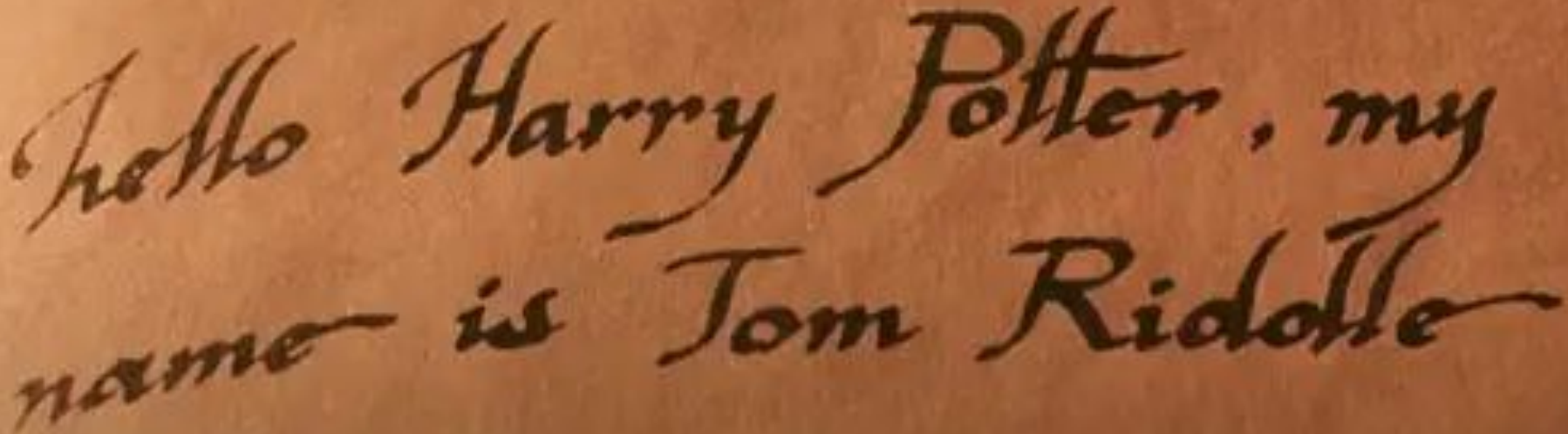


ELEC 424/553

Mobile & Embedded Systems

Lecture 11 - Writing Your Own Char Driver (2)



Hello Harry Potter, my
name is Tom Riddle

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As a Rice student, you can also have the application fee waived and potentially receive a tuition waiver for TA service or potentially be awarded a scholarship.

Email Joe at jy46@rice.edu with any questions



Functions In Your Driver

init

- **register_chrdev(0, DEVICE_NAME, &fops)**
 - *Provides major number for driver*
 - Multiple devices can use same driver (with same major number) but will each have different minor numbers
 - 1st arg: Desired major number - 0 means we will take whatever we are given (“dynamic”)
 - 2nd arg: Can be arbitrary - not used for /dev/device_name [instead has to do with device owner]
 - 3rd arg: file_operations struct to be linked between system call and driver

Functions In Your Driver

init

- **class_create(THIS_MODULE, CLASS_NAME)**
 - *Create class of device*
 - Can group together devices in /sys/class
 - 1st arg: Class owner module
 - 2nd arg: - Class name :)

Functions In Your Driver

init

- **device_create(mescharClass, NULL, MKDEV(majorNumber, 0), NULL, DEVICE_NAME)**

The following is quoted from the Linux source code from Bootlin Elixir - URL:

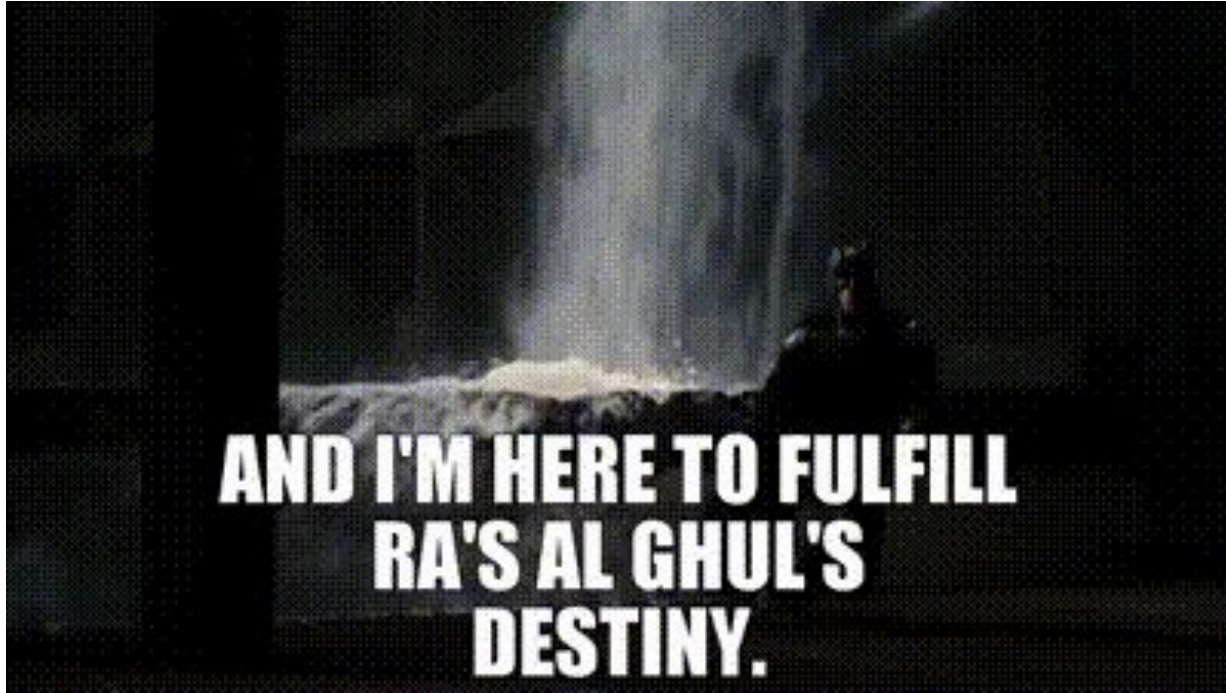
<https://elixir.bootlin.com/linux/latest/source/drivers/base/core.c#L4325>:

```
“* device_create - creates a device and registers it with sysfs
* @class: pointer to the struct class that this device should be registered to
* @parent: pointer to the parent struct device of this new device, if any
* @devt: the dev_t for the char device to be added
* @drvdata: the data to be added to the device for callbacks
* @fmt: string for the device's name”
```

MKDEV(majorNumber, 0) - 1st arg is major number, 2nd arg is minor number

Finishing What We Started

exit



Functions In Your Driver

exit

- **device_destroy(mescharClass, MKDEV(majorNumber,0))**
 - Undoes device_create - destroys device
- *class_unregister(mescharClass)*
 - Actually, this is called by class_destroy
- **class_destroy(mescharClass)**
 - Removes class
- **unregister_chrdev(majorNumber, DEVICE_NAME)**
 - Unassign major number to driver

The Code You'll See Today Is a Combination of:

- [Primarily] Derek Molloy's (Dr. Derek Molloy, School of Electronic Engineering, Dublin City University, Ireland) excellent work here:
<http://derekmolloy.ie/writing-a-linux-kernel-module-part-1-introduction/>
<http://derekmolloy.ie/writing-a-linux-kernel-module-part-2-a-character-device/>
- [Primarily] My own **craziness**
- [Somewhat] The Linux Kernel Module Programming Guide:
<https://tldp.org/LDP/lkmpg/2.4/html/c577.htm>
- [More referential] Corbet, Rubini, & Kroah-Hartman, Linux Device Drivers, 3rd Ed. URL: <https://lwn.net/Kernel/LDD3/>

Note: Copying Things To Raspberry Pi

From a terminal window not logged into the RPi, use SCP to copy files from your computer to the RPi

- **`scp hello.c Makefile test.c pi@raspberrypi.local:~/char_rw_driver`**

If you want to copy from the RPi to your computer:

- **`scp pi@raspberrypi.local:~/char_rw_driver/Makefile .`**

Let's walk through the code - here is where we started

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

MODULE_LICENSE("GPL");
MODULE_AUTHOR("Abraham Lincoln");
MODULE_DESCRIPTION("Greatest module in the world!");
MODULE_VERSION("0.000001");

static int multiplier = 10;
module_param(multiplier, int, S_IRUGO);

static int __init hello_init(void){
    printk(KERN_INFO "Oh hi mark - I love Lisa %dX more than you do\n", multiplier);
    return 0;
}

static void __exit hello_exit(void){
    printk(KERN_INFO "sad, but still love Lisa %dX more than you\n", multiplier);
}

module_init(hello_init);
module_exit(hello_exit);
```

Add On To Hi Mark Module: Header Files

```
#include <linux/module.h>
#include <linux/init.h>
#include <linux/kernel.h>
#include <linux/fs.h>
#include <linux/device.h>
#include <linux/uaccess.h>

MODULE_LICENSE("GPL");
MODULE_AUTHOR("Abraham Lincoln");
MODULE_DESCRIPTION("Greatest module in the world!");
MODULE_VERSION("0.000001");

static int multiplier = 10;
module_param(multiplier, int, S_IRUGO);

static int __init hello_init(void){
    printk(KERN_INFO "Oh hi mark - I love Lisa %dX more than you do\n", multiplier);
    return 0;
}

static void __exit hello_exit(void){
    printk(KERN_INFO "sad, but still love Lisa %dX more than you\n", multiplier);
}

module_init(hello_init);
module_exit(hello_exit);
```

Add DEVICE_NAME and CLASS_NAME

```
#include <linux/module.h>
#include <linux/init.h>
#include <linux/kernel.h>
#include <linux/fs.h>
#include <linux/device.h>
#include <linux/uaccess.h>
#define DEVICE_NAME "meschar"
#define CLASS_NAME "mes"

MODULE_LICENSE("GPL");
MODULE_AUTHOR("Abraham Lincoln");
MODULE_DESCRIPTION("Greatest module in the world!");
MODULE_VERSION("0.000001");

static int multiplier = 10;
module_param(multiplier, int, S_IRUGO);

static int __init hello_init(void){
    printk(KERN_INFO "Oh hi mark - I love Lisa %dX more than you do\n", multiplier);
    return 0;
}

static void __exit hello_exit(void){
    printk(KERN_INFO "sad, but still love Lisa %dX more than you\n", multiplier);
}
```

Add More Variables

```
#include <linux/module.h>
#include <linux/init.h>
#include <linux/kernel.h>
#include <linux/fs.h>
#include <linux/device.h>
#include <linux/uaccess.h>
#define DEVICE_NAME "meschar"
#define CLASS_NAME "mes"

static int majorNumber;
static struct class* mescharClass = NULL;
static struct device* mescharDevice = NULL;

MODULE_LICENSE("GPL");
MODULE_AUTHOR("Abraham Lincoln");
MODULE_DESCRIPTION("Greatest module in the world!");
MODULE_VERSION("0.000001");

static int multiplier = 10;
module_param(multiplier, int, S_IRUGO);

static int __init hello_init(void){
    printk(KERN_INFO "Oh hi mark - I love Lisa %dX more than you do\n", multiplier);
    return 0;
}
```

Add Prototype Function For Function To Use For open

```
#include <linux/module.h>
#include <linux/init.h>
#include <linux/kernel.h>
#include <linux/fs.h>
#include <linux/device.h>
#include <linux/uaccess.h>
#define DEVICE_NAME "meschar"
#define CLASS_NAME "mes"

static int majorNumber;
static struct class* mescharClass = NULL;
static struct device* mescharDevice = NULL;

static int device_open(struct inode *, struct file *);

MODULE_LICENSE("GPL");
MODULE_AUTHOR("Abraham Lincoln");
MODULE_DESCRIPTION("Greatest module in the world!");
MODULE_VERSION("0.000001");

static int multiplier = 10;
module_param(multiplier, int, S_IRUGO);

static int __init hello_init(void){
    printk(KERN_INFO "Oh hi mark - I love Lisa %dX more than you do\n", multiplier);
    return 0;
}
```

Link open System Call With Driver device_open

