A few notes on debugging the buggy ‘veth’ network driver using ‘crash’

Stack : traditional view
Typically, the lowest stack content are the parameters passed to the function!
(CPU ABI).

View by increasing addresses upwards:

```
[...        <-- 'Bottom'; higher (virtual) addresses
PARAMS
...]
RET addr
[E|R]BP/SFP  <-- RBP (base ptr) OR SFP (pointer to previous stack frame
                 [optional])

[...
LOCALS
...]        <-- 'Top' of the stack (ESP); lower (virtual) addresses
```

On the x86_64, the first 6 parameters to a function are passed in the registers *%rdi, %rsi, %rdx, %rcx, %r8, %r9* and Not via the stack. The seventh argument onward, if any, are passed via the stack in the usual manner.

View it the way we’re used to, by increasing addresses downwards:

```
[...           <-- 'Top' of the stack (ESP); lower (virtual) addresses
LOCALS
...]
[E|R]BP/SFP     <-- RBP (base ptr) OR SFP (pointer to previous stack frame
                    [optional])
RET addr
[...
PARAMS
...]           <-- 'Bottom'; higher (virtual) addresses
```

Stack Layout x86_64:
Src: [Extracting kernel stack function arguments from Linux x86-64 kernel crash dumps, Calum Mackay, Sept 2020]

```
...
# lower memory addresses
[%rsp]              top of the stack; new items are pushed on top of <<below>>
...                  this
...
[%rbp]              base of the stack; fixed. Contains the address of the
                     calling function's stack frame base.
<return address>    contains the address of where this function should
                     return to, in the calling function
```

```
# higher memory addresses
...
```

Test rig for kernel crash

1. Boot into custom debug kernel (with kdump enabled), an Ubuntu OSBoxes VM (am using the 5.10.153 kernel)
The bootloader MUST pass the kernel parameter '`crashkernel=<...>`'

Verify:
```
$ cat /proc/cmdline
BOOT_IMAGE=/vmlinuz-5.10.153-kdbg1 root=UUID=b67... ro quiet splash
crashkernel=256M
```

Ok.

```
$ uname -r
5.10.153-kdbg1
```

2. Perform the 'kexec' load of the dump kernel into reserved RAM:

2A. Install the kexec-tools software:

```
wget http://kernel.org/pub/linux/utils/kernel/kexec/kexec-tools.tar.gz
tar xf kexec-tools.tar.gz
cd kexec-tools-2.0.27
./configure
make
sudo make install
```

Now *kexec* should be installed and working.

2B. Within the *L5_kernel_debug* repo:

```
cd <...>/kdumpcrash/
./kexec_load
kexec_load: Loading the 5.10.153-kdbg1 dump-capture kernel into reserved RAM
[sudo] password for osboxes: xxx
kexec_load: kexec success
```

Ok.

3. Load the (buggy) driver (from the L5 (kernel debugging) github repo)

```
cd <...>/L5_debug_trg/kernel_debug/to_debug_assgn/netdrv_veth_buggy/netdriver
cat run
#!/bin/bash
DRV=veth_netdrv
make && {
  sudo rmmod ${DRV}
  sudo dmesg -C
  sudo insmod ${DRV}.ko
```

```
  sudo dmesg
  journalctl -f -k
}

$ ./run
[ ... ]
```

```
  LD [M]  /home/osboxes/kaiwanTECH/L5_debug_trg/kernel_debug/to_debug_assgn/netdrv_veth_buggy/netdriver/v
eth_netdrv.ko
make[1]: Leaving directory '/home/osboxes/linux-5.10.153'
[sudo] password for osboxes:
rmmod: ERROR: Module veth_netdrv is not currently loaded
[  701.781889] veth_netdrv:vnet_init(): vnet: Initializing network driver...
[  701.781953] veth_netdrv:vnet_probe(): vnet_probe:246 :
[  701.782309] veth_netdrv:vnet_init(): loaded.
Journal file /var/log/journal/99e625cfc17348078889e61898a6a36c/system@0005f67312b55fde-447ef64c62cf1eaa.j
ournal~ is truncated, ignoring file.
Jul 08 08:04:30 osboxes kernel: vboxvideo: loading version 6.1.38 r153438
Jul 08 08:04:32 osboxes kernel: e1000: enp0s8 NIC Link is Up 1000 Mbps Full Duplex, Flow Control: RX
Jul 08 08:04:32 osboxes kernel: IPv6: ADDRCONF(NETDEV_CHANGE): enp0s8: link becomes ready
Jul 08 08:04:32 osboxes kernel: rfkill: input handler disabled
Jul 08 08:04:32 osboxes kernel: process 'VBoxClient' launched '/usr/bin/VBoxDRMClient' with NULL argv: em
pty string added
Jul 08 08:16:07 osboxes kernel: veth_netdrv:vnet_init(): vnet: Initializing network driver...
Jul 08 08:16:07 osboxes kernel: veth_netdrv:vnet_probe(): vnet_probe:246 :
Jul 08 08:16:07 osboxes kernel: veth_netdrv:vnet_init(): loaded.
Jul 08 08:16:07 osboxes kernel: veth_netdrv:vnet_open(): vnet_open:191 :
Jul 08 08:16:07 osboxes kernel: veth_netdrv:vnet_start_xmit(): UDP pkt::src=68 dest=67 len=9473
Jul 08 08:16:07 osboxes kernel: x
Jul 08 08:16:07 osboxes kernel: xx
Jul 08 08:16:07 osboxes kernel: x
Jul 08 08:16:08 osboxes kernel: x
Jul 08 08:16:08 osboxes kernel: x
Jul 08 08:16:08 osboxes kernel: xx
```

[…]

It’s waiting to receive packet(s) from the user space ‘sender’ app...

4. In another terminal window, run the user space sender app (triggering the bug!)

```
cd <...>/L5_debug_trg/kernel_debug/to_debug_assgn/netdrv_veth_buggy/userspc
./runapp
```

… <sets up the ‘veth’ network intf, assigns it an IP, ...>

…

<transmits packet(s)>

…

The entire system abruptly and immediately hangs, then warm boots into the dump kernel!
Reboots only in console mode... into the ‘dump’ kernel!

