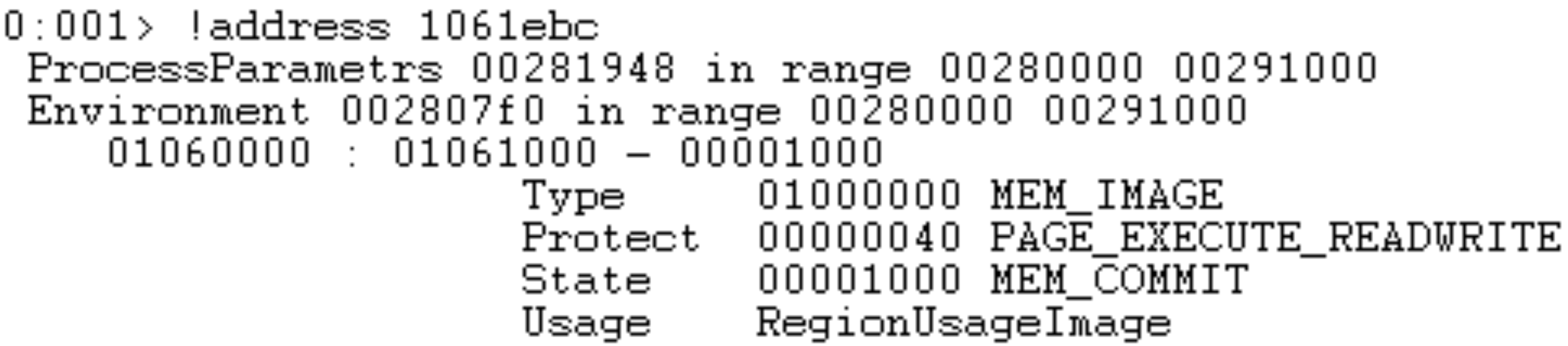
```
code base: 1061ebc
Exception Eip:          1061ebc
Exception Eax:          1061ebb
unknownisa = 1
EXCEPTION_ACCESS_VIOLATION_counter = 0
EXCEPTION_DATATYPE_MISALIGNMENT_counter = 0
EXCEPTION_BREAKPOINT_counter = 1
EXCEPTION_SINGLE_STEP_counter = 0
EXCEPTION_ARRAY_BOUNDS_EXCEEDED_counter = 0
EXCEPTION_FLT_DENORMAL_OPERAND_counter = 0
EXCEPTION_FLT_DIVIDE_BY_ZERO_counter = 0
EXCEPTION_FLT_INEXACT_RESULT_counter = 0
EXCEPTION_FLT_INVALID_OPERATION_counter = 0
EXCEPTION_FLT_OVERFLOW_counter = 0
EXCEPTION_FLT_STACK_CHECK_counter = 0
EXCEPTION_FLT_UNDERFLOW_counter = 0
EXCEPTION_INT_DIVIDE_BY_ZERO_counter = 0
EXCEPTION_INT_OVERFLOW_counter = 0
EXCEPTION_PRIV_INSTRUCTION_counter = 0
EXCEPTION_IN_PAGE_ERROR_counter = 0
EXCEPTION_ILLEGAL_INSTRUCTION_counter = 1
EXCEPTION_NONCONTINUABLE_EXCEPTION_counter = 0
EXCEPTION_STACK_OVERFLOW_counter = 0
EXCEPTION_INVALID_DISPOSITION_counter = 0
EXCEPTION_GUARD_PAGE_counter = 0
EXCEPTION_INVALID_HANDLE_counter = 0
EXCEPTION_INVALID_LOCK_SEQUENCE_counter = 0
unknownisa_others = 0
```

