07-2 Device Driver Basics

Using kernel modules

Free Electrons

Loadable kernel modules

- Modules: add a given functionality to the kernel (drivers, filesystem support, and many others)
- Can be loaded and unloaded at any time, only when their functionality is need
- Useful to keep the kernel image size to the minimum (essential in GNU/Linux distributions for PCs)
- Also useful to reduce boot time: you don't spent time initializing devices and kernel features that you only need later
- Caution: once loaded, have full access to the whole kernel address space. No particular protection

Minimal Device Driver (Listing 8-1)

```
/* Example Minimal Character Device Driver */
#include <linux/module.h>
static int __init hello_init(void) {
  printk(KERN_INFO "Hello Example Init\n");
  return 0;
}
static void __exit hello_exit(void) {
  printk("Hello Example Exit\n");
}
module_init(hello_init);
module_exit(hello_exit);

MODULE_AUTHOR("Chris Hallinan");
MODULE_DESCRIPTION("Hello World Example");
MODULE_LICENSE("GPL");
```

Module Build Infrastructure

1. Starting from the top-level Linux source directory, create a directory under **.../drivers/char** called **examples**.
2. Add a menu item to the kernel configuration to enable building **examples** and to specify built-in or loadable kernel module.
3. Add the new examples subdirectory to the **.../drivers/char/Makefile** conditional on the menu item created in step 2.
4. Create a **Makefile** for the new **examples** directory, and add the **hello1.o** module object to be compiled conditional on the menu item created in step 2.
5. Finally, create the driver **hello1.c** source file from Listing 8-1.

See Section 8.1.4, page 205

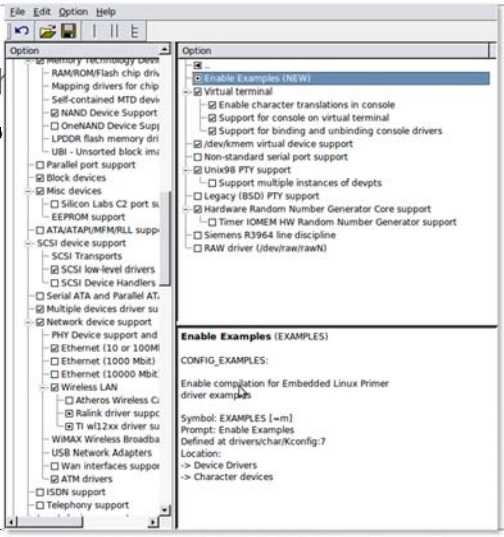
Typo page 206

```
diff --git a/drivers/char/Kconfig b/drivers/char/Kconfig
index 6f31c94..0805290 100644
--- a/drivers/char/Kconfig
+++ b/drivers/char/Kconfig
@@ -4,6 +4,13 @@

 menu "Character devices"

+config EXAMPLES
+       tristate "Enable Examples"
+       default m
+       ---help---
+         Enable compilation option for Embedded Linux Primer
+         driver examples
+
 config VT
       bool "Virtual terminal" if EMBEDDED
       depends on !S390
```

Must be lower case

Ch

ho



- ☑ Memory Technology Devi
  - RAM/ROM/Flash chip driv
  - Mapping drivers for chip
  - Self-contained MTD devi
  - ☑ NAND Device Support
  - □ OneNAND Device Supp
  - LPDDR flash memory dri
  - UBI - Unsorted block ima
- □ Parallel port support
- ☑ Block devices
- ☑ Misc devices
  - □ Silicon Labs C2 port su
  - EEPROM support
- □ ATA/ATAPI/MFM/RLL supp
- SCSI device support
  - SCSI Transports
  - ☑ SCSI low-level drivers
  - □ SCSI Device Handlers
- □ Serial ATA and Parallel AT
- ☑ Multiple devices driver su
- ☑ Network device support
  - PHY Device support and
  - ☑ Ethernet (10 or 100Mb
  - □ Ethernet (1000 Mbit)
  - □ Ethernet (10000 Mbit
  - ☑ Wireless LAN
    - □ Atheros Wireless C
    - ⊡ Ralink driver suppc
    - ⊡ TI wl12xx driver su
  - WiMAX Wireless Broadba
  - USB Network Adapters
  - □ Wan interfaces suppor
  - ☑ ATM drivers
- □ ISDN support
- □ Telephony support

