Kernel Modules

Kartik Gopalan
Kernel Modules

- Allow code to be added to the kernel, dynamically

- Only those modules that are needed are loaded. Unload when no longer required - frees up memory and other resources

- Reduces kernel size.

- Enables independent development of drivers for different devices
Workings of a generic module / typical usage:
Hello World Kernel Module

- [https://oscourse.github.io/examples/module/hello.c](https://oscourse.github.io/examples/module/hello.c)

```c
#include <linux/init.h>
#include <linux/module.h>
MODULE_LICENSE("DUAL BSD/GPL");
// called when module is installed
int __init hello_init()
{
    printk(KERN_ALERT "mymodule: Hello World!\n");
    return 0;
}

// called when module is removed
void __exit hello_exit()
{
    printk(KERN_ALERT "mymodule: Goodbye, cruel world!!\n");
}

module_init(hello_init);
module_exit(hello_exit);
```
Compiling the module

- Makefile
  - obj-m := testmod.o
  - [ For multiple files: module-objs := file1.o file2.o ]

- Compiling:
  - $ make -C /lib/modules/$(uname -r)/build M=`pwd` modules

- More information on kernel Makefiles
Module Utilities

- $ sudo insmod hello.ko
  - Inserts a module
  - Internally, makes a call to sys_init_module
  - Calls vmalloc() to allocate kernel memory
  - Copies module binary to memory
  - Resolves any kernel references (e.g. printk) via kernel symbol table
  - Calls module’s initialization function

- $ modprobe hello.ko
  - Same as insmod, except that it also loads any other modules that hello.ko references.

- $ sudo rmmod hello
  - Removes a module
  - Fails if module is still in use

- $ sudo lsmod
  - Tells what modules are currently loaded
  - Internally reads /proc/modules
Things to remember

• Modules can call other kernel functions
  ◦ Such as printk, kmalloc, kfree etc.
  ◦ But only the functions that are EXPORTed by the kernel
    ◦ using EXPORT(symbol_name)

• Modules (or any kernel code for that matter) cannot call user-space library functions
  ◦ Such as malloc, free, printf etc.

• Modules should not include standard header files
  ◦ Such as stdio.h, stdlib.h, etc.

• Segmentation fault may be harmless in user space
  ◦ But a kernel fault can crash the entire system

• Version Dependency:
  ◦ Module should be recompiled for each version of kernel that it is linked to.
Concurrency Issues

- Many processes could try to access your module concurrently.
  - So different parts of your module may be active at the same time

- Device interrupts can trigger Interrupt Service Routines (ISR)
  - ISRs may access common data that your module uses as well.

- Kernel timers can concurrently execute with your module and access common data.

- You may have symmetric multi-processor (SMP) system, so multiple processors may be executing your module code simultaneously (not just concurrently).

- Therefore, your module code (and most kernel code, in general) should be re-enterant
  - Capable of correctly executing correctly in more than one context simultaneously.
Error handling

```c
int __init my_init_function(void)
{
    int err;

    /* registration takes a pointer and a name */
    err = register_this(ptr1, "skull");
    if (err) goto fail_this;
    err = register_that(ptr2, "skull");
    if (err) goto fail_that;
    err = register_those(ptr3, "skull");
    if (err) goto fail_those;

    return 0; /* success */
}

fail_those: unregister_those(ptr3, "skull");
fail_that: unregister_this(ptr1, "skull");
fail_this: return err; /* propagate the error */
```

```c
void __exit my_cleanup_function(void)
{
    unregister_those(ptr3, "skull");
    unregister_that(ptr2, "skull");
    unregister_this(ptr1, "skull");
    return;
}
```

- In case of failure, undo every registration activity
- But only those that were registered successfully
Module Parameters

• Command line:
  • `insmod hellon.ko howmany=10 whom="Class"`

• Module code has:
  ```c
  static char *whom = "world";
  static int howmany = 1;
  ```

```c
module_param(howmany, int, S_IRUGO);
module_param(whom, charp, S_IRUGO);
```

• See example module
  • [https://oscourse.github.io/examples/module/hellon.c](https://oscourse.github.io/examples/module/hellon.c)
Character devices in Linux
Device Classification

• Character (char) devices
  • byte-stream abstraction
  • E.g. keyboard, mouse

• Block devices
  • reads/writes in fixed block granularity
  • E.g. hard disks, CD drives

• Network devices
  • message abstraction
  • send/receive packets of varying sizes
  • E.g. network interface cards

• Others
  • USB, SCSI, Firewire, I2O
  • Can (mostly) be used to implement one or more of the above three classes
“Miscellaneous” Devices in Linux

- These are character devices used for simple device drivers.