Code at Runtime



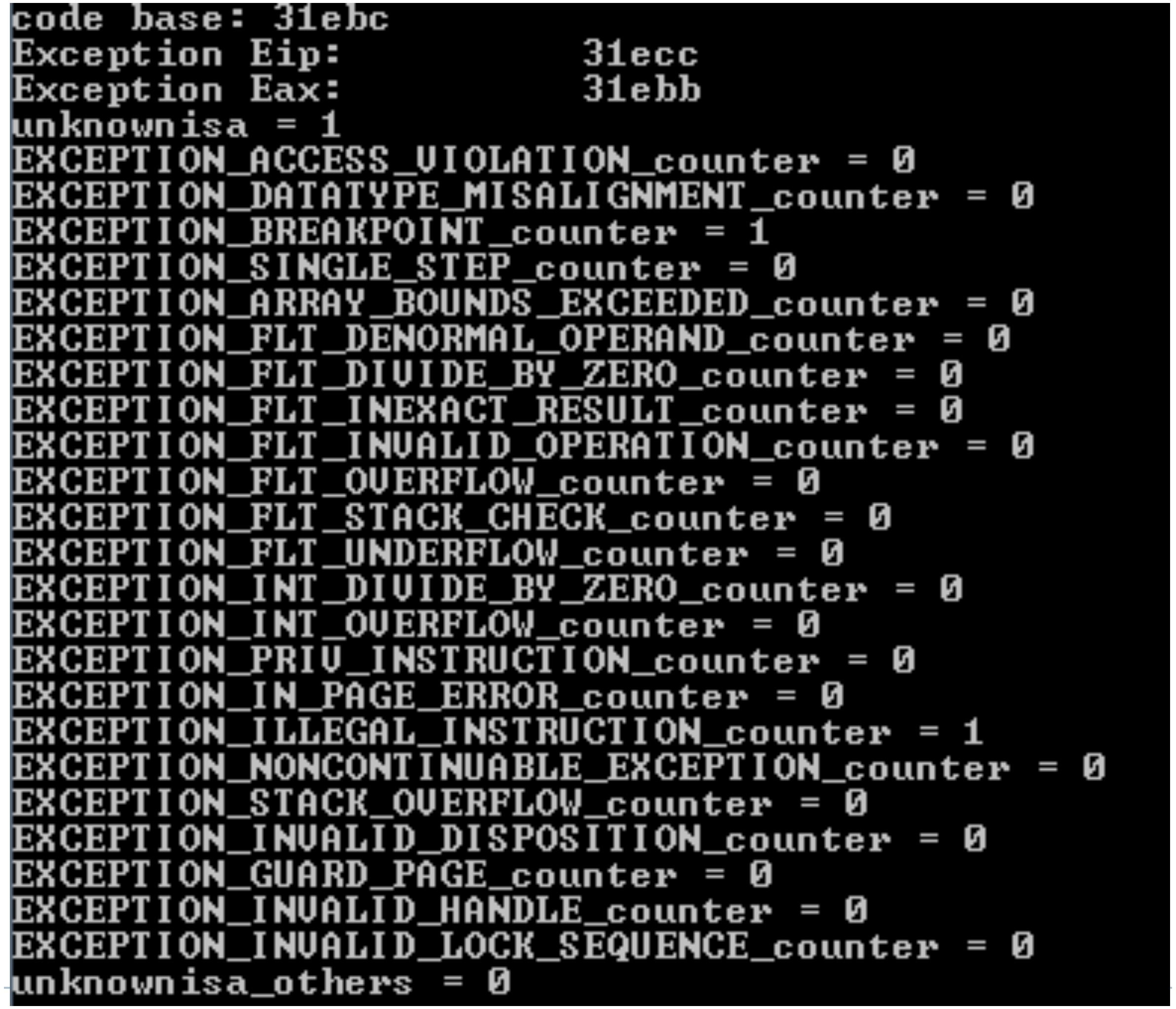
```
01061e9d 60                pushad
01061e9e 894598            mov     dword ptr [ebp-68h],eax
01061ea1 895dbc            mov     dword ptr [ebp-44h],ebx
01061ea4 894da4            mov     dword ptr [ebp-5Ch],ecx
01061ea7 8955a0            mov     dword ptr [ebp-60h],edx
01061eaa 897da8            mov     dword ptr [ebp-58h],edi
01061ead 8975cc            mov     dword ptr [ebp-34h],esi
01061eb0 896dc4            mov     dword ptr [ebp-3Ch],ebp
01061eb3 8965b0            mov     dword ptr [ebp-50h],esp
01061eb6 e800000000        call    dr_detection_exception+0x1ebb (01061ebb)
01061ebb 58                pop     eax
01061ebc 66                ???
01061ebd 0f                ???
01061ebe 0f0000            sldt    word ptr [eax]
01061ec1 90                nop
01061ec2 90                nop
01061ec3 90                nop
01061ec4 90                nop
01061ec5 90                nop
01061ec6 90                nop
01061ec7 90                nop
01061ec8 90                nop
01061ec9 90                nop
01061eca 90                nop
01061ecb 90                nop
01061ecc 89459c            mov     dword ptr [ebp-64h],eax
01061ecf 895dd0            mov     dword ptr [ebp-30h],ebx
01061ed2 894dd4            mov     dword ptr [ebp-2Ch],ecx
01061ed5 8955b8            mov     dword ptr [ebp-48h],edx
01061ed8 897dc0            mov     dword ptr [ebp-40h],edi
01061edb 8975c8            mov     dword ptr [ebp-38h],esi
01061ede 896db4            mov     dword ptr [ebp-4Ch],ebp
01061ee1 8965ac            mov     dword ptr [ebp-54h],esp
01061ee4 8b65b0            mov     esp,dword ptr [ebp-50h]
01061ee7 61                popad
```

Code Property



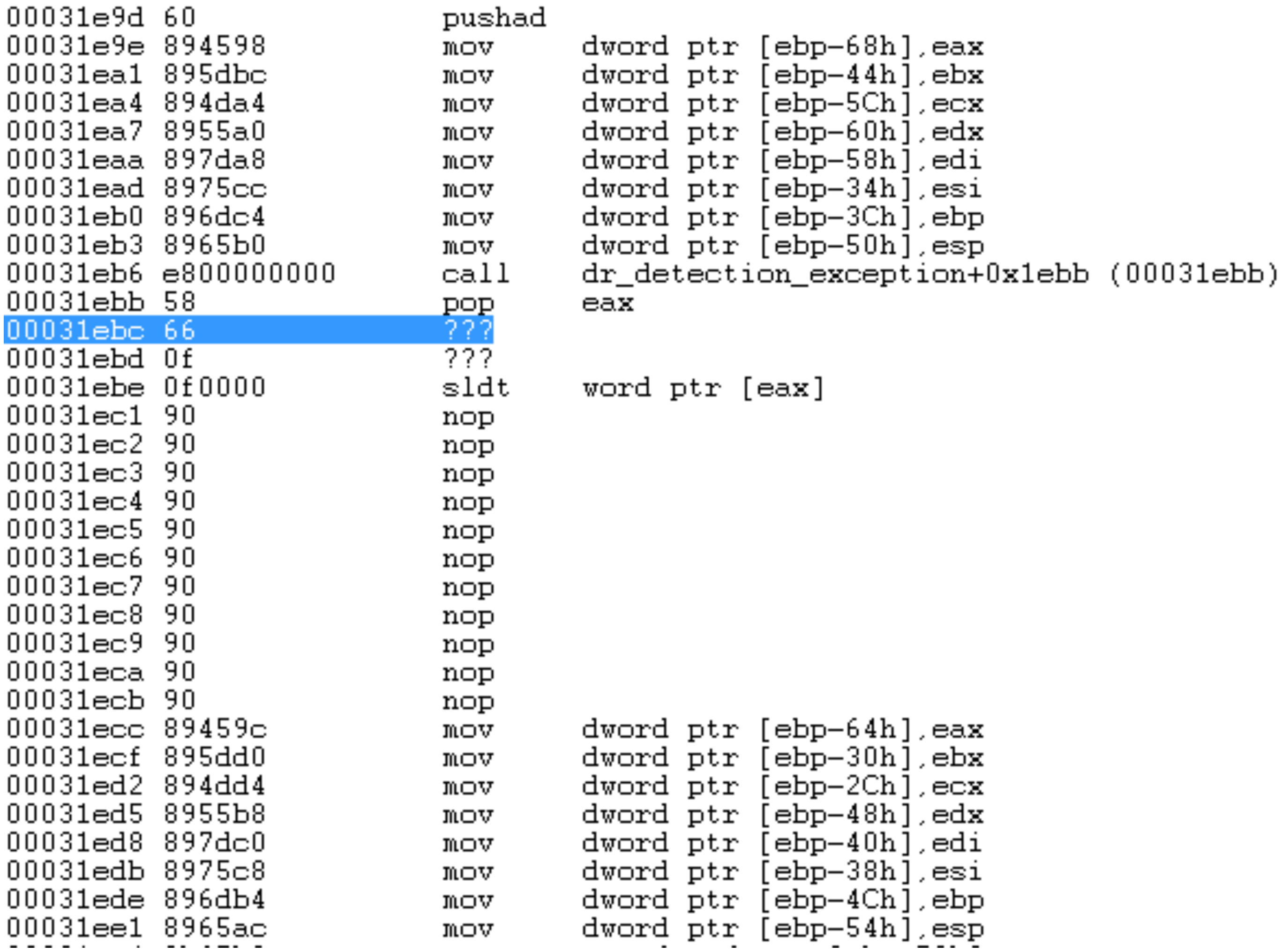
```
0:001> !address 1061ebc
 ProcessParametrs 00281948 in range 00280000 00291000
 Environment 002807f0 in range 00280000 00291000
    01060000 : 01061000 - 00001000
                    Type     01000000 MEM_IMAGE
                    Protect  00000040 PAGE_EXECUTE_READWRITE
                    State    00001000 MEM_COMMIT
                    Usage    RegionUsageImage
```

