Kernel Modules

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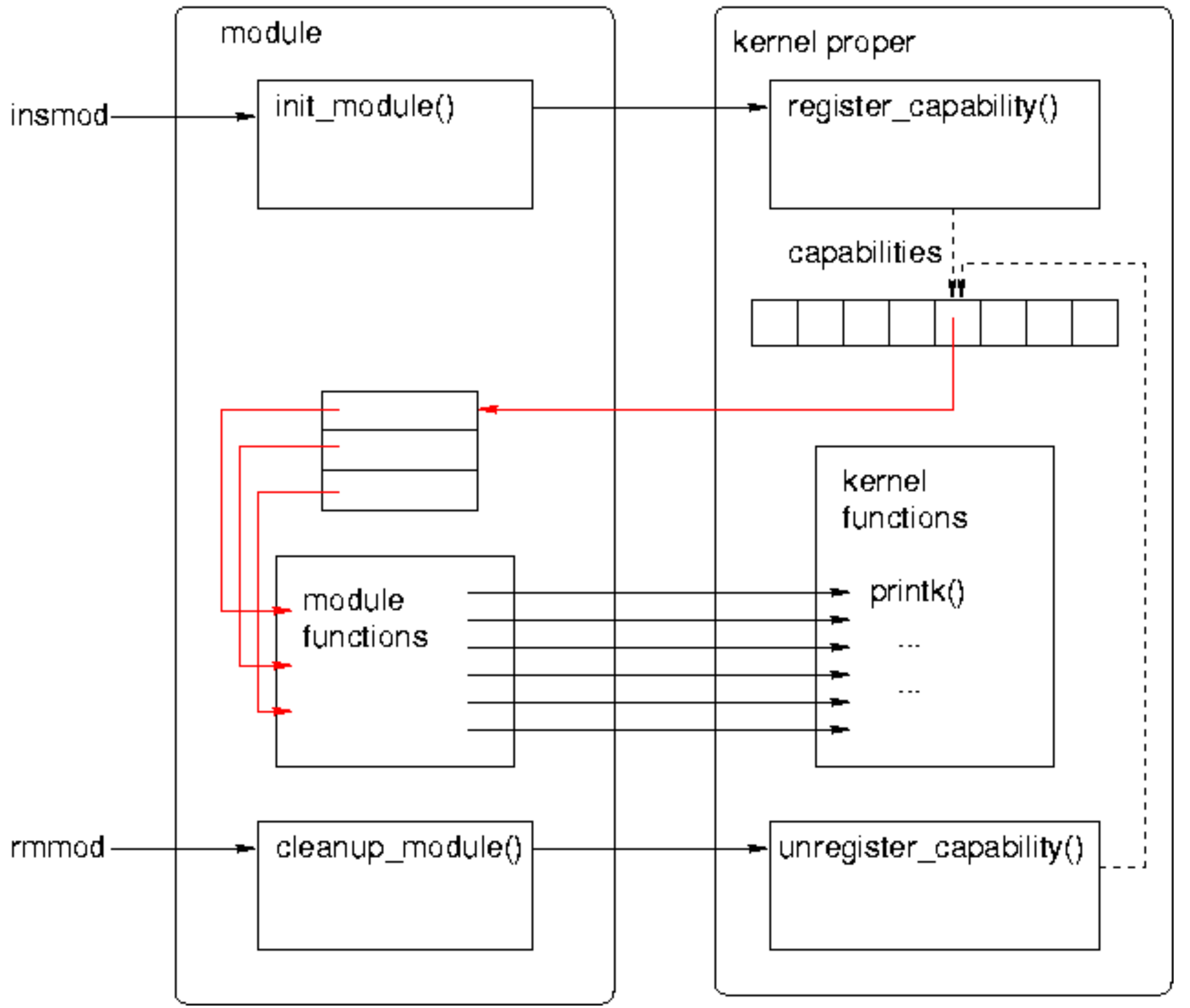
Kernel Modules

- 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

```
#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
  - https://www.kernel.org/doc/Documentation/kbuild/makefiles.txt
  - https://www.kernel.org/doc/Documentation/kbuild/modules.txt

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

```
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_that(ptr2, "skull");
 fail_that: unregister_this(ptr1, "skull");
 fail_this: return err; /* propagate the error */
}
```

```
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:

```
static char *whom = "world";
static int howmany = 1;


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

- See example module
  - 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

```
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

```
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.

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.

- Call “open” system call to open “mydevice” file

- Call “read” system call to read from the “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) instruction in my_module_init() registers the module. 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.

Implementing a device driver for a miscellaneous device

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

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

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

```
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

```
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()

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

  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.

  void * vmalloc(unsigned long size)

- Memory Deallocation: kfree()

GNU General Public License (GPL)

- http://en.wikipedia.org/wiki/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/
- Device drivers need not be licensed under the GPL, but the mainstream ones are