

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ ТЕХНІЧНИЙ УНІВЕРСИТЕТ УКРАЇНИ
«КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ
імені ІГОРЯ СІКОРСЬКОГО»

ЗВІТ
ПРО ЛАБОРАТОРНУ РОБОТУ №5

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Історія виконаних команд:

```
cd
cd AK/Lab5/
vi hello3.c
vi Makefile
// встановлення змінних середовища, які використовуються при збиранні ядра Linux
// для архітектури ARM
export KDIR=$HOME/repos/linux-stable
export PATH=/opt/gcc-arm-8.3-2019.03-x86_64-arm-eabi/bin:$PATH
export CROSS_COMPILE='ccache arm-eabi-'
export ARCH=arm
make
cp hello3.ko ~/repos/busybox/_install/hello1.ko      // Додаємо hello3.ko до директорії BBB
cd
cd repos/busybox/_install
find . | cpio -o -H newc | gzip > ../rootfs.cpio.gz    // Перезбираємо BBB
cd ..
qemu-system-arm -kernel _install/boot/zImage -initrd rootfs.cpio.gz \
-m 512M -machine virt -nographic -m 512 \
--append "root=/dev/ram0 rw console=ttyAMA0,115200 mem=512M"
ls
insmod hello3.ko myParam=8
rmmod hello3.ko
insmod hello3.ko myParam=11
${CROSS_COMPILE}objdump -dS hello3.o | grep e7f001f2
```

Вихідний код hello3.c:

```
#include <linux/init.h>
#include <linux/module.h>
#include <linux/printk.h>
#include <linux/list.h>
#include <linux/ktime.h>
#include <linux/slab.h>

MODULE_AUTHOR("nazar ");
MODULE_DESCRIPTION("Lab5 Module hello.c");
MODULE_LICENSE("Dual BSD/GPL");

static uint myParam = 1;

// 0444 = S_IRUGO - флаг дозволу на читання параметра
module_param(myParam, uint, 0444);
MODULE_PARM_DESC(myParam, "My description");

struct myStruct {
    struct list_head list;
    ktime_t myTime;
};

// статична зміна голови списку
static LIST_HEAD(myList);
int counter;

static void freeMemory(int message) {
    struct myStruct *ptr, *next;
    list_for_each_entry_safe(ptr, next, &myList, list) {
        if (message == 1) {
            pr_emerg("Time in nanoseconds: %lld\n", ktime_to_ns(ptr->myTime));
        }
        list_del(&ptr->list);
        kfree(ptr);
    }
}

static int __init hello_init(void)
{
    BUG_ON(myParam > 10);

    if (myParam == 0 || (myParam <= 10 && myParam >= 5)) {
        pr_emerg("Warning: %u\n", myParam);
    }

    counter = 0;
    while (counter < myParam) {
        struct myStruct *ptr = kmalloc(sizeof(*ptr), GFP_KERNEL);
        // Примусово встановлення ptr на 0 для 9-го елемента
        if (counter == 9) {
            ptr = NULL;
        }
    }
}
```

```

    }
    if (!ptr) {
        pr_err("kmalloc() returned 0\n");
        freeMemory(0);
        BUG();
    }
    ptr->myTime = ktime_get();
    list_add_tail(&ptr->list, &myList);
    pr_emerg("Hello world!\n");
    counter += 1;
}

return 0;
}

static void __exit hello_exit(void)
{
    freeMemory(1);
}

module_init(hello_init);
module_exit(hello_exit);

```

Вихідний код Makefile зроблений по аpendix1:

```

ifneq ($(KERNELRELEASE),)
# kbuild part of makefile
obj-m := hello3.o
ccflags-y += -g                # add debugging info
else
# normal makefile
KDIR ?= /lib/modules/`uname -r`/build

default:
    $(MAKE) -C $(KDIR) M=$$PWD
    cp hello3.ko hello3.ko.unstripped
    $(CROSS_COMPILE)strip -g hello3.ko    # strip only debugging info

clean:
    $(MAKE) -C $(KDIR) M=$$PWD clean

%.s %.i: %.c                    # just use make hello.s instead of objdump
    $(MAKE) -C $(KDIR) M=$$PWD $$@

endif