On Native Windows 7 32-bits + DynamoRIO



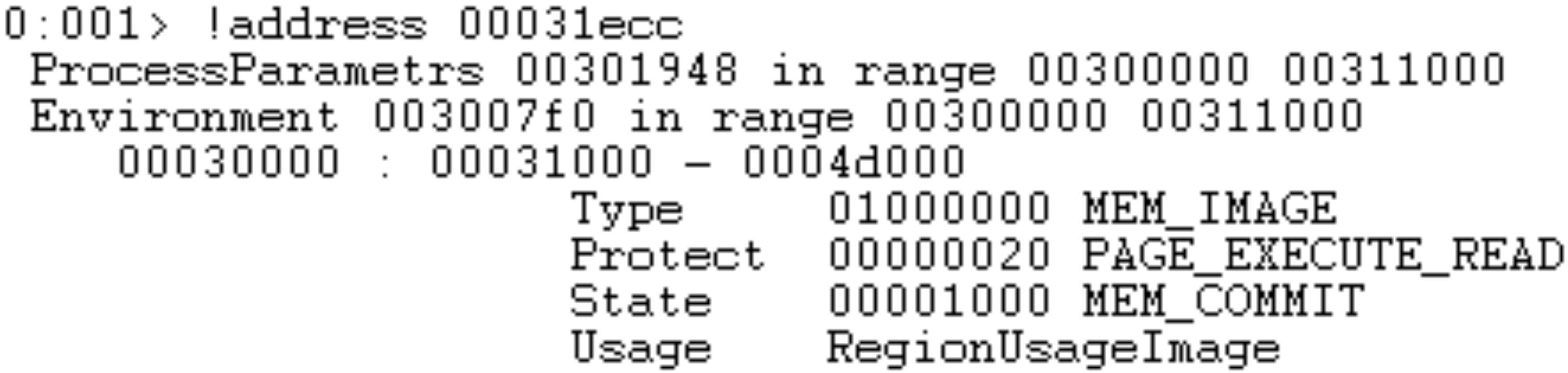
```
code base: 31ebc
Exception Eip:            31ecc
Exception Eax:            31ebb
unknownisa = 1
EXCEPTION_ACCESS_VIOLATION_counter = 0
EXCEPTION_DATATYPE_MISALIGNMENT_counter = 0
EXCEPTION_BREAKPOINT_counter = 1
EXCEPTION_SINGLE_STEP_counter = 0
EXCEPTION_ARRAY_BOUNDS_EXCEEDED_counter = 0
EXCEPTION_FLT_DENORMAL_OPERAND_counter = 0
EXCEPTION_FLT_DIVIDE_BY_ZERO_counter = 0
EXCEPTION_FLT_INEXACT_RESULT_counter = 0
EXCEPTION_FLT_INVALID_OPERATION_counter = 0
EXCEPTION_FLT_OVERFLOW_counter = 0
EXCEPTION_FLT_STACK_CHECK_counter = 0
EXCEPTION_FLT_UNDERFLOW_counter = 0
EXCEPTION_INT_DIVIDE_BY_ZERO_counter = 0
EXCEPTION_INT_OVERFLOW_counter = 0
EXCEPTION_PRIV_INSTRUCTION_counter = 0
EXCEPTION_IN_PAGE_ERROR_counter = 0
EXCEPTION_ILLEGAL_INSTRUCTION_counter = 1
EXCEPTION_NONCONTINUABLE_EXCEPTION_counter = 0
EXCEPTION_STACK_OVERFLOW_counter = 0
EXCEPTION_INVALID_DISPOSITION_counter = 0
EXCEPTION_GUARD_PAGE_counter = 0
EXCEPTION_INVALID_HANDLE_counter = 0
EXCEPTION_INVALID_LOCK_SEQUENCE_counter = 0
unknownisa_others = 0
```