- ▣ ...
- ⊡ Enable Examples (NEW)
- ☑ Virtual terminal
  - ☑ Enable character translations in console
  - ☑ Support for console on virtual terminal
  - ☑ Support for binding and unbinding console drivers
- ☑ /dev/kmem virtual device support
- □ Non-standard serial port support
- ☑ Unix98 PTY support
  - □ Support multiple instances of devpts
- □ Legacy (BSD) PTY support
- ☑ Hardware Random Number Generator Core support
  - □ Timer IOMEM HW Random Number Generator support
- □ Siemens R3964 line discipline
- □ RAW driver (/dev/raw/rawN)

Enable Examples (EXAMPLES)

CONFIG_EXAMPLES:

Enable compilation for Embedded Linux Primer
driver examples

Symbol: EXAMPLES [=m]
Prompt: Enable Examples
Defined at drivers/char/Kconfig:7
Location:
-> Device Drivers
-> Character devices

Module Build Output

```
host$ time make modules
  CHK     include/linux/version.h
make[1]: `include/asm-arm/mach-types.h' is up to date.
  CHK     include/linux/utsrelease.h
  SYMLINK include/asm -> include/asm-arm
  CALL    scripts/checksyscalls.sh
<stdin>:1097:2: warning: #warning syscall fadvise64 not implemented
<stdin>:1265:2: warning: #warning syscall migrate_pages not implemented
  CC [M]  drivers/char/examples/hello1.o
  Building modules, stage 2.
  MODPOST 691 modules
  CC      drivers/char/examples/hello1.mod.o
  LD [M]  drivers/char/examples/hello1.ko

real    0m41.559s
user    0m10.905s
sys     0m23.877s
```

Module First Build Output

```
host$ time make modules
 HOSTLD  scripts/kconfig/conf
scripts/kconfig/conf -s arch/arm/Kconfig
*
* Restart config...
*
*
* Character devices
*
Enable Examples (EXAMPLES) [M/n/y/?] (NEW)
Virtual terminal (VT) [Y/n/?] y
  Enable character translations in console (CONSOLE_TRANSLATIONS) [Y/n/?] y
  Support for console on virtual terminal (VT_CONSOLE) [Y/n/?] y
  Support for binding and unbinding console drivers (VT_HW_CONSOLE_BINDING) [Y/n/?] y
/dev/kmem virtual device support (DEVKMEM) [Y/n/?] y
Non-standard serial port support (SERIAL_NONSTANDARD) [N/y/?] n
Unix98 PTY support (UNIX98_PTYS) [Y/n/?] y
  Support multiple instances of devpts (DEVPTS_MULTIPLE_INSTANCES) [N/y/?] n
Legacy (BSD) PTY support (LEGACY_PTYS) [N/y/?] n
Hardware Random Number Generator Core support (HW_RANDOM) [Y/n/m/?] y
  Timer IOMEM HW Random Number Generator support (HW_RANDOM_TIMERIOMEM) [N/m/y/?] n
Siemens R3964 line discipline (R3964) [N/m/y/?] n
RAW driver (/dev/raw/rawN) (RAW_DRIVER) [N/m/y/?] n
```

Module Build Output

```
#
# configuration written to .config
#
  CHK     include/linux/version.h
make[1]: `include/asm-arm/mach-types.h' is up to date.
  CHK     include/linux/utsrelease.h
  SYMLINK include/asm -> include/asm-arm
  CALL    scripts/checksyscalls.sh
<stdin>:1523:2: warning: #warning syscall recvmmsg not implemented
  HOSTCC  scripts/genksyms/lex.o
  HOSTLD  scripts/genksyms/genksyms
  HOSTCC  scripts/mod/sumversion.o
  HOSTLD  scripts/mod/modpost
  HOSTCC  scripts/pnmtologo
  Building modules, stage 2.
  MODPOST 700 modules

real    1m25.549s
user    0m47.680s
sys     0m15.810s
```

Once built… Option 1

On the Beagle…Two choices….