```

Скріншоти виконання та перевірки

Вхідний параметр 8:

```
/ # insmod hello1.ko
[ 108.034318] hello1: loading out-of-tree module taints kernel.
/ # insmod hello2.ko myParam=8
[ 120.121231] Calling print_hello() from hello2...
[ 120.122257] Warning: 8
[ 120.122454] Hello world!
[ 120.122800] Hello world!
[ 120.123575] Hello world!
[ 120.124121] Hello world!
[ 120.124389] Hello world!
[ 120.124653] Hello world!
[ 120.124797] Hello world!
[ 120.125046] Hello world!
/ # rmmod hello2.ko
/ # rmmod hello1.ko
[ 184.535990] Time in nanoseconds: 290384
[ 184.538083] Time in nanoseconds: 772272
[ 184.544546] Time in nanoseconds: 514800
[ 184.544972] Time in nanoseconds: 264704
[ 184.545606] Time in nanoseconds: 261568
[ 184.545761] Time in nanoseconds: 145552
[ 184.545924] Time in nanoseconds: 243664
[ 184.546283] Time in nanoseconds: 596960
```

Вхідний параметр 11 (максимально можливий - 10):

```
/ # insmod hello3.ko myParam=11
[ 72.044499] -----[ cut here ]-----
[ 72.044709] kernel BUG at /home/bozhyk_n/AK/Lab5/hello3.c:41!
[ 72.044986] Internal error: Oops - BUG: 0 [#1] SMP ARM
[ 72.045281] Modules linked in: hello3(O+) [last unloaded: hello3]
[ 72.045659] CPU: 0 PID: 67 Comm: insmod Tainted: G          0      4.19.296 #1
[ 72.045832] Hardware name: Generic DT based system
[ 72.046437] PC is at hello_init+0x18/0x1000 [hello3]
[ 72.046800] LR is at do_one_initcall+0x54/0x214
[ 72.046932] pc : [<bf00d018>]   lr : [<c0302dcc>]   psr: 200f0013
[ 72.047222] sp : c8ad1db8 ip : c8ae0400 fp : bf00a040
[ 72.047416] r10: 00000000 r9 : c1604c48 r8 : 00000000
[ 72.047492] r7 : bf00d000 r6 : bf00a000 r5 : c1604c48 r4 : c1787d00
[ 72.047574] r3 : 00000000 r2 : d7077925 r1 : 0000000b r0 : 00000000
[ 72.047744] Flags: nzCv IRQs on FIQs on Mode SVC_32 ISA ARM Segment none
[ 72.047841] Control: 10c5387d Table: 48b5806a DAC: 00000051
[ 72.048147] Process insmod (pid: 67, stack limit = 0x(ptrval))
[ 72.048322] Stack: (0xc8ad1db8 to 0xc8ad2000)
[ 72.048529] 1da0:                                     c1787d00 c1604c48
[ 72.048782] 1dc0: fffffe00 bf00d000 00000000 c1604c48 00000000 c0302dcc c8ae0f00 c04f1d08
[ 72.049070] 1de0: 00000000 00000002 00000000 00000000 c8ae0ee4 c04f26e4 00000000 e0b7bfff
[ 72.049318] 1e00: ffe00000 fffff000 c0f12218 c8ae0480 dbceec00 dbbd9000 dbceec00 00000001
[ 72.049489] 1e20: bf00a040 d7077925 bf00a040 00000002 c8ae0440 00000002 c8ae0f00 c03d21d4