Code in Runtime



```
00031e9d 60             pushad
00031e9e 894598         mov     dword ptr [ebp-68h],eax
00031ea1 895dbc         mov     dword ptr [ebp-44h],ebx
00031ea4 894da4         mov     dword ptr [ebp-5Ch],ecx
00031ea7 8955a0         mov     dword ptr [ebp-60h],edx
00031eaa 897da8         mov     dword ptr [ebp-58h],edi
00031ead 8975cc         mov     dword ptr [ebp-34h],esi
00031eb0 896dc4         mov     dword ptr [ebp-3Ch],ebp
00031eb3 8965b0         mov     dword ptr [ebp-50h],esp
00031eb6 e800000000     call    dr_detection_exception+0x1ebb (00031ebb)
00031ebb 58             pop     eax
00031ebc 66             ???
00031ebd 0f             ???
00031ebe 0f0000         sldt    word ptr [eax]
00031ec1 90             nop
00031ec2 90             nop
00031ec3 90             nop
00031ec4 90             nop
00031ec5 90             nop
00031ec6 90             nop
00031ec7 90             nop
00031ec8 90             nop
00031ec9 90             nop
00031eca 90             nop
00031ecb 90             nop
00031ecc 89459c         mov     dword ptr [ebp-64h],eax
00031ecf 895dd0         mov     dword ptr [ebp-30h],ebx
00031ed2 894dd4         mov     dword ptr [ebp-2Ch],ecx
00031ed5 8955b8         mov     dword ptr [ebp-48h],edx
00031ed8 897dc0         mov     dword ptr [ebp-40h],edi
00031edb 8975c8         mov     dword ptr [ebp-38h],esi
00031ede 896db4         mov     dword ptr [ebp-4Ch],ebp
00031ee1 8965ac         mov     dword ptr [ebp-54h],esp
```

Code Property

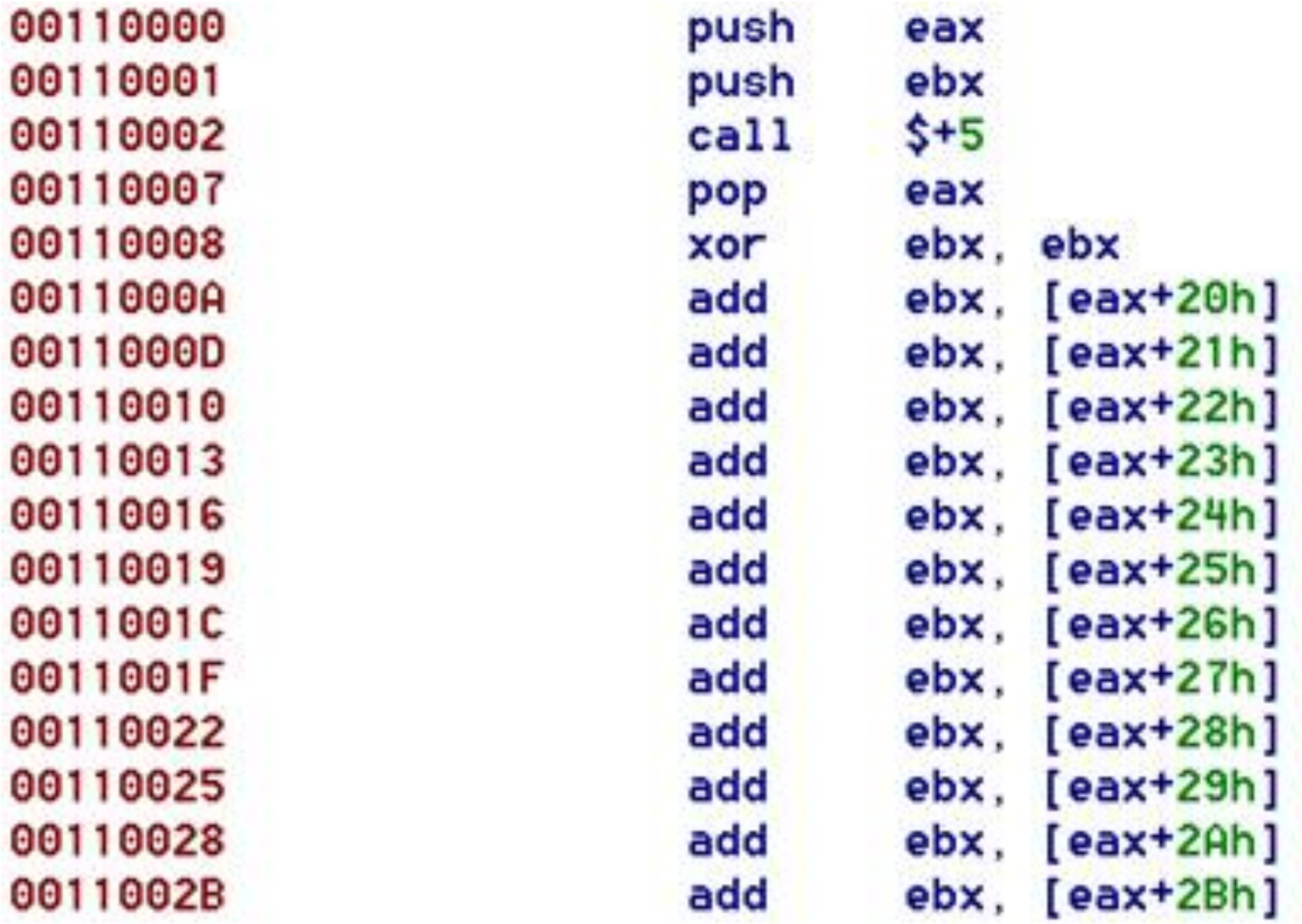


```
0:001> !address 00031ecc
 ProcessParametrs 00301948 in range 00300000 00311000
 Environment 003007f0 in range 00300000 00311000
    00030000 : 00031000 - 0004d000
                    Type     01000000 MEM_IMAGE
                    Protect  00000020 PAGE_EXECUTE_READ
                    State    00001000 MEM_COMMIT
                    Usage    RegionUsageImage
```

Fixed by revision r2688 ☺
(May, 2014)