- Option 1:

```
make INSTALL_MOD_PATH=~/BeagleBoard modules_install
```

- Will create **lib** directory in **~/BeagleBoard** with everything that goes in **/lib** on the Beagle
- Then

```
host$ scp -r ~/BeagleBoard/lib root@beagle:/lib
```

- Could take a while to transfer

Once built… Option 2

- Just copy the new file you created

```
host$ scp …/drivers/char/examples/hello1.ko root@beagle:.
```

- On the Beagle

```
beagle$ mv hello1.ko
  /lib/modules/2.6.32/kernel/drivers/char/examples/
beagle$ cd /lib/modules/2.6.32
beagle$ mv modules.dep.bin modules.dep.bin.orig
beagle$ edit modules.dep
```

- add:

```
kernel/drivers/char/examples/hello1.ko:
```

Loading and Unloading a Module

```
beagle$ /sbin/modprobe hello1
beagle$ dmesg | tail -4
[   47.095764] OMAPFB: ioctl QUERY_PLANE
[   47.095794] OMAPFB: ioctl GET_CAPS
[   49.005889] eth0: no IPv6 routers present
[  651.947784] Hello Example Init
beagle$ /sbin/modprobe -r hello1
beagle$ dmesg | tail -4
[   47.095794] OMAPFB: ioctl GET_CAPS
[   49.005889] eth0: no IPv6 routers present
[  651.947784] Hello Example Init
[  677.682769] Hello Example Exit
```

Module Utilities

```
$ insmod /lib/modules/`uname -r`/kernel/drivers/char/examples/hello1.ko
```

- **No need to edit modules.dep**

Example Driver with Parameter

```
/* Example Minimal Character Device Driver */
#include <linux/module.h>

static int debug_enable = 0;
module_param(debug_enable, int, 0);

MODULE_PARM_DESC(debug_enable, "Enable module debug mode.");

static int __init hello_init(void) {
    /* Now print value of new module parameter */
    printk("Hello Example Init - debug mode is %s\n",
           debug_enable ? "enabled" : "disabled")
    return 0;
}
```

```
static void __exit hello_exit(void) {
    printk("Hello Example Exit\n");
}

module_init(hello_init);
module_exit(hello_exit);

MODULE_AUTHOR("Chris Hallinan");
MODULE_DESCRIPTION("Hello World
    Example");
MODULE_LICENSE("GPL");
```

Passing Parameters to a Module

```
insmod /lib/modules/…/examples/hello1.ko
debug_enable=1
Hello Example Init – debug mode is enabled
insmod /lib/modules/…/examples/hello1.ko
Hello Example Init – debug mode is disabled
```

Other module commands

```
# /sbin/lsmod
# /sbin/modinfo hello1
# /sbin/rmmod hello1
# /sbin/depmod
```
(creates modules.dep.bin)

- Go play with them

Adding File System Ops to Hello.c

- Section 8.3, page 217 has a long example about adding file system operations to **`hello.c`**
- Look it over
- Creates a new device (**`/dev/hello1`**)
- You can read and write it
- Do it.

Driver File System Operations

- Once a device driver is loaded into the live kernel…
  - **`open()`**is used to prepare it for subsequent operations
  - **`release()`**is used to clean up
  - **`ioclt()`**is used for nonstandard communication

- Think in terms of reading and writing a file…

```
fd = open("file", …
read(fd, …
close(fd)
```

open/release additions to hello.c

```
#include <linux/fs.h>

#define  HELLO_MAJOR 234
…
struct file_operations hello_fops;

static int hello_open(struct inode *inode, struct file *file) {
    printk("hello_open: successful\n");
    return 0;
}

static int hello_release(struct inode *inode, struct file *file) {
    printk("hello_release: successful\n");
    return 0;
}
```

read/write additions to hello.c

```
static ssize_t hello_read(struct file *file,
        char *buf, size_t count, loff_t *ptr) {
     printk("hello_read: returning zero bytes\n");
     return 0;
}

static ssize_t hello_write(struct file *file,
     const char *buf, size_t count, loff_t * ppos)
{
     printk("hello_read: accepting zero bytes\n");
     return 0;
}
```