[ 72.049822] 1e40: c8ae0f00 c0463338 c8ad1f30 c8ad1f30 00000002 c8ae0ec0 00000002 c03d4588
[ 72.050067] 1e60: bf00a04c 00007fff bf00a040 c03d1410 c8b4b418 bf00a088 c8b4b6e4 bf00a234
[ 72.050314] 1e80: 00000001 bf00a170 c135a458 c1220694 c1220704 c1604c48 c1608f04 c8ae0400
[ 72.050546] 1ea0: fffff000 e0800000 c8ae0400 c8ae0440 00000000 00000000 00000000 00000000
[ 72.050775] 1ec0: 00000000 00000000 6e72656b 00006c65 00000000 00000000 00000000 00000000
[ 72.050947] 1ee0: 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000
[ 72.051299] 1f00: 00000000 d7077925 00000080 000016fc 00000000 e0b7a6fc 0011c954 c1604c48
[ 72.051532] 1f20: 0011b1f8 fffffe00 00000051 c03d49ec e0b792c2 e0b793c0 e0b79000 000016fc
[ 72.051762] 1f40: e0b7a0bc e0b79f14 e0b79bf4 00003000 00003060 00000000 00000000 00000000
[ 72.051998] 1f60: 000016d8 00000025 00000026 0000001d 00000000 00000015 00000000 d7077925
[ 72.052401] 1f80: 000f411f 0011b1f8 b6fb5950 000016fc 00000080 c0301264 c8ad0000 00000080
[ 72.052638] 1fa0: 000f411f c0301000 0011b1f8 b6fb5950 0011b258 000016fc 0011b1f8 00000000
[ 72.052865] 1fc0: 0011b1f8 b6fb5950 000016fc 00000080 00000001 bec7fea0 001086c5 000f411f
[ 72.053095] 1fe0: bec7fb58 bec7fb48 0003b270 b6e6f1b0 600f0010 0011b258 00000000 00000000
[ 72.054497] [<bf00d018>] (hello_init [hello3]) from [<c0302dcc>] (do_one_initcall+0x54/0x214)
[ 72.054733] [<c0302dcc>] (do_one_initcall) from [<c03d21d4>] (do_init_module+0x48/0x1ec)
[ 72.054901] [<c03d21d4>] (do_init_module) from [<c03d4588>] (load_module+0x21a8/0x24b4)
[ 72.055534] [<c03d4588>] (load_module) from [<c03d49ec>] (sys_init_module+0x158/0x18c)
[ 72.057988] [<c03d49ec>] (sys_init_module) from [<c0301000>] (ret_fast_syscall+0x0/0x54)
[ 72.058160] Exception stack(0xc8ad1fa8 to 0xc8ad1ff0)
[ 72.058376] 1fa0:                                0011b1f8 b6fb5950 0011b258 000016fc 0011b1f8 00000000
[ 72.058621] 1fc0: 0011b1f8 b6fb5950 000016fc 00000080 00000001 bec7fea0 001086c5 000f411f
[ 72.058923] 1fe0: bec7fb58 bec7fb48 0003b270 b6e6f1b0
[ 72.059426] Code: e34b6f00 e5961008 e351000a 9a000000 (e7f001f2)
[ 72.059812] ---[ end trace f7ea3aa01a9f5b47 ]---
Segmentation fault
```

Спроба force remove:

```
/ # rmmod -f hello3.ko
rmmod: remove 'hello3': Device or resource busy
```

Для вирішення цієї проблеми допомагає перезапуск емулятора.