Login.

```
ls -lh /proc/vmcore
-r-------- 1 root root 1.8G Jul  8 08:27 /proc/vmcore
```

Copy in the kdump image (to disk or across n/w via scp):

```
sudo cp /proc/vmcore kdump_img
```

Reboot into regular kernel, retrieve the kdump image..

Sample run with crash app on the kdump image obtained (after it crashed)

Key ref:
Extracting kernel stack function arguments from Linux x86-64 kernel crash dumps, Calum Mackay, Sept 2020, Oracle Linux blog.

Run the crash app on the kdump image file:
A wrapper script runs:
```
$ cat ./crash_run
sudo crash <...>/vmlinux-5.10.153-kdbg1 $1
```
(where the parameter is the kernel dump image just generated. So of course you MUST have both – the kdump image and the vmlinux with debug symbols matching the kernel version..).

```
$ ls -lh ~/kdump_img
-r-------- 1 root root 1.8G Jul  8 08:29 /home/osboxes/kdump_img
$
$ ./crash_run
Usage: crash_run </path/to/kdump.img-OR-/proc/kcore>
$ ./crash_run ~/kdump_img

crash 8.0.0
Copyright (C) 2002-2021  Red Hat, Inc.
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Copyright (C) 1999-2006  Hewlett-Packard Co
Copyright (C) 2005, 2006, 2011, 2012  Fujitsu Limited
Copyright (C) 2006, 2007  VA Linux Systems Japan K.K.
Copyright (C) 2005, 2011, 2020-2021  NEC Corporation
Copyright (C) 1999, 2002, 2007  Silicon Graphics, Inc.
Copyright (C) 1999, 2000, 2001, 2002  Mission Critical Linux, Inc.
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This program has absolutely no warranty.  Enter "help warranty" for details.

GNU gdb (GDB) 10.2
Copyright (C) 2021 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "x86_64-pc-linux-gnu".
Type "show configuration" for configuration details.
Find the GDB manual and other documentation resources online at:
    <http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...

      KERNEL: ./vmlinux-5.10.153-kdbg1  [TAINTED]
    DUMPFILE: /home/osboxes/kdump_img
        CPUS: 6
[ … ]
       TASKS: 563
    NODENAME: osboxes
```
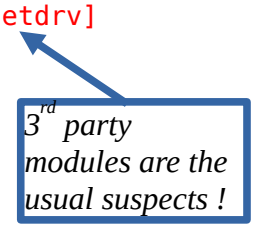

```
     RELEASE: 5.10.153-kdbg1
     VERSION: #1 SMP Tue Jun 13 15:51:43 IST 2023
     MACHINE: x86_64  (2592 Mhz)
      MEMORY: 2 GB
       PANIC: "kernel BUG at mm/slub.c:305!"
         PID: 3610
     COMMAND: "talker_dgram"          << our user space 'sender' app! >>
        TASK: ffff8a61d098c740  [THREAD_INFO: ffff8a61d098c740]
         CPU: 2
       STATE: TASK_RUNNING (PANIC)

crash>
crash> bt
PID: 3610   TASK: ffff8a61d098c740  CPU: 2   COMMAND: "talker_dgram"
 #0 [ffffa08ec21fb530] machine_kexec at ffffffffa5a80283
 #1 [ffffa08ec21fb590] __crash_kexec at ffffffffa5b7f762
 #2 [ffffa08ec21fb660] crash_kexec at ffffffffa5b80f3d
 #3 [ffffa08ec21fb678] oops_end at ffffffffa5a3cb96
 #4 [ffffa08ec21fb6a0] die at ffffffffa5a3ce43
 #5 [ffffa08ec21fb6d0] do_trap at ffffffffa5a38d39
 #6 [ffffa08ec21fb720] do_error_trap at ffffffffa5a38e0f
 #7 [ffffa08ec21fb768] exc_invalid_op at ffffffffa66204b3
 #8 [ffffa08ec21fb790] asm_exc_invalid_op at ffffffffa6800aa2
    [exception RIP: kfree+1129]
    RIP: ffffffffa5d148e9  RSP: ffffa08ec21fb840  RFLAGS: 00010246
    RAX: ffff8a623b5f6c00  RBX: ffff8a623b5f6c00  RCX: ffff8a623b5f6d00
    RDX: 0000000000005915  RSI: ffff8a61c0000000  RDI: ffff8a61c1042600
    RBP: ffffa08ec21fb8b8   R8: ffff8a61c1042600   R9: ffffffffffcb200
    R10: 0000000000000000  R11: ffff8a623b5f6c00  R12: ffffea3181ed7d80
    R13: ffffea3181ed7d80  R14: ffff8a61c1042600  R15: ffffffffa63c6612
    ORIG_RAX: ffffffffffffffff  CS: 0010  SS: 0018
 #9 [ffffa08ec21fb8c0] skb_release_data at ffffffffa63c6612
#10 [ffffa08ec21fb8e8] consume_skb at ffffffffa63c6a0e
#11 [ffffa08ec21fb900] vnet_start_xmit at ffffffffc03682ad [veth_netdrv]
#12 [ffffa08ec21fb930] dev_hard_start_xmit at ffffffffa63e2b70
#13 [ffffa08ec21fb980] sch_direct_xmit at ffffffffa6433c62
#14 [ffffa08ec21fb9d0] __dev_queue_xmit at ffffffffa63e33d9
#15 [ffffa08ec21fba40] dev_queue_xmit at ffffffffa63e35e0
#16 [ffffa08ec21fba50] neigh_resolve_output at ffffffffa63f0ff4
#17 [ffffa08ec21fba88] ip_finish_output2 at ffffffffa646dc7b
#18 [ffffa08ec21fbae0] __ip_finish_output at ffffffffa646ea6c
#19 [ffffa08ec21fbb20] ip_finish_output at ffffffffa646eb31
#20 [ffffa08ec21fbb58] ip_output at ffffffffa6470518
#21 [ffffa08ec21fbbc0] ip_send_skb at ffffffffa6470fb3
#22 [ffffa08ec21fbbe8] udp_send_skb at ffffffffa64a761e
#23 [ffffa08ec21fbc28] udp_sendmsg at ffffffffa64aaff6
#24 [ffffa08ec21fbdb8] inet_sendmsg at ffffffffa64ba0dd
#25 [ffffa08ec21fbdc8] inet_sendmsg at ffffffffa64ba0dd
#26 [ffffa08ec21fbdf0] __sys_sendto at ffffffffa63b95fb   << app sendto() >>
#27 [ffffa08ec21fbea8] vfs_write at ffffffffa5d4f5b9
#28 [ffffa08ec21fbeb0] vfs_write at ffffffffa5d4f5b9
#29 [ffffa08ec21fbf28] __x64_sys_sendto at ffffffffa63b9654
#30 [ffffa08ec21fbf38] do_syscall_64 at ffffffffa661fe98
#31 [ffffa08ec21fbf50] entry_SYSCALL_64_after_hwframe at ffffffffa68000a9
    RIP: 00007f02f4293bba  RSP: 00007ffd80dde498  RFLAGS: 00000246
    RAX: fffffffffffffda  RBX: 0000000000000000  RCX: 00007f02f4293bba
    RDX: 0000000000000011  RSI: 00007ffd80de0855  RDI: 0000000000000003
    RBP: 00007ffd80dde4f0   R8: 00007ffd80dde4d0   R9: 0000000000000010
```