```
#include <linux/module.h>
#include <linux/init.h>
#include <linux/kernel.h>
#include <linux/fs.h>
#include <linux/device.h>
#include <linux/uaccess.h>
#define DEVICE_NAME "meschar"
#define CLASS_NAME "mes"

static int majorNumber;
static struct class* mescharClass = NULL;
static struct device* mescharDevice = NULL;

static int device_open(struct inode *, struct file *);

static struct file_operations fops =
{
    .open = device_open
};

MODULE_LICENSE("GPL");
MODULE_AUTHOR("Abraham Lincoln");
MODULE_DESCRIPTION("Greatest module in the world!");
MODULE_VERSION("0.000001");

static int multiplier = 10;
```

Overhaul hello_init

```
MODULE_AUTHOR("Adrianam Lincoln");
MODULE_DESCRIPTION("Greatest module in the world!");
MODULE_VERSION("0.000001");

static int multiplier = 10;
module_param(multiplier, int, S_IRUGO);

static int __init hello_init(void){
    majorNumber = register_chrdev(0, DEVICE_NAME, &fops);
    mescharClass = class_create(THIS_MODULE, CLASS_NAME);
    mescharDevice = device_create(mescharClass, NULL, MKDEV(majorNumber, 0), NULL, DEVICE_NAME);
    printk(KERN_INFO "Oh hi mark - I love Lisa %dX more than you do\n", multiplier);
    return 0;
}

static void __exit hello_exit(void){
    printk(KERN_INFO "sad, but still love Lisa %dX more than you\n", multiplier);
}

module_init(hello_init);
module_exit(hello_exit);
```


Overhaul hello_exit

```
MODULE_AUTHOR("Adrianam Lincoln");
MODULE_DESCRIPTION("Greatest module in the world!");
MODULE_VERSION("0.000001");

static int multiplier = 10;
module_param(multiplier, int, S_IRUGO);

static int __init hello_init(void){
    majorNumber = register_chrdev(0, DEVICE_NAME, &fops);
    mescharClass = class_create(THIS_MODULE, CLASS_NAME);
    mescharDevice = device_create(mescharClass, NULL, MKDEV(majorNumber, 0), NULL, DEVICE_NAME);
    printk(KERN_INFO "Oh hi mark - I love Lisa %dX more than you do\n", multiplier);
    return 0;
}

static void __exit hello_exit(void){
    device_destroy(mescharClass, MKDEV(majorNumber,0));
    class_unregister(mescharClass);
    class_destroy(mescharClass);
    unregister_chrdev(majorNumber, DEVICE_NAME);
    printk(KERN_INFO "sad, but still love Lisa %dX more than you\n", multiplier);
}

module_init(hello_init);
module_exit(hello_exit);
```

Define device_open

```
}
```

```
static void __exit hello_exit(void){  
    device_destroy(mescharClass, MKDEV(majorNumber,0));  
    class_unregister(mescharClass);  
    class_destroy(mescharClass);  
    unregister_chrdev(majorNumber, DEVICE_NAME);  
    printk(KERN_INFO "sad, but still love Lisa %dX more than you\n", multiplier);  
}
```

```
static int device_open(struct inode *inodep, struct file *filep){  
    printk(KERN_INFO "You're tearing me apart, Lisa!\n");  
    return 0;  
}
```

```
module_init(hello_init);
```

```
module_exit(hello_exit);
```

User Interaction

- We need a user application to call **open** for this device
- This will also require an addition to the **Makefile**

Create New File: testmeschar.c

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <fcntl.h>

int main(){
    int fd;
    printf("Warm it up.exe\n");
    fd = open("/dev/meschar", O_RDWR); // Capital o, not zero
    return 0;
}
```



From GIFER. URL:
<https://i.gifer.com/YgY.gif>

Modify Makefile

```
obj-m+=hello.o
```

```
all:
```

```
    make -C /lib/modules/$(shell uname -r)/build/ M=$(PWD) modules  
    $(CC) testmeschar.c -o test
```

```
clean:
```

```
    make -C /lib/modules/$(shell uname -r)/build/ M=$(PWD) clean  
    rm test
```

Try It Out!