Вхідний параметр 10 (Помилка на 9-му елементі):

```
/ # insmod hello3.ko myParam=10
[ 39.527191] Warning: 10
[ 39.527497] Hello world!
[ 39.527623] Hello world!
[ 39.527664] Hello world!
[ 39.527699] Hello world!
[ 39.527732] Hello world!
[ 39.527824] Hello world!
[ 39.527861] Hello world!
[ 39.527894] Hello world!
[ 39.528010] Hello world!
[ 39.528053] kmalloc() returned 0
[ 39.528856] -----[ cut here ]-----
[ 39.529040] kernel BUG at /home/bozhyk_n/AK/Lab5/hello3.c:57!
[ 39.529346] Internal error: Oops - BUG: 0 [#1] SMP ARM
[ 39.529594] Modules linked in: hello3(0+) [last unloaded: hello3]
[ 39.530313] CPU: 0 PID: 67 Comm: insmod Tainted: G          0      4.19.296 #1
[ 39.530466] Hardware name: Generic DT based system
[ 39.531058] PC is at hello_init+0xa8/0x1000 [hello3]
[ 39.531216] LR is at 0x3bf6
[ 39.531335] pc : [<bf00d0a8>]   lr : [<00003bf6>]   psr: 600f0013
[ 39.531471] sp : c8b1ddb8 ip : dbceebc0 fp : bf00a040
[ 39.531538] r10: 00000000 r9 : 006000c0 r8 : c135c34c
[ 39.531663] r7 : bf0090e8 r6 : bf00a000 r5 : c8ade980 r4 : bf00a280
[ 39.531809] r3 : dbbccfb4 r2 : dbbccfb0 r1 : 1a669000 r0 : db001e40
[ 39.532175] Flags: nZCv IRQs on FIQs on Mode SVC_32 ISA ARM Segment none
[ 39.532363] Control: 10c5387d Table: 48ad006a DAC: 00000051
[ 39.532576] Process insmod (pid: 67, stack limit = 0x(ptrval))
[ 39.532760] Stack: (0xc8b1ddb8 to 0xc8b1e000)
[ 39.532964] dda0:                                c1787d00 c1604c48
[ 39.533269] ddc0: fffffe00 bf00d000 00000000 c1604c48 00000000 c0302dcc c8b3af40 c04f1d08
[ 39.533555] dde0: 00000000 00000002 00000000 00000000 c8b3af24 c04f26e4 00000000 e0b7bfff
[ 39.533840] de00: ffe00000 ffffff00 c0f12218 c8b3a3c0 dbceed00 dbbd9000 dbceed00 00000001
[ 39.534122] de20: bf00a040 d78dc82f bf00a040 00000002 c8b3a400 00000002 c8b3af40 c03d21d4
[ 39.534423] de40: c8b3af40 c0463338 c8b1df30 c8b1df30 00000002 c8b3af00 00000002 c03d4588
[ 39.534706] de60: bf00a04c 00007fff bf00a040 c03d1410 c8b0b418 bf00a088 c8b0b6e4 bf00a234
[ 39.534987] de80: 00000001 bf00a170 c135a458 c1220694 c1220704 c1604c48 c1608f04 c8b3a380
[ 39.535590] dea0: ffffff00 e0800000 c8b3a380 c8b3a400 00000000 00000000 00000000 00000000
[ 39.535891] dec0: 00000000 00000000 6e72656b 00006c65 00000000 00000000 00000000 00000000
[ 39.536174] dee0: 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000
[ 39.536457] df00: 00000000 d78dc82f 00000080 000016fc 00000000 e0b7a6fc 0011c954 c1604c48
[ 39.536738] df20: 0011b1f8 fffffe00 00000051 c03d49ec e0b792c2 e0b793c0 e0b79000 000016fc
[ 39.537019] df40: e0b7a0bc e0b79f14 e0b79bf4 00003000 00003060 00000000 00000000 00000000
[ 39.537300] df60: 000016d8 00000025 00000026 0000001d 00000000 00000015 00000000 d78dc82f
[ 39.537583] df80: 000f411f 0011b1f8 b6f35950 000016fc 00000080 c0301264 c8b1c000 00000080
[ 39.537863] dfa0: 000f411f c0301000 0011b1f8 b6f35950 0011b258 000016fc 0011b1f8 00000000
[ 39.538188] dfc0: 0011b1f8 b6f35950 000016fc 00000080 00000001 bee6dea0 001086c5 000f411f
[ 39.538470] dfe0: bee6db58 bee6db48 0003b270 b6def1b0 600f0010 0011b258 00000000 00000000
[ 39.539213] [<bf00d0a8>] (hello_init [hello3]) from [<c0302dcc>] (do_one_initcall+0x54/0x214)
[ 39.539540] [<c0302dcc>] (do_one_initcall) from [<c03d21d4>] (do_init_module+0x48/0x1ec)
[ 39.539753] [<c03d21d4>] (do_init_module) from [<c03d4588>] (load_module+0x21a8/0x24b4)
[ 39.539980] [<c03d4588>] (load_module) from [<c03d49ec>] (sys_init_module+0x158/0x18c)
[ 39.540189] [<c03d49ec>] (sys_init_module) from [<c0301000>] (ret_fast_syscall+0x0/0x54)
[ 39.540402] Exception stack(0xc8b1dfa8 to 0xc8b1dff0)
[ 39.540591] dfa0: 0011b1f8 b6f35950 0011b258 000016fc 0011b1f8 00000000
[ 39.540878] dfc0: 0011b1f8 b6f35950 000016fc 00000080 00000001 bee6dea0 001086c5 000f411f
[ 39.541127] dfe0: bee6db58 bee6db48 0003b270 b6def1b0
[ 39.541436] Code: e34b0f00 eb7a0e65 e3a00000 ebffebd5 (e7f001f2)
[ 39.541808] ---[ end trace 5a03f31d489c17de ]---
Segmentation fault
```