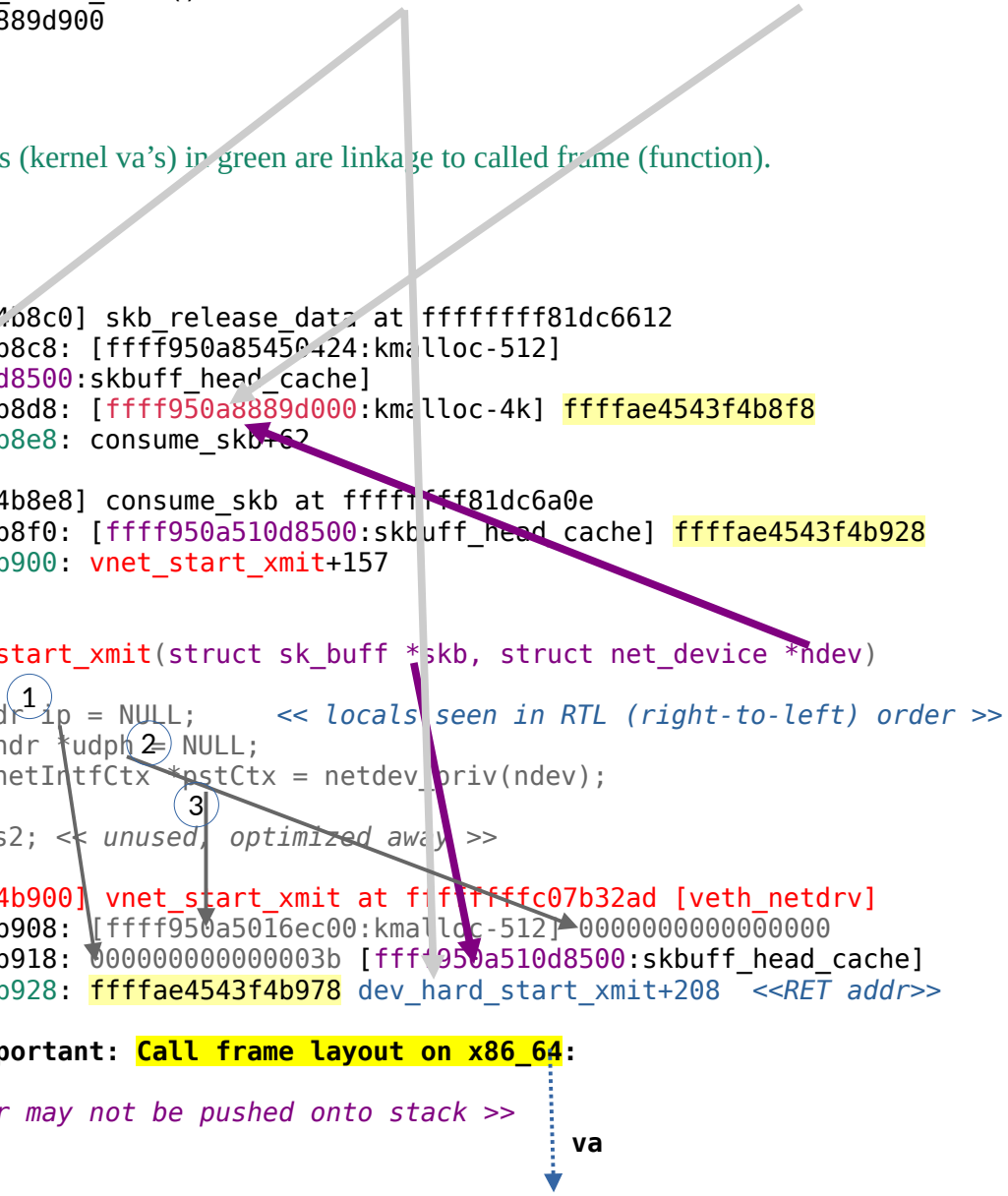


```
    R10: 0000000000000000  R11: 0000000000000246  R12: 00007ffd80dde638
    R13: 0000556b356ba3f4  R14: 0000556b356bcd50  R15: 00007f02f43ee040
    ORIG_RAX: 000000000000002c  CS: 0033  SS: 002b
crash>
crash> log   << look up kernel log (dmesg) >>
...
crash> log | grep "netdev="
veth_netdrv:vnet_start_xmit(): skb=ffff950a510d8500 netdev=ffff950a8889d000
pstCtx=ffff950a8889d900
...
```