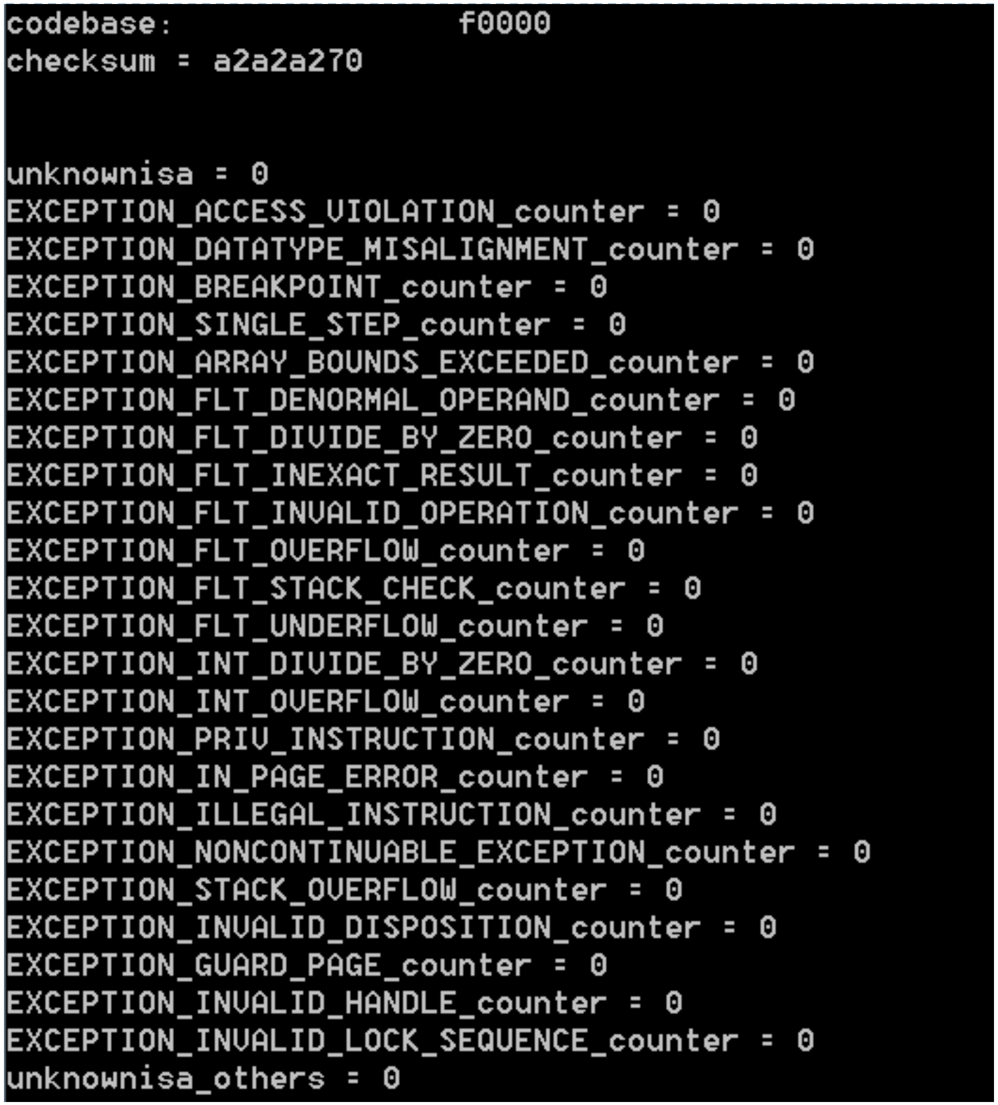
Example #5: Unexpected Exception

Calculate Code Checksum



```
00110000        push    eax
00110001        push    ebx
00110002        call    $+5
00110007        pop     eax
00110008        xor     ebx, ebx
0011000A        add     ebx, [eax+20h]
0011000D        add     ebx, [eax+21h]
00110010        add     ebx, [eax+22h]
00110013        add     ebx, [eax+23h]
00110016        add     ebx, [eax+24h]
00110019        add     ebx, [eax+25h]
0011001C        add     ebx, [eax+26h]
0011001F        add     ebx, [eax+27h]
00110022        add     ebx, [eax+28h]
00110025        add     ebx, [eax+29h]
00110028        add     ebx, [eax+2Ah]
0011002B        add     ebx, [eax+2Bh]
```