- `make`
- `sudo insmod hello.ko`
- `ls /dev`
- `ls /dev/mes*` (* is a wildcard, different from a [Yellowcard](#))
- `ls /sys/class/mes`
 - `ls /sys/class/mes/meschar`
- `cat /sys/module/hello/parameters/multiplier`
- (other terminal window) `tail -f /var/log/kern.log`
 - Or: `dmesg`
- `sudo ./test` (run many times) [MAKE SURE TO RUN WITH sudo!]
- `sudo rmmod hello.ko`

Let's Make device_open Actually Do Something - Add Open Counter

```
1 #include <linux/module.h>
2 #include <linux/init.h>
3 #include <linux/kernel.h>
4 #include <linux/fs.h>
5 #include <linux/device.h>
6 #include <linux/uaccess.h>
7 #define DEVICE_NAME "meschar"
8 #define CLASS_NAME "mes"
9
10 static int majorNumber;
11 static struct class* mescharClass = NULL;
12 static struct device* mescharDevice = NULL;
13 static int timesCalled = 0;
14
15 static int device_open(struct inode *, struct file *);
16
17 static struct file_operations fops =
18 {
19     .open = device_open
20 };
21
```

Increment Open Counter in device_open

```
38 static void __exit hello_exit(void){
39     device_destroy(mescharClass, MKDEV(majorNumber,0));
40     class_unregister(mescharClass);
41     class_destroy(mescharClass);
42     unregister_chrdev(majorNumber, DEVICE_NAME);
43     printk(KERN_INFO "sad, but still love Lisa %dX more than you\n", multiplier);
44 }
45
46 static int device_open(struct inode *inodep, struct file *filep){
47     timesCalled++;
48     printk(KERN_INFO "You're tearing me apart, Lisa! Also I've been opened %d times.\n", timesCalled);
49     return 0;
50 }
51
52 module_init(hello_init);
53 module_exit(hello_exit);
```


Try It Out

- **sudo insmod hello.ko**
- (other terminal window) **tail -f /var/log/kern.log**
- **sudo ./test** (run many times)
- **sudo rmmod hello.ko**

file_operations

open() c
function in
user space

system call
handler in
kernel space

fops struct

open()
function in
driver

/ include / linux / fs.h

```
2022 struct file_operations {
2023     struct module *owner;
2024     loff_t (*llseek) (struct file *, loff_t, int, loff_t *);
2025     ssize_t (*read) (struct file *, char __user *, size_t, loff_t *);
2026     ssize_t (*write) (struct file *, const char __user *, size_t, loff_t *);
2027     ssize_t (*read_iter) (struct kiocb *, struct iov_iter *);
2028     ssize_t (*write_iter) (struct kiocb *, struct iov_iter *);
2029     int (*iopoll)(struct kiocb *kiocb, bool spin);
2030     int (*iterate) (struct file *, struct dir_context *);
2031     int (*iterate_shared) (struct file *, struct dir_context *);
2032     __poll_t (*poll) (struct file *, struct poll_table_struct *);
2033     long (*unlocked_ioctl) (struct file *, unsigned long, void __user *);
2034     long (*compat_ioctl) (struct file *, unsigned long, void __user *);
2035     int (*mmap) (struct file *, struct vm_area_struct *);
2036     unsigned long (*mmap_supported_flags);
2037     int (*open) (struct inode *, struct file *);
2038     int (*flush) (struct file *, fl_owner_t id);
2039     int (*release) (struct inode *, struct file *);
2040     int (*fsync) (struct file *, loff_t, loff_t, int datasync);
2041     int (*fasync) (int, struct file *, int);
2042     int (*lock) (struct file *, int, struct file_lock *);
```

Now let's implement
read and write

Implemented
open last time

Goal: Interact With User String Using `read` and `write`

- **`write`**
 - Allow user to enter string
 - Save the string
- **`read`**
 - Print out the saved string

Considerations: The user is not always our friend.

Also, what could go wrong in a concurrent situation?



