University of Colorado at Colorado Springs
Operating Systems Project 2
Kernel Modules and Processes

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Total Points: 100
Out: 8/26/2024
Due: 11:59 pm, 10/24/2024

Introduction

The purpose of this project is to study how to write Linux kernel modules and learn how processes are managed by the Linux OS. The objectives of this project is to learn:

1. How to write a helloworld Linux kernel module. The free book The Linux Kernel Module Programming Guide will be super helpful.
2. How to obtain various information for a running process from the Linux kernel.

Project submission

For each project, please create a zipped file containing the following items, and submit it to Canvas.

1. A report that includes (1) the (printed) full names of the project members, and the statement: **We have neither given nor received unauthorized assistance on this work**; (2) the name and location of your virtual machine (VM), the path in VM where your code is located, and the password for the user to run the code; and (3) a brief description about how you solved the problems and what you learned. The report can be in **txt, doc, or pdf format**. A Word template is provided in Canvas under Modules → Tutorial and template.
2. Your code and `Makefile`; **please do not include compiled output**. Even though you have your code in your VM, submitting code in Canvas will provide a backup if we have issues accessing your VM.

Project

Part 0.0: Use the provided template for report (5 points)

Part 0.1: Preparation

First, run the following command using **sudo**:

```
$ sudo apt-get install gcc-12 vim
```

I just secretly made you install `vim` because I like using `vim` to write my code. But you are free to install and use other editors.

Part 1: Create a helloworld kernel module (25 points)

The following code is a complete helloworld module. Be careful about the quotation marks – type the `printk` function by hand rather than copy&pasta to avoid encoding issues. Save the code as `hello.c`.

```
#include <linux/module.h>
#include <linux/kernel.h>

int init_module(void) {
    printk(KERN_INFO "Hello world!\n");
    return 0;
}

void cleanup_module(void){
    printk(KERN_INFO "Goodbye world!\n");
}

module_init(init_module);
module_exit(cleanup_module);

MODULE_LICENSE("GPL");
```

Note that on the last line `MODULE_LICENSE("GPL")`, there's an underscore between `MODULE` and `LICENSE`. This module defines two functions. `init_module` is invoked when the module is loaded into the kernel and `cleanup_module` is called when the module is removed from the kernel. `module_init` and `module_exit` are special kernel macros to indicate the role of these two functions.

Use the `Makefile` below to compile the module. **Even though for regular C programs both `Makefile` and `makefile` would work, the kernel build scripts expect `Makefile` as a convention. Also, please make sure that your project directory and sub-directory names do not have any white spaces**, e.g., do not name your directory `Project 2`. Because this `Makefile` uses `PWD`, any white spaces in your project directory's path will lead to errors that are very hard to troubleshoot. Please use underscores and dashes instead, or simply remove any white space.

```
obj-m += hello.o
all:
	make -C /lib/modules/$(shell uname -r)/build M=$(PWD) modules
clean:
	make -C /lib/modules/$(shell uname -r)/build M=$(PWD) clean
```

Do you see any errors when you type `make`? If so, how to fix the error (10pts)? To remove all compiled output, do `make clean`. After fixing, you will need to load your module into the kernel. Run this command using `sudo`:

```
$ sudo insmod hello.ko
```

Then use this to see the output:

```
$ sudo dmesg -T | tail
```

If you see a message like "loading out-of-tree module taints kernel" and "module verification failed: signature and/or required key missing - tainting kernel", it means that you

are loading a kernel module that hasn't been fully tested or integrated with the kernel. This message was intended to identify conditions which may make it difficult to properly troubleshoot a kernel problem. For example, loading a proprietary module can make kernel debug output unreliable because kernel developers have no access to the module's source code. For this project, messages like this can be ignored (at least for now).

Next, use the following command to verify the module has been loaded:

```
$ sudo lsmod
```

To remove the module from the kernel do the following (`.ko` is not needed):

```
$ sudo rmmod hello
```

Use `dmesg` again to see the module's output:

```
$ sudo dmesg -T | tail
```

`dmesg` displays the kernel ring buffer, from almost everything (more info about kernel ring buffer). You need to look at the most recent event logs to see messages from your module. The `-T` option will print the timestamp as human readable time; piping the output to `tail` will print the last 10 lines. If you want to see the last 20 lines, provide an option to `tail` as `tail -20`. Notice the different timestamps when `Hello world!` and `Goodbye world!` are printed (15pts).

Part 2: Create a print_self kernel module (30 points)

Follow the instructions above and implement a module `print_self`. This module identifies the current process at the user-level and print out various information of the process. Implement the `print_self` module and print out the following:

- Process name, id, and state;
- The same above information of its parent process until `init`.

To keep things clean, I recommend that you create different sub-directories for different modules and create a different `Makefile` than Part 1. In your report, please (1) list steps to load and remove your module, and read your module's output; and (2) answer the following questions:

1. The macro `current` returns a pointer to the `task_struct` of the current running process. See the following link: `https://linuxgazette.net/133/saha.html` When you load your module, which process is recognized as `current`? Because this link is very old (from 2006), **one of the header files in the `#include` is no longer used. See this post to modify it to use the correct header file.**

2. As discussed in our lecture, in old kernels the mother of all processes is called `init`, or the process with a pid of 1. In newer kernels, what is it called and what do you see from your module's output?

3. To see the different states of a process, please refer to the same page above `https://linuxgazette.net/133/saha.html` Do you notice something not working again? **Please see this kernel commit where `task_struc->state` has been renamed as `task_struc->__state`.** When printing state in your code, please map the numeric state to its string state, e.g., print `TASK_RUNNING` if state is 0. From your module's output, which state(s) are observed?

Part 3: Create a print_other kernel module (30 points)

Implement another module `print_other` to print the information for an arbitrary process. The module takes a process PID as its argument and outputs the above information (same as Part 2) of this process all the way back to `init`.

Some hints:

1. There are some functions and macros that the Linux kernel provides to look up a process in the process table. However, not all of the functions and macros are available to modules. Please refer to the lecture slides which ones should be used. See this very old thread as an example.

2. To get a valid PID for a process that's running, you may use command `pgrep bash`. `bash` is the default command line shell. `pgrep bash` will provide PIDs of all instances of `bash`. You can choose any of them if you get more than one.

3. Refer to the free book The Linux Kernel Module Programming Guide how to pass an argument to your kernel module. In your report, please list steps to load and remove your module, and read your module's output.

Part 4: Kernel Modules and System Calls (10 points)

So what exactly is a kernel module? Please read this short article (kernel modules are also known as loadable modules). Use your own words, please answer the following:

1. What's the difference between a kernel module and a system call?

2. This article is over 20 years old. If you try this example from the article, does it still work? Use your own words to explain why you think this may be a good (or bad) thing.