Помилки OOPS, або "Out Of Kernel Space", можуть виникнути в результаті серйозної помилки в коді ядра або в модулях ядра, які призводять до некоректної поведінки або навіть до аварійного завершення роботи системи. У нашому випадку – це навмисно створені помилки за допомогою BUG() та BUG_ON().

Дизасемблерный код:

```
Disassembly of section .init.text:

00000000 <init_module>:
    }

static int __init hello_init(void)
{
    0: e92d47f0    push    {r4, r5, r6, r7, r8, r9, sl, lr}
        BUG_ON(myParam > 10);
    4: e3006000    movw    r6, #0
    8: e3406000    movt    r6, #0
   c: e5961008    ldr     r1, [r6, #8]
  10: e351000a    cmp     r1, #10
  14: 9a000000    bls     1c <init_module+0x1c>
  18: e7f001f2    .word   0xe7f001f2

        if (myParam == 0 || (myParam <= 10 && myParam >= 5)) {
  1c: e2413005    sub     r3, r1, #5
  20: e3510000    cmp     r1, #0
  24: 13530005    cmpne   r3, #5
  28: 8a000002    bhi     38 <init_module+0x38>
        pr_emerg("Warning: %u\n", myParam);
  2c: e3000000    movw    r0, #0
  30: e3400000    movt    r0, #0
  34: ebfffffe    bl      0 <printk>
    }
}
```

...

```
init_module (counter, myParam) {
  60: e5942000    ldr     r2, [r4]
  64: e5963008    ldr     r3, [r6, #8]
  68: e1520003    cmp     r2, r3
  6c: 2a00001b    bcs     e0 <init_module+0xe0>
  70: e3a02010    mov     r2, #16
  74: e1a01009    mov     r1, r9
  78: e5980018    ldr     r0, [r8, #24]
  7c: ebfffffe    bl      0 <kmem_cache_alloc_trace>

        if (counter == 9) {
  80: e5943000    ldr     r3, [r4]
        if (!ptr) {
  84: e3500000    cmp     r0, #0
  88: 13530009    cmpne   r3, #9
  8c: e1a05000    mov     r5, r0
  90: 1a000005    bne     ac <init_module+0xac>
        pr_err("kmalloc() returned 0\n");
  94: e3000000    movw    r0, #0
  98: e3400000    movt    r0, #0
  9c: ebfffffe    bl      0 <printk>
        freeMemory(0);
  a0: e3a00000    mov     r0, #0
  a4: ebfffffe    bl      0 <init_module>
        BUG();
  a8: e7f001f2    .word   0xe7f001f2
        ptr->myTime = ktime_get();
  ac: ebfffffe    bl      0 <ktime_get>
        __list_add(new, head->prev, head);
  b0: e5963004    ldr     r3, [r6, #4]
}
```


Посилання на репозиторій github:

<https://github.com/bozhik45/ak-2-labs/tree/lab-5>