Look up the stack

Looks like the KVA's (kernel va's) in green are linkage to called frame (function).

```
crash> bt -FF
...
...
 #9 [ffffae4543f4b8c0] skb_release_data at ffffffff81dc6612
    ffffae4543f4b8c8: [ffff950a85450424:kmalloc-512]
    [ffff950a510d8500:skbuff_head_cache]
    ffffae4543f4b8d8: [ffff950a8889d000:kmalloc-4k] ffffae4543f4b8f8
    ffffae4543f4b8e8: consume_skb+62

#10 [ffffae4543f4b8e8] consume_skb at ffffffff81dc6a0e
    ffffae4543f4b8f0: [ffff950a510d8500:skbuff_head_cache] ffffae4543f4b928
    ffffae4543f4b900: vnet_start_xmit+157

<<
static int vnet_start_xmit(struct sk_buff *skb, struct net_device *ndev)
{
      struct iphdr *ip = NULL;     << locals seen in RTL (right-to-left) order >>
      struct udphdr *udph = NULL;
      struct stVnetIntfCtx *pstCtx = netdev_priv(ndev);
      ...
      u64 ts1, ts2; << unused, optimized away >>
>>
#11 [ffffae4543f4b900] vnet_start_xmit at ffffffffc07b32ad [veth_netdrv]
    ffffae4543f4b908: [ffff950a5016ec00:kmalloc-512] 0000000000000000
    ffffae4543f4b918: 000000000000003b [ffff950a510d8500:skbuff_head_cache]
    ffffae4543f4b928: ffffae4543f4b978 dev_hard_start_xmit+208  <<RET addr>>

<<-- So, very important: Call frame layout on x86_64:
LOCALS […,3,2,1]
<< PARAMS* may or may not be pushed onto stack >>
[SFP?]RBP+                                          va
RET addr
-->>
<<
```



** See the disassembly (you might find a **push**)*

+ See notes below for inferring RBP

Of course, the RET / RBP / PARAM are our annotations here …

>>

```
#12 [ffffae4543f4b930] dev_hard_start_xmit at ffffffff81de2b70
    ffffae4543f4b938: ffffae4543f4b994 [RBP]ff950a8889d088:kmalloc-4k]
```

```
    ffffae4543f4b948: ffffae4543f4b978 [ffff950a5016ec00:kmalloc-512]
    ffffae4543f4b958: [ffff950a88b57e00:kmalloc-512]
                       [ffff950a510d8500:skbuff_head_cache] PARAM
    ffffae4543f4b968: [ffff950a88b57eac:kmalloc-512] [ffff950a8889d000:kmalloc-4k]
 RET ffffae4543f4b978: ffffae4543f4b9c8 sch_direct_xmit+226
                                        RBP]
#13 [ffffae4543f4b980] sch_direct_xmit at ffffffff81e33c62
    ffffae4543f4b988: 0000000581ec13f1 000000100089d000
    ffffae4543f4b998: 277ccc06ec916700 0000000000000000
    ffffae4543f4b9a8: [ffff950a510d8500:skbuff_head_cache] PARAM
                       [ffff950a88b57e00:kmalloc-512]
    ffffae4543f4b9b8: [ffff950a8889d000:kmalloc-4k] [ffff950a5016ec00:kmalloc-512]
 RET ffffae4543f4b9c8: ffffae4543f4ba38 __dev_queue_xmit+1705
                                        RBP]
#14 [ffffae4543f4b9d0] __dev_queue_xmit at ffffffff81de33d9
    ffffae4543f4b9d8: ffffae4543f4b9e8 [ffff950a88b57eac:kmalloc-512]
    ffffae4543f4b9e8: ffffffff443f4ba70 0000000000000000
    ffffae4543f4b9f8: ffffae4543f4bb44 [ffff950a412f0000:task_struct]
    ffffae4543f4ba08: 277ccc06ec916700 [ffff950a85451000:kmalloc-512]
    ffffae4543f4ba18: 0000000000000000 [ffff950a510d8500:skbuff_head_cache]PARAM
    ffffae4543f4ba28: [ffff950a8889d000:kmalloc-4k] 0000000000000008
 RET ffffae4543f4ba38: ffffae4543f4ba48 dev_queue_xmit+16
                                        RBP]
#15 [ffffae4543f4ba40] dev_queue_xmit at ffffffff81de35e0
 RET ffffae4543f4ba48: ffffae4543f4ba80 neigh_resolve_output+276
...
```