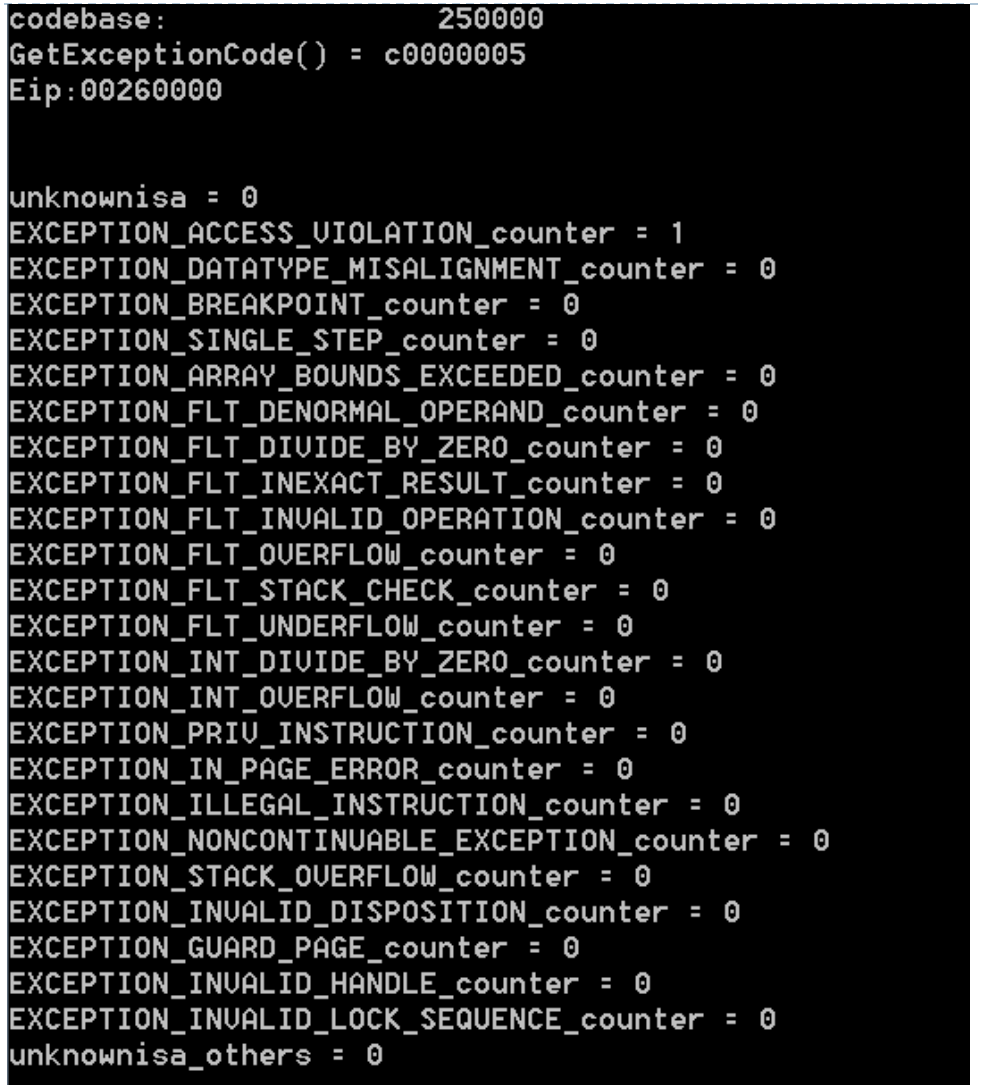
On Native Windows 7 32-bits



```
codebase:                  f0000
checksum = a2a2a270


unknownisa = 0
EXCEPTION_ACCESS_VIOLATION_counter = 0
EXCEPTION_DATATYPE_MISALIGNMENT_counter = 0
EXCEPTION_BREAKPOINT_counter = 0
EXCEPTION_SINGLE_STEP_counter = 0
EXCEPTION_ARRAY_BOUNDS_EXCEEDED_counter = 0
EXCEPTION_FLT_DENORMAL_OPERAND_counter = 0
EXCEPTION_FLT_DIVIDE_BY_ZERO_counter = 0
EXCEPTION_FLT_INEXACT_RESULT_counter = 0
EXCEPTION_FLT_INVALID_OPERATION_counter = 0
EXCEPTION_FLT_OVERFLOW_counter = 0
EXCEPTION_FLT_STACK_CHECK_counter = 0
EXCEPTION_FLT_UNDERFLOW_counter = 0
EXCEPTION_INT_DIVIDE_BY_ZERO_counter = 0
EXCEPTION_INT_OVERFLOW_counter = 0
EXCEPTION_PRIV_INSTRUCTION_counter = 0
EXCEPTION_IN_PAGE_ERROR_counter = 0
EXCEPTION_ILLEGAL_INSTRUCTION_counter = 0
EXCEPTION_NONCONTINUABLE_EXCEPTION_counter = 0
EXCEPTION_STACK_OVERFLOW_counter = 0
EXCEPTION_INVALID_DISPOSITION_counter = 0
EXCEPTION_GUARD_PAGE_counter = 0
EXCEPTION_INVALID_HANDLE_counter = 0
EXCEPTION_INVALID_LOCK_SEQUENCE_counter = 0
unknownisa_others = 0
```

On Native Windows 7 32-bits + DynamoRIO



```
codebase:                  250000
GetExceptionCode() = c0000005
Eip:00260000


unknownisa = 0
EXCEPTION_ACCESS_VIOLATION_counter = 1
EXCEPTION_DATATYPE_MISALIGNMENT_counter = 0
EXCEPTION_BREAKPOINT_counter = 0
EXCEPTION_SINGLE_STEP_counter = 0
EXCEPTION_ARRAY_BOUNDS_EXCEEDED_counter = 0
EXCEPTION_FLT_DENORMAL_OPERAND_counter = 0
EXCEPTION_FLT_DIVIDE_BY_ZERO_counter = 0
EXCEPTION_FLT_INEXACT_RESULT_counter = 0
EXCEPTION_FLT_INVALID_OPERATION_counter = 0
EXCEPTION_FLT_OVERFLOW_counter = 0
EXCEPTION_FLT_STACK_CHECK_counter = 0
EXCEPTION_FLT_UNDERFLOW_counter = 0
EXCEPTION_INT_DIVIDE_BY_ZERO_counter = 0
EXCEPTION_INT_OVERFLOW_counter = 0
EXCEPTION_PRIV_INSTRUCTION_counter = 0
EXCEPTION_IN_PAGE_ERROR_counter = 0
EXCEPTION_ILLEGAL_INSTRUCTION_counter = 0
EXCEPTION_NONCONTINUABLE_EXCEPTION_counter = 0
EXCEPTION_STACK_OVERFLOW_counter = 0
EXCEPTION_INVALID_DISPOSITION_counter = 0
EXCEPTION_GUARD_PAGE_counter = 0
EXCEPTION_INVALID_HANDLE_counter = 0
EXCEPTION_INVALID_LOCK_SEQUENCE_counter = 0
unknownisa_others = 0
```

What more can be done?

What can be done?

- To improve DBI transparency (evade detection)
  - Avoid implementation artifacts
  - A challenging task in general …

- To detect DBI
  - More systematic fuzzing
    - Comparing regular App and DBI-App side-by-side

  - Performance based detection
    - Design binary that triggers the most code cache overhead

Summary

- The increasing use of BT and DBI
  - Runtime program analysis

- Transparency is preserved very well for
  - regular applications, and even buggy applications that make invalid memory accesses

- Transparency is easily broken by detecting anomaly in
  - Resource usage
  - Hidden libraries
  - Exception Handling

Disclaimers and Acknowledgment

- DynamoRIO Developers
  - Providing Powerful Open Source DBI Framework
    - Targets are Benign Applications
    - Not Intentionally Designed for Evading Detection

- Dr. Qin Zhao @ Google
  - Respond to reports
  - Feedback to our slides

- Research Support
  - Dr. Kang Li's research is partially supported by NSF award 1319115