Defining The Problem: A Lack of Synchronization



Also Remember: We Don't Trust User Applications, Ever

```
/ include / linux / uaccess.h All syr ▼ Search
```

```
188 static __always_inline unsigned long __must_check
189 copy_from_user(void *to, const void __user *from, unsigned long n)
190 {
191     if (likely(check_copy_size(to, n, false)))
192         n = _copy_from_user(to, from, n);
193     return n;
194 }
195
196 static __always_inline unsigned long __must_check
197 copy_to_user(void __user *to, const void *from, unsigned long n)
198 {
199     if (likely(check_copy_size(from, n, true)))
200         n = _copy_to_user(to, from, n);
201     return n;
202 }
```

Add On To fops struct

```
17 static struct file_operations fops =
18 {
19     .open = device_open,
20     .read = device_read,
21     .write = device_write,
22 };
23
24 MODULE_LICENSE("GPL");
25 MODULE_AUTHOR("Abraham Lincoln");
26 MODULE_DESCRIPTION("Greatest module in the world!");
27 MODULE_VERSION("0.000001");
28
29 static int multiplier = 10;
30 module_param(multiplier, int, S_IRUGO);
31
32 static int __init hello_init(void){
33     majorNumber = register_chrdev(0, DEVICE_NAME, &fops);
34     mescharClass = class_create(THIS_MODULE, CLASS_NAME);
35     mescharDevice = device_create(mescharClass, NULL, MKDEV(majorNumber, 0), NULL, DEVICE_NAME);
36     printk(KERN_INFO "Oh hi mark - I love Lisa %dX more than you do\n", multiplier);
37     return 0;
38 }
39
40 static void __exit hello_exit(void){
```

We can put a comma here, no problem

This is good practice since the code may be modified later and someone will forget to put a comma

file_operations

write() or read()
c function in
user space

system call
handler in
kernel space

fops struct

write() or read()
function in
driver

```
/ include / linux / fs.h      All symbols Search Identifier

2022 struct file_operations {
2023     struct module *owner;
2024     loff_t (*llseek) (struct file *, loff_t, int);
2025     ssize_t (*read) (struct file *, char __user *, size_t, loff_t *);
2026     ssize_t (*write) (struct file *, const char __user *, size_t, loff_t *);
2027     ssize_t (*read_iter) (struct kiocb *, struct iov_iter *);
2028     ssize_t (*write_iter) (struct kiocb *, struct iov_iter *);
2029     int (*iopoll)(struct kiocb *kiocb, bool spin);
2030     int (*iterate) (struct file *, struct dir_context *);
2031     int (*iterate_shared) (struct file *, struct dir_context *);
2032     __poll_t (*poll) (struct file *, struct poll_table_struct *);
2033     long (*unlocked_ioctl) (struct file *, unsigned int, unsigned long);
2034     long (*compat_ioctl) (struct file *, unsigned int, unsigned long);
2035     int (*mmap) (struct file *, struct vm_area_struct *);
2036     unsigned long mmap_supported_flags;
2037     int (*open) (struct inode *, struct file *);
2038     int (*flush) (struct file *, fl_owner_t id);
2039     int (*release) (struct inode *, struct file *);
2040     int (*fsync) (struct file *, loff_t, loff_t, int datasync);
2041     int (*fasync) (int, struct file *, int);
2042     int (*lock) (struct file *, int, struct file_lock *);
```

Add Skeletons For New Functions

```
47
48 static int device_open(struct inode *inodep, struct file *filep){
49     timesCalled++;
50     printk(KERN_INFO "You're tearing me apart, Lisa! Also I've been opened %d times.\n", timesCalled);
51     return 0;
52 }
53
54 static ssize_t device_read(){
55
56 }
57
58 static ssize_t device_write(){
59
60 }
61
62
63 module_init(hello_init);
64 module_exit(hello_exit);
```


Add Input Argument Types For New Functions

```
47
48 static int device_open(struct inode *inodep, struct file *filep){
49     timesCalled++;
50     printk(KERN_INFO "You're tearing me apart, Lisa! Also I've been opened %d times.\n", timesCalled);
51     return 0;
52 }
53
54 static ssize_t device_read(struct file *, char __user *, size_t, loff_t *){
55
56 }
57
58 static ssize_t device_write(struct file *, const char __user *, size_t, loff_t *){
59
60 }
61
62
63 module_init(hello_init);
64 module_exit(hello_exit);
```