crash> log

```
...
...
[ 1280.033638] veth_netdrv:vnet_start_xmit(): UDP pkt::src=56894 dest=54295
len=6400
[ 1280.033639] veth_netdrv:vnet_start_xmit(): ah, a UDP packet Tx via our app
(dest port 54295)
[ 1280.033640] veth_netdrv:vnet_start_xmit(): skb=ffff8a61cf4fab00
netdev=ffff8a61d090b000 pstCtx=ffff8a61d090b900
[ 1280.033642] veth_netdrv:vnet_start_xmit(): 002)  talker_dgram :3610   |  ...1
/* vnet_start_xmit() */
[ 1280.033644] veth_netdrv:vnet_start_xmit(): ////////////////////////// SKB_PEEK
               skb ptr: ffff8a61cf4fab00
                len=59 truesize=768 users=1
                Offsets: mac_header:2 network_header:16 transport_header:36
                SKB packet pointers & offsets:
                 headroom : head:ffff8a623b5f6c00 - data:ffff8a623b5f6c02 [   2
bytes]
                 pkt data :                         data - tail: 61       [  59
bytes]
                 tailroom :                                tail - end:192 [ 131
bytes]
[ 1280.033645] veth_netdrv:vnet_start_xmit(): //////////////////////
[ 1280.033651]  00000000: 00 00 48 0f 0e 0d 0a 02 48 0f 0e 0d 0a 02 08
00  ..H.....H.......
[ 1280.033652]  00000010: 45 00 00 2d a5 be 40 00 40 11 7c 20 0a 00 02 d2
E..-..@.@.| ....
```

```
[ 1280.033652]  00000020: 0a 00 02 10 de 3e d4 17 00 19 ff 7a 68 65 79
2c  .....>.....zhey,
[ 1280.033653]  00000030: 20 76 65 74 68 2c 20 77 61 73 73 75 70 00 00 00   veth,
wassup...
[ 1280.033653]  00000040: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00  ................
[ 1280.033654]  00000050: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00  ................
[ 1280.033655]  00000060: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00  ................
[ 1280.033655]  00000070: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00  ................
[ 1280.033656]  00000080: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00  ................
[ 1280.033656]  00000090: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00  ................
[ 1280.033657]  000000a0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00  ................
[ 1280.033657]  000000b0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00  ................
[ 1280.033658] ------------[ cut here ]------------
[ 1280.033658] refcount_t: underflow; use-after-free.
[ 1280.033670] WARNING: CPU: 2 PID: 3610 at lib/refcount.c:28
refcount_warn_saturate+0xf7/0x150
[ 1280.033671] Modules linked in: veth_netdrv(OE) vboxvideo(OE) binfmt_misc
vboxsf(OE) intel_rapl_msr vmwgfx intel_rapl_common crct10dif_pclmul snd_intel8x0
crc32_pclmul snd_ac97_codec ghash_clmulni_intel aesni_intel ac97_bus glue_helper
crypto_simd snd_pcm cryptd drm_kms_helper rapl joydev snd_seq syscopyarea
sysfillrect sysimgblt fb_sys_fops cec snd_timer rc_core snd_seq_device ttm snd
input_leds serio_raw soundcore vboxguest(OE) video sch_fq_codel drm msr parport_pc
ppdev lp parport ip_tables x_tables autofs4 hid_generic usbhid hid psmouse ahci
libahci e1000 i2c_piix4 pata_acpi
[ 1280.033702] CPU: 2 PID: 3610 Comm: talker_dgram Kdump: loaded Tainted: G
OE     5.10.153-kdbg1 #1
[ 1280.033703] Hardware name: innotek GmbH VirtualBox/VirtualBox, BIOS VirtualBox
12/01/2006
[ 1280.033705] RIP: 0010:refcount_warn_saturate+0xf7/0x150
[ 1280.033706] Code: eb 9e 0f b6 1d 84 0d a4 01 80 fb 01 0f 87 e7 d6 63 00 83 e3
01 75 89 48 c7 c7 c8 b5 fa a6 c6 05 68 0d a4 01 01 e8 38 8f 60 00 <0f> 0b e9 6f ff
ff ff 0f b6 1d 53 0d a4 01 80 fb 01 0f 87 a4 d6 63
[ 1280.033706] RSP: 0018:ffffa08ec21fb8a0 EFLAGS: 00010286
[ 1280.033707] RAX: 0000000000000000 RBX: 0000000000000000 RCX: 0000000000000027
[ 1280.033708] RDX: ffff8a623dca0a48 RSI: 0000000000000001 RDI: ffff8a623dca0a40
[ 1280.033708] RBP: ffffa08ec21fb8a8 R08: 0000000000000003 R09: fffffffffffcb200
[ 1280.033709] R10: 0000000000000001 R11: 0000000000000001 R12: ffff8a61c5d5b300
[ 1280.033710] R13: ffff8a61c5d5b43c R14: ffff8a61d090b91c R15: ffff8a61d090b000
[ 1280.033711] FS:  00007f02f4169740(0000) GS:ffff8a623dc80000(0000)
knlGS:0000000000000000
[ 1280.033711] CS:  0010 DS: 0000 ES: 0000 CR0: 0000000080050033
[ 1280.033712] CR2: 00007f02f432b423 CR3: 000000000ffe6006 CR4: 00000000000706e0
[ 1280.033714] Call Trace:
[ 1280.033720]  sock_wfree+0xc0/0xd0
[ 1280.033722]  skb_release_head_state+0x36/0x80
[ 1280.033723]  consume_skb+0x2b/0xb0
[ 1280.033726]  vnet_start_xmit+0x9d/0xb0 [veth_netdrv]
[ 1280.033727]  dev_hard_start_xmit+0xd0/0x1e0
[ 1280.033729]  sch_direct_xmit+0xe2/0x260
[ 1280.033730]  __dev_queue_xmit+0x6a9/0x8a0
```

A valuable hint : a Use After Free bug?

The last call from our module before the bug...

```
...
```

```
[ffff950a510d8500:skbuff_head_cache]
```
 # *root-cause:* the SKB that's freed up too soon, by our module, resulting in a UAF; the root cause of the bug.

Useful
```
crash> bt -FF |grep -C3 --color=always ffff8a61f6a55600
...
```

Original un-annotated stack frames
```
crash> bt -F
...
...
 #9 [ffffae4543f4b8c0] skb_release_data at ffffffff81dc6612
    ffffae4543f4b8c8: [kmalloc-512]    [skbuff_head_cache]
    ffffae4543f4b8d8: [kmalloc-4k]     ffffae4543f4b8f8
    ffffae4543f4b8e8: consume_skb+62
#10 [ffffae4543f4b8e8] consume_skb at ffffffff81dc6a0e
    ffffae4543f4b8f0: [skbuff_head_cache] ffffae4543f4b928
    ffffae4543f4b900: vnet_start_xmit+157
#11 [ffffae4543f4b900] vnet_start_xmit at ffffffffc07b32ad [veth_netdrv]
    ffffae4543f4b908: [kmalloc-512]    0000000000000000
    ffffae4543f4b918: 000000000000003b [skbuff_head_cache]
    ffffae4543f4b928: ffffae4543f4b978 dev_hard_start_xmit+208
#12 [ffffae4543f4b930] dev_hard_start_xmit at ffffffff81de2b70
    ffffae4543f4b938: ffffae4543f4b994 [kmalloc-4k]
    ffffae4543f4b948: ffffae4543f4b978 [kmalloc-512]
    ffffae4543f4b958: [kmalloc-512]    [skbuff_head_cache]
    ffffae4543f4b968: [kmalloc-512]    [kmalloc-4k]
    ffffae4543f4b978: ffffae4543f4b9c8 sch_direct_xmit+226
#13 [ffffae4543f4b980] sch_direct_xmit at ffffffff81e33c62
    ffffae4543f4b988: 0000000581ec13f1 000000100089d000
    ffffae4543f4b998: 277ccc06ec916700 0000000000000000
    ffffae4543f4b9a8: [skbuff_head_cache] [kmalloc-512]
    ffffae4543f4b9b8: [kmalloc-4k]     [kmalloc-512]
    ffffae4543f4b9c8: ffffae4543f4ba38 __dev_queue_xmit+1705
#14 [ffffae4543f4b9d0] __dev_queue_xmit at ffffffff81de33d9
    ffffae4543f4b9d8: ffffae4543f4b9e8 [kmalloc-512]
    ffffae4543f4b9e8: fffffff443f4ba70 0000000000000000
    ffffae4543f4b9f8: ffffae4543f4bb44 [task_struct]
    ffffae4543f4ba08: 277ccc06ec916700 [kmalloc-512]
    ffffae4543f4ba18: 0000000000000000 [skbuff_head_cache]
    ffffae4543f4ba28: [kmalloc-4k]     0000000000000008
    ffffae4543f4ba38: ffffae4543f4ba48 dev_queue_xmit+16
#15 [ffffae4543f4ba40] dev_queue_xmit at ffffffff81de35e0
    ffffae4543f4ba48: ffffae4543f4ba80 neigh_resolve_output+276
...
```

```
================================================================================
```

Excellent article!
Src: [Extracting kernel stack function arguments from Linux x86-64 kernel crash dumps, Calum Mackay, Sept 2020]

...