- All miscellaneous devices share a major number (10).

- But each device gets its own minor number
  - Requested at registration time
Implementing a device driver for a miscellaneous device

• Step 1: Declare a device struct

```c
static struct miscdevice my_misc_device = {
    .minor = MISC_DYNAMIC_MINOR,
    .name = "my device",
    .fops = &my_fops
};
```
Implementing a device driver for a miscellaneous device

- Step 2: Declare the file operations struct

```c
static struct file_operations my_fops = {
    .owner = THIS_MODULE,
    .open = my_open,
    .release = my_close,
    .read = my_read,
    ...
    .llseek = noop_llseek
};
```

The function pointers that are not initialized above will be assigned some sensible default value by the kernel.
Implementing a device driver for a miscellaneous device

- Step 3: register the device with kernel
  - usually in the module initialization code

```c
static int __init my_module_init()
{
    ...
    misc_register(&my_misc_device);
    ...
}
```

And don’t forget to unregister the device when removing the module

```c
static void __exit my_exit(void)
{
    misc_deregister(&my_misc_device);
    ...
}
```
Implementing a device driver for a miscellaneous device

• **Step 4: Implement the fops functions**

```c
static ssize_t my_read(struct file *file, char __user * out, size_t size, loff_t * off)
{
    ....
    sprintf(buf, “Hello World\n”);
    copy_to_user(out, buf, strlen(buf)+1);
    ....
}
```

Don’t forget to
• allocate memory for buf
• Check if “out” points to a valid user memory location using access_OK()
• check for errors during copy_to_user()
How do file ops work on character devices

• A file operation on a device file will be handled by the kernel module associated with the device.

• Use “open()” system call to open “mydevice” file
  • fd = open("/dev/mydevice", O_RDWR);
  • opens /dev/mydevice device for read and write operation.
  • OS will call my_open() file operation handler in the kernel module which is associated with the device.
  • misc_register(&my_misc_device) in my_module_init() registers the character device. It creates an entry in the “/dev” directory for “mydevice” file and informs the operating system what file-operations handler functions are available for this device.

• Use “read()” system call to read from the “mydevice” file
  • n = read( fd, buffer, size);
  • finally calls the my_read() function passed through the fops structure in your kernel module.
Moving data in and out of the Kernel

• **copy_to_user()**
  - unsigned long copy_to_user (void __user * dst, const void * src, unsigned long n);
  - Copies data **from kernel space to user space**
  - Returns number of bytes that could not be copied. On success, this will be zero.
  - Checks that dst is writable by calling access_ok on dst with a type of VERIFY_WRITE. If it returns non-zero, copy_to_user proceeds to copy

• **copy_from_user()**
  - unsigned long copy_from_user (void * dst, const void __user * src, unsigned long n);
  - Copies data **from user space to kernel**
  - Returns number of bytes that could not be copied. On success, this will be zero.

• **Question:** Why shouldn’t you use memcpy or call by reference to access userspace data?
Memory allocation/deallocation in Kernel

- Memory Allocation:
  - kmalloc(): Allocates physically contiguous memory
    ```c
    void * kmalloc(size_t size, int flags)
    ```
  - kzalloc(): Allocates memory and sets it to zero
  - vmalloc(): Allocates memory that is virtually contiguous and not necessarily physically contiguous.
    ```c
    void * vmalloc(unsigned long size)
    ```

- Memory Deallocation: kfree()
GNU General Public License (GPL)


- Basis for all of the GNU software development, including Linux

- Allows users to modify software as they see the need

- Requires source code be distributed with binaries

- EXPORT_SYMBOL Vs EXPORT_SYMBOL_GPL
  - Read [http://lwn.net/Articles/154602/](http://lwn.net/Articles/154602/)

- Device drivers need not be licensed under the GPL, but the mainstream ones are