Bonus Materials

Multiple Bytes NOPs

NOPs

- No Operation Instruction
- 0x90 decoded as "xchg eax, eax"
- 1-9 bytes for X86

Examples:

66 NOP	- 66 90H
NOP DWORD ptr [EAX]	- 0F 1F 00H
NOP DWORD ptr [EAX + 00H]	- 0F 1F 40 00H
NOP DWORD ptr [EAX + EAX*1 + 00H]	- 0F 1F 44 00 00H
66 NOP DWORD ptr [EAX + EAX*1 + 00H]	- 66 0F 1F 44 00 00H
NOP DWORD ptr [EAX + 00000000H]	- 0F 1F 80 00 00 00 00H
NOP DWORD ptr [EAX + EAX*1 + 00000000H]	- 0F 1F 84 00 00 00 00 00H
66 NOP DWORD ptr [EAX + EAX*1 + 00000000H]	- 66 0F 1F 84 00 00 00 00 00H

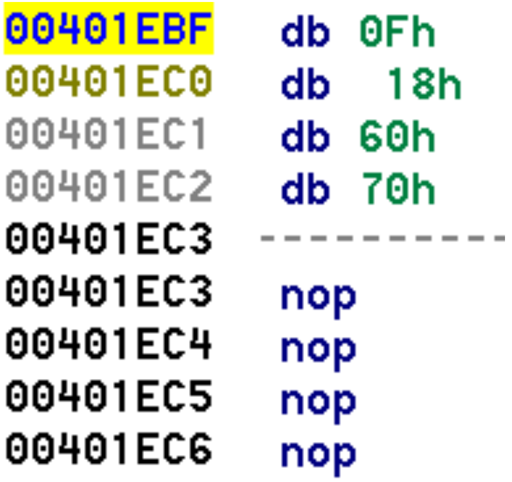
4 Byte NOPs

- 0x0F,0x18,0x60,0x70 is a 4 byte NOP
- Output from XED:

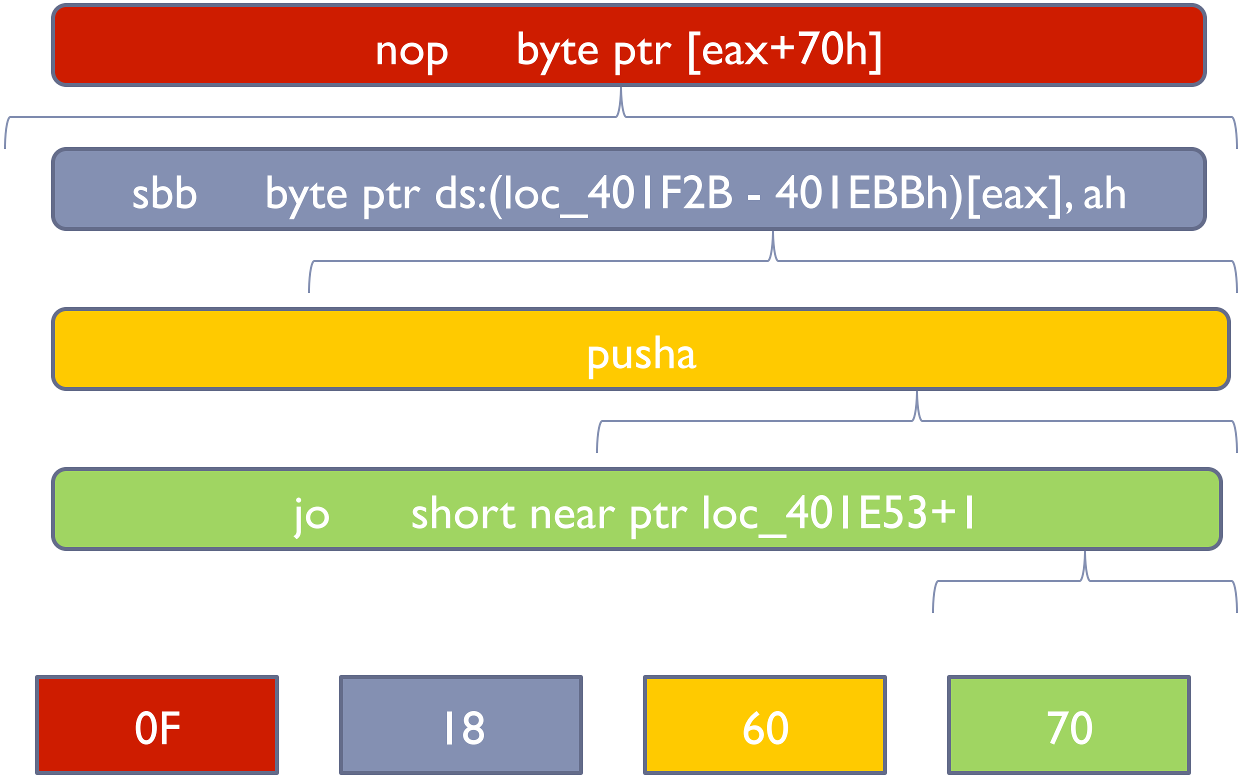
```
0F186070
ICLASS: NOP   CATEGORY: WIDENOP   EXTENSION: BASE  IFORM: NOP_MEMv_0F18r4   ISA_SET: PPRO
SHORT: nop dword ptr [eax+0x70]
```