The **stack frame base pointer**, (%RBP), for a function, may be found:

- As the second-last *value* in the stack frame above the function (i.e. above in the ***bt*** output)
- As the *location* of the second-last value in the stack frame for the function

…

<<
Eg. find RBP for the function consume_skb():

```
crash> bt -FF
...
 #9 [ffffa08ec21fb8c0] skb_release_data at ffffffffa63c6612
    ffffa08ec21fb8c8: [ffff8a623b5f6c24:kmalloc-512]
[ffff8a61cf4fab00:skbuff_head_cache]
    ffffa08ec21fb8d8: [ffff8a61d090b000:kmalloc-4k] ffffa08ec21fb8f8
    ffffa08ec21fb8e8: consume_skb+62
#10 [ffffa08ec21fb8e8] consume_skb at ffffffffa63c6a0e
    ffffa08ec21fb8f0: [ffff8a61cf4fab00:skbuff_head_cache] ffffa08ec21fb928
    ffffa08ec21fb900: vnet_start_xmit+157
#11 [ffffa08ec21fb900] vnet_start_xmit at ffffffffc03682ad [veth_netdrv]
    ffffa08ec21fb908: [ffff8a61f6a55600:kmalloc-512] 0000000000000000
    ffffa08ec21fb918: 000000000000003b [ffff8a61cf4fab00:skbuff_head_cache]
    ffffa08ec21fb928: ffffa08ec21fb978 dev_hard_start_xmit+208
...
...
```

First method: RBP is the value ffffa08ec21fb8f8
Second method: 2nd last value in stack frame of consume_skb() is `ffffa08ec21fb928.` Its location is `ffffa08ec21fb8f0+0x8 = ffffa08ec21fb8f8 !`

>>
...
<< Very Important! >>
…

Summary of steps

1. Note which registers you need, corresponding to the position of the called function's arguments you need *<< Recall: on x86_64, first 6 parameters are passed via the registers %rdi, %rsi, %rdx, %rcx, %r8, %r9, not via the stack >>*
    1. Refer to the register-naming table above, in case the quantities passed are smaller than 64-bit, e.g. integers, other non-pointer types. The 1st argument will be passed in *%rdi*, *%edi*, *%di* or *%dil*. Note that all the names contain "*di*".

2. Disassemble the calling function, and inspect the instructions leading up to where it calls the function you're interested in. Note from where the compiler gets the values it places in those registers

    1. If from the stack, find the caller's stack frame base pointer, and from there find the value in the stack frame
    2. If from memory, can you calculate the memory address used? If so, read the value from memory
    3. If from another register, from where was *that* register's contents obtained? And see case 3.3 below. << Very often, the parameter's in a register (say, %r12); so where/how did r12 get set? In effect, you have to keep following the disassembly… again, often/hopefully, an earlier function's assembly code PUSHed that register on the stack somewhere! Now you can find what the value in the register is by looking up that stack location! >>

3. Disassemble the first part of the called function. Note where it stores the values passed in the registers you need
    1. If onto the stack, find the called function's stack frame base pointer, and find the value in the stack frame
    2. If from memory, can you calculate the memory address used? If so, read the value from memory
    3. If the calling function obtained the value from another register (case 2.3 above) does the called function save *that* register to stack/memory?

4. If none of the above gave a usable result, see if the values you need are passed to another function call further up or down the stack, or may be derived from a different value.
    1. For example the structure you want is referenced from another structure that is passed to a function elsewhere in the stack trace

5. Once you've obtained answers, perform a sanity check
    1. Is the value obtained on a slab cache? If so, is the cache of the expected type?
    2. Is the value, or what it points to, of the expected type?
    3. If the value is a pointer to a structure, does the structure content look correct? e.g. pointers where pointers are expected, function op pointers pointing to real functions, etc

6. Read the *Caveats* section, to understand whether you can rely on the answer you've found

At this point, you may either skip directly to the *Worked Examples* , or read on for more detail.
…

Investigation: find how & which params are passed by the caller of vnet_start_xmit(), i.e., by dev_hard_start_xmit():

```
crash>bt -FF
...
 #9 [ffffa543410ab8c0] skb_release_data at ffffffff8a3c6612
    ffffa543410ab8c8: [ffff955112efb424:kmalloc-512]
[ffff955111e5ab00:skbuff_head_cache]
    ffffa543410ab8d8: [ffff95511c085000:kmalloc-4k] ffffa543410ab8f8
    ffffa543410ab8e8: consume_skb+62
#10 [ffffa543410ab8e8] consume_skb at ffffffff8a3c6a0e
```

```
    ffffa543410ab8f0: [ffff955111e5ab00:skbuff_head_cache] ffffa543410ab928
    ffffa543410ab900: ()+157
#11 [ffffa543410ab900] vnet_start_xmit at ffffffffc083b2ad [veth_netdrv]
    ffffa543410ab908: [ffff95514bc29200:kmalloc-512] 0000000000000000
    ffffa543410ab918: 000000000000003b [ffff955111e5ab00:skbuff_head_cache]
    ffffa543410ab928: ffffa543410ab978 dev_hard_start_xmit+208
#12 [ffffa543410ab930] dev_hard_start_xmit at ffffffff8a3e2b70
    ffffa543410ab938: ffffa543410ab994 [ffff95511c085088:kmalloc-4k]
    ffffa543410ab948: ffffa543410ab978 [ffff95514bc29200:kmalloc-512]
    ffffa543410ab958: [ffff95514bc28600:kmalloc-512]
[ffff955111e5ab00:skbuff_head_cache]
    ffffa543410ab968: [ffff95514bc286ac:kmalloc-512]
[ffff95511c085000:kmalloc-4k]
    ffffa543410ab978: ffffa543410ab9c8 sch_direct_xmit+226
#13 [ffffa543410ab980] sch_direct_xmit at ffffffff8a433c62
    ffffa543410ab988: 000000058a4c13f1 0000001000085000
    ffffa543410ab998: 5979a8f4c1114800 0000000000000000
    ffffa543410ab9a8: [ffff955111e5ab00:skbuff_head_cache]
[ffff95514bc28600:kmalloc-512]
    ffffa543410ab9b8: [ffff95511c085000:kmalloc-4k] [ffff95514bc29200:kmalloc-
512]
    ffffa543410ab9c8: ffffa543410aba38 __dev_queue_xmit+1705
#14 [ffffa543410ab9d0] __dev_queue_xmit at ffffffff8a3e33d9
    ffffa543410ab9d8: ffffa543410ab9e8 [ffff95514bc286ac:kmalloc-512]
    ffffa543410ab9e8: ffffffff4410aba70 0000000000000000
    ffffa543410ab9f8: ffffa543410abb44 [ffff955103238000:task_struct]
    ffffa543410aba08: 5979a8f4c1114800 [ffff955112efa000:kmalloc-512]
    ffffa543410aba18: 0000000000000000 [ffff955111e5ab00:skbuff_head_cache]
    ffffa543410aba28: [ffff95511c085000:kmalloc-4k] 0000000000000008
    ffffa543410aba38: ffffa543410aba48 dev_queue_xmit+16
...


static int vnet_start_xmit(struct sk_buff *skb, struct net_device *ndev);
```