ioctl additions to hello.c

```
static int hello_ioctl(struct inode *inode,
      struct file *file, unsigned int cmd,
      unsigned long arg) {
    printk("hello_ioctl: cmd=%ld, arg=%ld\n",
          cmd, arg);
    return 0;
}
```

init additions to hello.c

```
#define  HELLO_MAJOR 234
static int __init hello_init(void)
{
    int ret;
    printk("Hello Example Init - debug mode is %s\n",
           debug_enable ? "enabled" : "disabled");
    ret = register_chrdev(HELLO_MAJOR, "hello1", &hello_fops);
        if (ret < 0) {
            printk("Error registering hello device\n");
            goto hello_fail1;
        }
    printk("Hello: registered module successfully!\n");

    /* Init processing here... */

    return 0;

hello_fail1:
    return ret;
}
```

Major number for device driver

- Every device has a major and minor number

```
$ ls -ls /dev/console
0 crw------- 1 yoder root 5, 1 2011-02-06 17:57 /dev/console
```

- Device numbers *used* to be statically assigned
- See …/Documentation/devices.txt

```
 5 char  Alternate TTY devices
                   0 = /dev/tty             Current TTY device
                   1 = /dev/console System console
                   2 = /dev/ptmx            PTY master multiplex
                  64 = /dev/cua0            Callout device for ttyS0
```

- The text uses static assignment

```
234-239       UNASSIGNED
240-254 char  LOCAL/EXPERIMENTAL USE
```

Registering our functions

- Struct file_operations is used bind our functions to the requests from the file system.

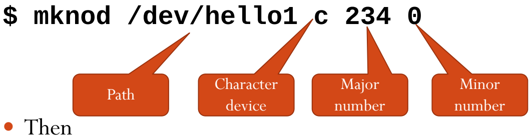
```
struct file_operations hello_fops = {
    owner:   THIS_MODULE,
    read:    hello_read,
    write:   hello_write,
    ioctl:   hello_ioctl,
    open:    hello_open,
    release: hello_release,
};
```

init additions to hello.c

```
#define  HELLO_MAJOR 234
static int __init hello_init(void)
{
    int ret;
    printk("Hello Example Init - debug mode is %s\n",
           debug_enable ? "enabled" : "disabled");
    ret = register_chrdev(HELLO_MAJOR, "hello1", &hello_fops);
        if (ret < 0) {
            printk("Error registering hello device\n");
            goto hello_fail1;
        }
    printk("Hello: registered module successfully!\n");
    /* Init processing here... */
    return 0;
hello_fail1:
    return ret;
}
```

Device Nodes and **mknod**

- Use **mknod** to create a new device



```
$ mknod /dev/hello1 c 234 0
```

- Then

```
$ ls –l /dev/hello1
crw-r—r--   1 root  root  234, 0 Apr 2 2011  /dev/hello1
```

Dynamic Major Number

- The above example uses the older *static* method to assign a device number
- Today dynamic allocation is preferred
- Here is how:

```
#include <linux/kdev_t.h>
dev_t dev;
```

- This declares **dev** to be a device number (both major and minor). Now assign it a value
- **dev = MKDEV(234, 0);**

Requesting a number

- Now request a number

```
#include <linux/fs.h>
int register_chrdev_region(dev, 4, "hello");
```

  - This requests a device number starting with 234 (previous page)
  - It asks for 4 minor numbers
  - Uses the name “hello”
- When done with the device use:

```
void unregister_chrdev_region(dev, 4);
```

Using **mknod**

- If you major number is assigned dynamically, how do you use **mknod**? Try the following

```
module="hello"
device="hello"
mode="664"
/sbin/insmod ./$module.ko $* || exit 1
# remove stale nodes
rm -f /dev/${device}0
major=`awk "\\$2==\"$module\" {print \\$1} /proc/devices`
mknod /dev/${device}0 c $major 0
```

Assignment

- See http://elinux.org/ECE497_Lab08_Device_Drivers

Module dependencies

- Some kernel modules can depend on other modules, which need to be loaded first.
- Example: the usb-storage module depends on the scsi_mod, libusual and usbcore modules.
- Dependencies are described in /lib/modules/<kernel-version>/modules.dep

Kernel log

When a new module is loaded,
related information is available in the kernel log.