Why Position Independent NOPs

- X86 instruction with different offsets could be decoded as different instructions



```
00401EBF   db 0Fh
00401EC0   db  18h
00401EC1   db 60h
00401EC2   db 70h
00401EC3  -----------
00401EC3   nop
00401EC4   nop
00401EC5   nop
00401EC6   nop
```



nop byte ptr [eax+70h]

sbb byte ptr ds:(loc_401F2B - 401EBBh)[eax], ah

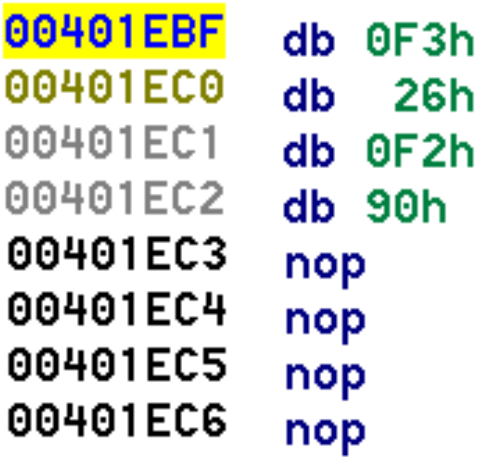
pusha

jo short near ptr loc_401E53+1

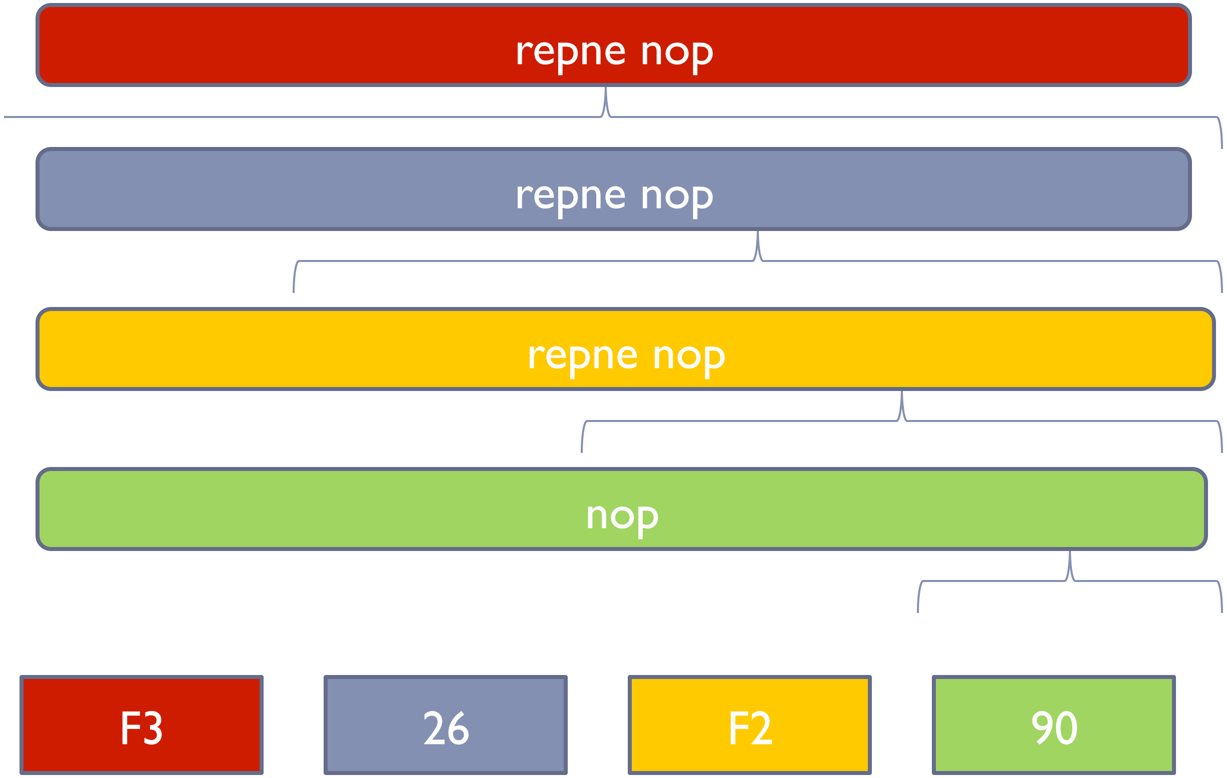
0F	18	60	70

PIN(Position Independent NOP)

- Always NOP instructions even decoded at different offsets



```
00401EBF    db 0F3h
00401EC0    db  26h
00401EC1    db 0F2h
00401EC2    db 90h
00401EC3    nop
00401EC4    nop
00401EC5    nop
00401EC6    nop
```



How to create a 4 byte PIN

- Single byte NOP

[0x90], [0x90], 0x90, 0x90

- 2 byte NOP

[0xF2, [0x90]], 0xF2, 0x90

- 3 byte NOP

[*0x90*], [0x26, [0xF2, 0x90]]

- 4 byte NOP

[0xF3, [0x26, [0xF2, [0x90]]]]

2 Byte PINs

- Examples
  - 0x26, 0x90
  - 0x2E, 0x90
  - 0x36, 0x90
  - 0x3E, 0x90
  - 0x64, 0x90
  - 0x65, 0x90
  - 0x66, 0x90
  - 0x67, 0x90
  - 0xF2, 0x90
  - …

3 Byte PINs

- Examples
  - 0x2E, 0x26, 0x90
  - 0x2E, 0x2E, 0x90
  - 0x2E, 0x36, 0x90
  - 0x2E, 0x3E, 0x90
  - 0x2E, 0x64, 0x90
  - 0x2E, 0x65, 0x90
  - 0x2E, 0x66, 0x90
  - 0x2E, 0x67, 0x90
  - 0x2E, 0xF2, 0x90
  - 0x36, 0x26, 0x90
  - …

4 Byte PINs

- Examples
  - 0x2E, 0x2E, 0x26, 0x90
  - 0x36, 0x2E, 0x26, 0x90
  - 0x3E, 0x2E, 0x26, 0x90
  - 0x64, 0x2E, 0x26, 0x90
  - 0x65, 0x2E, 0x26, 0x90
  - 0x66, 0x2E, 0x26, 0x90
  - 0x67, 0x2E, 0x26, 0x90
  - 0xF2, 0x2E, 0x26, 0x90
  - …

Thanks!

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Reference

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[2] Process-Shared and Persistent Code Caches, Derek Bruening, Vladimir Kiriansky, International Conference on Virtual Execution Environments (VEE-08), 2008

[3] Design and Implementation of a Dynamic Optimization Framework for Windows, Derek Bruening, Evelyn Duesterwald, Saman Amarasinghe, 4th ACM Workshop on Feedback-Directed and Dynamic Optimization (FDDO-4), 2001