Can see that dev_hard_start_xmit() calls vnet_start_xmit(). **But where in the disassembly?? not apparent as it's a virtual func call (a call to a struct ptr)...**
Look at this:

```
#11 [ffffa543410ab900] vnet_start_xmit at ffffffffc083b2ad [veth_netdrv]
...
ffffa543410ab928: ffffa543410ab978 dev_hard_start_xmit+208   <---
```

The RET addr is 208 bytes after the start of dev_hard_start_xmit()!
So, now we can easily gauge the call point and thus the prologue - the setting up of (param) registers!

```
crash> dis -l dev_hard_start_xmit
/home/osboxes/linux-5.10.153/net/core/dev.c: 3596
0xffffffff8a3e2aa0 <dev_hard_start_xmit>:       nopl   0x0(%rax,%rax,1)
[FTRACE NOP]
/home/osboxes/linux-5.10.153/net/core/dev.c: 3597
0xffffffff8a3e2aa5 <dev_hard_start_xmit+5>:     push   %rbp
/home/osboxes/linux-5.10.153/net/core/dev.c: 2308
0xffffffff8a3e2aa6 <dev_hard_start_xmit+6>:     lea    0x88(%rsi),%rax
/home/osboxes/linux-5.10.153/net/core/dev.c: 3596  <---
```

```
0xffffffff8a3e2aad <dev_hard_start_xmit+13>:    mov    %rsp,%rbp
0xffffffff8a3e2ab0 <dev_hard_start_xmit+16>:    push   %r15
0xffffffff8a3e2ab2 <dev_hard_start_xmit+18>:    mov    %rsi,%r15
0xffffffff8a3e2ab5 <dev_hard_start_xmit+21>:    push   %r14
0xffffffff8a3e2ab7 <dev_hard_start_xmit+23>:    mov    %rdi,%r14

<<
net/core/dev.c
 3594 struct sk_buff *dev_hard_start_xmit(struct sk_buff *first, struct
net_device *dev,
 3595                                        struct netdev_queue *txq, int *ret)
 3596 {    <---  [A]          << see below >>
 3597         struct sk_buff *skb = first;
>>

/home/osboxes/linux-5.10.153/net/core/dev.c: 3600
0xffffffff8a3e2aba <dev_hard_start_xmit+26>:    push   %r13
0xffffffff8a3e2abc <dev_hard_start_xmit+28>:    push   %r12
0xffffffff8a3e2abe <dev_hard_start_xmit+30>:    push   %rbx
0xffffffff8a3e2abf <dev_hard_start_xmit+31>:    mov    %rdx,%rbx
/home/osboxes/linux-5.10.153/net/core/dev.c: 3598
0xffffffff8a3e2ac2 <dev_hard_start_xmit+34>:    xor    %edx,%edx
/home/osboxes/linux-5.10.153/net/core/dev.c: 3596
0xffffffff8a3e2ac4 <dev_hard_start_xmit+36>:    sub    $0x18,%rsp
0xffffffff8a3e2ac8 <dev_hard_start_xmit+40>:    mov    %rcx,-0x40(%rbp)
/home/osboxes/linux-5.10.153/net/core/dev.c: 2308
0xffffffff8a3e2acc <dev_hard_start_xmit+44>:    mov    %rax,-0x38(%rbp)
/home/osboxes/linux-5.10.153/net/core/dev.c: 3600
0xffffffff8a3e2ad0 <dev_hard_start_xmit+48>:    test   %r14,%r14
0xffffffff8a3e2ad3 <dev_hard_start_xmit+51>:    je     0xffffffff8a3e2bb6
<dev_hard_start_xmit+278>
/home/osboxes/linux-5.10.153/net/core/dev.c: 3601
0xffffffff8a3e2ad9 <dev_hard_start_xmit+57>:    mov    (%r14),%r12
/home/osboxes/linux-5.10.153/./include/linux/skbuff.h: 1503
0xffffffff8a3e2adc <dev_hard_start_xmit+60>:    movq   $0x0,(%r14)
/home/osboxes/linux-5.10.153/net/core/dev.c: 3604
0xffffffff8a3e2ae3 <dev_hard_start_xmit+67>:    mov    0x1626806(%rip),%rax
# 0xffffffff8ba092f0 <ptype_all>
0xffffffff8a3e2aea <dev_hard_start_xmit+74>:    test   %r12,%r12
0xffffffff8a3e2aed <dev_hard_start_xmit+77>:    setne  %cl
/home/osboxes/linux-5.10.153/./include/linux/list.h: 282
0xffffffff8a3e2af0 <dev_hard_start_xmit+80>:    cmp
$0xffffffff8ba092f0,%rax
0xffffffff8a3e2af6 <dev_hard_start_xmit+86>:    je     0xffffffff8a3e2c67
<dev_hard_start_xmit+455>
/home/osboxes/linux-5.10.153/net/core/dev.c: 3583
0xffffffff8a3e2afc <dev_hard_start_xmit+92>:    mov    %r15,%rsi
0xffffffff8a3e2aff <dev_hard_start_xmit+95>:    mov    %r14,%rdi
0xffffffff8a3e2b02 <dev_hard_start_xmit+98>:    mov    %cl,-0x2c(%rbp)
0xffffffff8a3e2b05 <dev_hard_start_xmit+101>:   call   0xffffffff8a3dcba0
<dev_queue_xmit_nit>
0xffffffff8a3e2b0a <dev_hard_start_xmit+106>:   movzbl -0x2c(%rbp),%ecx
/home/osboxes/linux-5.10.153/net/core/dev.c: 3585