- The kernel keeps its messages in a circular buffer (so that it doesn't consume more memory with many messages)
- Kernel log messages are available through the dmesg command.
 (“**d**iagnostic **mes**sa**g**e”)
- Kernel log messages are also displayed in the system console (messages can be filtered by level using `/proc/sys/kernel/printk`)

printk

- **`/proc/sys/kernel/printk`**
- The four values in this file are
  - *console_loglevel*,
  - *default_message_loglevel*,
  - *minimum_console_level* and
  - *default_con- sole_loglevel*.
- These values influence **`printk()`** behavior when printing or logging error messages.
- Messages with a higher priority than *console_loglevel* will be printed to the console.
- Messages without an explicit priority will be printed with priority *default_message_level*.

http://www.tin.org/bin/man.cgi?section=5&topic=proc

Kernel log levels

0 (KERN_EMERG)	The system is unusable.
1 (KERN_ALERT)	Actions that must be taken care of immediately.
2 (KERN_CRIT)	Critical conditions.
3 (KERN_ERR)	Noncritical error conditions.
4 (KERN_WARNING)	Warning conditions that should be taken care of.
5 (KERN_NOTICE)	Normal, but significant events.
6 (KERN_INFO)	Informational messages that require no action.
7 (KERN_DEBUG)	Kernel debugging messages, output by the

Module utilities (1)

- modinfo <module_name>
  modinfo <module_path>.ko
  Gets information about a module: parameters, license, description and dependencies.
  Very useful before deciding to load a module or not.
- sudo insmod <module_path>.ko
  Tries to load the given module. The full path to the module object file must be given.

Understanding module loading

- When loading a module fails,
  insmod often doesn't give you enough details!
- Details are often available in the kernel log.
- Example:

```
> sudo insmod ./intr_monitor.ko
insmod: error inserting './intr_monitor.ko': -1
Device or resource busy
> dmesg
[17549774.552000] Failed to register handler for
irq channel 2
```

Module utilities (2)

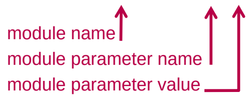
- sudo modprobe <module_name>
  Most common usage of modprobe: tries to load all the modules the given module depends on, and then this module. Lots of other options are available. modprobe automatically looks in `/lib/modules/<version>/` for the object file corresponding to the given module name.
- lsmod
  Displays the list of loaded modules
  Compare its output with the contents of /proc/modules!

Module utilities (3)

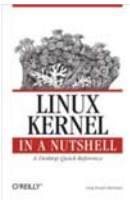
- sudo rmmod <module_name>
  Tries to remove the given module.
  Will only be allowed if the module is no longer in use (for example, no more processes opening a device file)
- sudo modprobe -r <module_name>
  Tries to remove the given module and all dependent modules (which are no longer needed after the module removal)

Passing parameters to modules

- Find available parameters:
  modinfo snd-intel8x0m
- Through insmod:
  sudo insmod ./snd-intel8x0m.ko index=-2
- Through modprobe:
  Set parameters in /etc/modprobe.conf or in any file in /etc/modprobe.d/:
  options snd-intel8x0m index=-2
- Through the kernel command line,
  when the module is built statically into the kernel:
  snd-intel8x0m.index=-2



Useful reading



Linux Kernel in a Nutshell, Dec 2006

- By Greg Kroah-Hartman, O'Reilly
  http://www.kroah.com/lkn/
- A good reference book and guide on configuring, compiling and managing the Linux kernel sources.
- Freely available on-line!
  Great companion to the printed book for easy electronic searches!
  Available as single PDF file on
  http://free-electrons.com/community/kernel/lkn/

Useful reading too

Linux Device Drivers, Third Edition, February 2005

- By Jonathan Corbet, Alessandro Rubini, Greg Kroah-Hartman, O'Reilly
  http://lwn.net/Kernel/LDD3/
- Freely available on-line!
  Great companion to the printed book for easy electronic searches!
  Available as single PDF file
- LDD3 is current as of the 2.6.10 kernel (Old?)