Give Names To Input Arguments For New Functions

```
47
48 static int device_open(struct inode *inodep, struct file *filep){
49     timesCalled++;
50     printk(KERN_INFO "You're tearing me apart, Lisa! Also I've been opened %d times.\n", timesCalled);
51     return 0;
52 }
53
54 static ssize_t device_read(struct file *filep, char __user *buf, size_t length, loff_t *offset){
55
56 }
57
58 static ssize_t device_write(struct file *filep, const char __user *buf, size_t length, loff_t *offset){
59
60 }
61
62
63 module_init(hello_init);
64 module_exit(hello_exit);
```

Let's Make device_write Do Something

```
47
48 static int device_open(struct inode *inodep, struct file *filep){
49     timesCalled++;
50     printk(KERN_INFO "You're tearing me apart, Lisa! Also I've been opened %d times.\n", timesCalled);
51     return 0;
52 }
53
54 static ssize_t device_read(struct file *filep, char __user *buf, size_t length, loff_t *offset){
55
56 }
57
58 static ssize_t device_write(struct file *filep, const char __user *buf, size_t length, loff_t *offset){
59     long error_count;
60     printk("Running device_write\n");
61     error_count = copy_from_user(message,buf,length);
62     size_of_message = strlen(message);
63     printk(KERN_INFO "mesChar: Received %d characters from the user\n", size_of_message);
64     printk(KERN_INFO "Message received: %s\n", message);
65     return length;
66 }
67
68
69 module_init(hello_init);
70 module_exit(hello_exit);
```

Add return to device_read

```
1
2 static int device_open(struct inode *inodep, struct file *filep){
3     timesCalled++;
4     printk(KERN_INFO "You're tearing me apart, Lisa! Also I've been opened %d times.\n", timesCalled);
5     return 0;
6 }
7
8 static ssize_t device_read(struct file *filep, char __user *buf, size_t length, loff_t *offset){
9     return 0;
10 }
11
12 static ssize_t device_write(struct file *filep, const char __user *buf, size_t length, loff_t *offset){
13     long error_count;
14     printk("Running device_write\n");
15     error_count = copy_from_user(message,buf,length);
16     size_of_message = strlen(message);
17     printk(KERN_INFO "mesChar: Received %d characters from the user\n", size_of_message);
18     printk(KERN_INFO "Message received: %s\n", message);
19     return length;
20 }
21
22
23 module_init(hello_init);
24 module_exit(hello_exit);
```

Need To Add message & size_of_message

```
1 #include <linux/module.h>
2 #include <linux/init.h>
3 #include <linux/kernel.h>
4 #include <linux/fs.h>
5 #include <linux/device.h>
6 #include <linux/uaccess.h>
7 #define DEVICE_NAME "meschar"
8 #define CLASS_NAME "mes"
9
10 static int majorNumber;
11 static struct class* mescharClass = NULL;
12 static struct device* mescharDevice = NULL;
13 static int timesCalled = 0;
14 static char message[256] = {0};
15 static short size_of_message;
16
17 static int device_open(struct inode *, struct file *);
18
19 static struct file_operations fops =
20 {
21     .open = device_open,
22     .read = device_read,
23     .write = device_write,
24 };
```

Also Need To Add Function Prototypes

```
1 #include <linux/module.h>
2 #include <linux/init.h>
3 #include <linux/kernel.h>
4 #include <linux/fs.h>
5 #include <linux/device.h>
6 #include <linux/uaccess.h>
7 #define DEVICE_NAME "meschar"
8 #define CLASS_NAME "mes"
9
10 static int majorNumber;
11 static struct class* mescharClass = NULL;
12 static struct device* mescharDevice = NULL;
13 static int timesCalled = 0;
14 static char message[256] = {0};
15 static short size_of_message;
16
17 static int device_open(struct inode *, struct file *);
18 static ssize_t device_read(struct file *, char __user *, size_t, loff_t *);
19 static ssize_t device_write(struct file *, const char __user *, size_t, loff_t *);
20
21 static struct file_operations fops =
22 {
23     .open = device_open,
24     .read = device_read,
25     .write = device_write,
```