0xffffffff8a3e2b0e <dev_hard_start_xmit+110>:   mov    0x68(%r14),%esi
/home/osboxes/linux-5.10.153/net/core/dev.c: 3586
```

```
0xffffffff8a3e2b12 <dev_hard_start_xmit+114>:   mov    0x1224e67(%rip),%rax
# 0xffffffff8b607980 <jiffies>
/home/osboxes/linux-5.10.153/net/core/dev.c: 3585
0xffffffff8a3e2b19 <dev_hard_start_xmit+121>:   mov    %rsi,%r13
/home/osboxes/linux-5.10.153/net/core/dev.c: 3586
0xffffffff8a3e2b1c <dev_hard_start_xmit+124>:   add    %rax,%rsi
/home/osboxes/linux-5.10.153/./include/linux/prandom.h: 57
0xffffffff8a3e2b1f <dev_hard_start_xmit+127>:   mov    %gs:0x75c4efb9(%rip),
%rax        # 0x31ae0
0xffffffff8a3e2b27 <dev_hard_start_xmit+135>:   xor    %r14,%rax
/home/osboxes/linux-5.10.153/./include/linux/bitops.h: 85
0xffffffff8a3e2b2a <dev_hard_start_xmit+138>:   lea    (%rbx,%rsi,1),%rdx
0xffffffff8a3e2b2e <dev_hard_start_xmit+142>:   rol    $0x10,%rsi
/home/osboxes/linux-5.10.153/./include/linux/prandom.h: 58
0xffffffff8a3e2b32 <dev_hard_start_xmit+146>:   add    %r15,%rax
0xffffffff8a3e2b35 <dev_hard_start_xmit+149>:   xor    %rsi,%rdx
/home/osboxes/linux-5.10.153/./include/linux/bitops.h: 85
0xffffffff8a3e2b38 <dev_hard_start_xmit+152>:   rol    $0x20,%rax
0xffffffff8a3e2b3c <dev_hard_start_xmit+156>:   add    %rdx,%rax
0xffffffff8a3e2b3f <dev_hard_start_xmit+159>:   rol    $0x15,%rdx
/home/osboxes/linux-5.10.153/./include/linux/prandom.h: 59
0xffffffff8a3e2b43 <dev_hard_start_xmit+163>:   xor    %rdx,%rax
0xffffffff8a3e2b46 <dev_hard_start_xmit+166>:   mov    %rax,
%gs:0x75c4ef92(%rip)        # 0x31ae0
/home/osboxes/linux-5.10.153/./arch/x86/include/asm/jump_label.h: 25
0xffffffff8a3e2b4e <dev_hard_start_xmit+174>:   nopl   0x0(%rax,%rax,1)
/home/osboxes/linux-5.10.153/./include/linux/netdevice.h: 4803
0xffffffff8a3e2b53 <dev_hard_start_xmit+179>:   mov    0x1e0(%r15),%rax
/home/osboxes/linux-5.10.153/./include/linux/netdevice.h: 4791
0xffffffff8a3e2b5a <dev_hard_start_xmit+186>:   mov    %r15,%rsi      ← 2nd
parameter
0xffffffff8a3e2b5d <dev_hard_start_xmit+189>:   mov    %r14,%rdi      ← 1st
parameter
0xffffffff8a3e2b60 <dev_hard_start_xmit+192>:   mov    %cl,
%gs:0x75c522fb(%rip)        # 0x34e62
/home/osboxes/linux-5.10.153/./include/linux/netdevice.h: 4792
0xffffffff8a3e2b67 <(+199>:   mov    0x20(%rax),%rax
0xffffffff8a3e2b6b <dev_hard_start_xmit+203>:   call   0xffffffff8aa02100
<__x86_indirect_thunk_array>
0xffffffff8a3e2b70 <dev_hard_start_xmit+208>:   mov    %eax,%edx
```

...
See the 'call' instr (2nd last line)!

Now the assembly which first touches %r14 's here:

```
0xffffffff8a3e2ab5 <dev_hard_start_xmit+21>:    push   %r14
```

So it corr to src code line 3596; here:
See pt [A] :

```
 3594 struct sk_buff *dev_hard_start_xmit(struct sk_buff *first, struct
net_device *dev,
 3595                                     struct netdev_queue *txq, int *ret)
 3596 {    <---  [A]
 3597         struct sk_buff *skb = first;
```

Aha! the compiler's setting the local variable - ***using register r14 for optimization!*** - the SKB to the first param (rdi val);
So we confirm that r14, and thus rdi, and thus the first parameter, is the SKB ptr !!!

2nd param: rsi:

```
 ...
 /home/osboxes/linux-5.10.153/net/core/dev.c: 3583
0xffffffff8a3e2afc <dev_hard_start_xmit+92>:    mov    %r15,%rsi
...
```

It's set to the register r15's value. We need to find what that is…

See the disassembly (search for the needed register (%r15 here) being set):

This line sets rsi to r15; rsi is the 2nd param passed to this func - dev_hard_start_xmit(); thus it's struct net_device *dev ! Now setting this to r15

```
0xffffffff8a3e2ab2 <dev_hard_start_xmit+18>:    mov    %rsi,%r15
```

and then r15 gets set to rsi before calling our vnet_start_xmit() func ; thus, the 2nd param passed is indeed the ptr to struct net_device.

Done.
