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

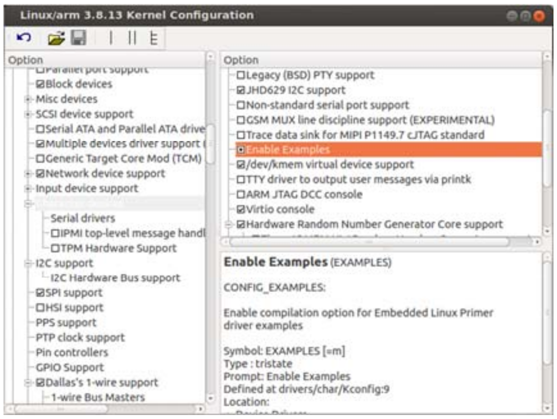
Typo page 206

```
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 DEVKMEM
         bool "/dev/kmem virtual device support"
         default y
         help
```

Must be lower case

In new kernel

Check Config



- ☐Parallel port support
- ☑Block devices
- Misc devices
- SCSI device support
- ☐Serial ATA and Parallel ATA drive
- ☑Multiple devices driver support (
- ☐Generic Target Core Mod (TCM)
- ☑Network device support
- Input device support
- Serial drivers
- ☐IPMI top-level message handl
- ☐TPM Hardware Support
- I2C support
- I2C Hardware Bus support
- ☑SPI support
- ☐HSI support
- PPS support
- PTP clock support
- Pin controllers
- GPIO Support
- ☑Dallas's 1-wire support
- 1-wire Bus Masters

- ☐Legacy (BSD) PTY support
- ☑JHD629 I2C support
- ☐Non-standard serial port support
- ☐GSM MUX line discipline support (EXPERIMENTAL)
- ☐Trace data sink for MIPI P1149.7 cJTAG standard
- ⊡Enable Examples
- ☑/dev/kmem virtual device support
- ☐TTY driver to output user messages via printk
- ☐ARM JTAG DCC console
- ☑Virtio console
- ☑Hardware Random Number Generator Core support

Enable Examples (EXAMPLES)

CONFIG_EXAMPLES:

Enable compilation option for Embedded Linux Primer driver examples

Symbol: EXAMPLES [=m]
Type : tristate
Prompt: Enable Examples
Defined at drivers/char/Kconfig:9
Location:

Module Build Output

```
host$ time make modules
 CHK     include/generated/uapi/linux/version.h
 CHK     include/generated/utsrelease.h
make[1]: `include/generated/mach-types.h' is up to date.
  CALL    scripts/checksyscalls.sh
  CC [M]  drivers/char/examples/hello1.o
  Building modules, stage 2.
  MODPOST 1326 modules
  LD [M]  drivers/char/examples/hello1.ko

real     0m33.706s
user     0m31.462s
sys      0m4.824s
```

First time takes much longer
Try make –j*X* modules

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

```
host$ ls -F ~/BeagleBoard/lib/modules/3.8.13+/
build@              modules.dep.bin      modules.seriomap
kernel/             modules.devname      modules.softdep
modules.alias       modules.ieee1394map  modules.symbols
modules.alias.bin   modules.inputmap     modules.symbols.bin
modules.builtin     modules.isapnpmap    modules.usbmap
modules.builtin.bin modules.ofmap        source@
modules.ccwmap      modules.order
modules.dep         modules.pcimap
```

- Then

```
host$ rm build source
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$ cd /lib/modules/3.8.13/kernel/drivers/char/
beagle$ mkdir examples
beagle$ cd examples
beagle$ mv ~/hello1.ko  .
```

Loading and Unloading a Module

```
beagle$ cd /lib/modules/3.8.13/kernel/drivers/char/examples
beagle$ insmod hello1.ko
beagle$ dmesg | tail -4
[    9.106206] snd-usb-audio 1-1:1.0: usb_probe_interface
[    9.106244] snd-usb-audio 1-1:1.0: usb_probe_interface - got id
[    9.813239] usbcore: registered new interface driver snd-usb-audio
[  109.308551] Hello Example Init
beagle$ rmmod hello1
beagle$ dmesg | tail -4
[    9.106244] snd-usb-audio 1-1:1.0: usb_probe_interface - got id
[    9.813239] usbcore: registered new interface driver snd-usb-audio
[  109.308551] Hello Example Init
[  241.037368] 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
  - **`ioctl()`**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,
};
```

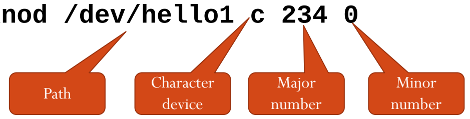
init additions to hello.c

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

/proc/devices

```
Character
devices:
  1 mem
  4 /dev/vc/0
  4 tty
  4 ttyS
  5 /dev/tty
  5 /dev/console
  5 /dev/ptmx
  7 vcs
 10 misc
 13 input
 14 sound
 21 sg
 29 fb
 81 video4linux
89 i2c
90 mtd
116 alsa
128 ptm
136 pts
153 spi
161 ircomm
180 usb
189 usb_device
216 rfcomm
247 bccat
248 pvrsrvkm
249 rtc
250 ttySDIO
251 omap-resizer
252 omap-
previewer
253 usbmon
254 bsg

Block devices:
  1 ramdisk
259 blkext
  7 loop
  8 sd
 11 sr
 31 mtdblock
 65 sd
 66 sd
 67 sd
 68 sd
 69 sd
70 sd
 71 sd
128 sd
129 sd
130 sd
131 sd
132 sd
133 sd
134 sd
135 sd
179 mmc
```

Assignment

- See http://elinux.org/EBC_Exercise_26_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

/lib/modules/2.6.32/models.dep

```
kernel/drivers/char/examples/hello1.ko:
kernel/crypto/twofish_common.ko:
kernel/crypto/ctr.ko:
kernel/crypto/blowfish.ko:
kernel/crypto/ghash-generic.ko:
kernel/crypto/gf128mul.ko
kernel/crypto/xts.ko:
kernel/crypto/gf128mul.ko
kernel/crypto/gcm.ko:
kernel/crypto/cryptd.ko:
kernel/crypto/md4.ko:
kernel/crypto/lrw.ko:
kernel/crypto/gf128mul.ko
```

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_console_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:

```
beagle$ sudo insmod ./intr_monitor.ko
insmod: error inserting './intr_monitor.ko': -1
Device or resource busy
beagle$ 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!

lsmod

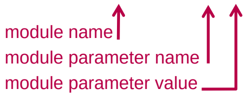
```
beagle$ lsmod
Module                  Size  Used by
bufferclass_ti          4768  0
omaplfb                 8733  0
pvrsrvkm              154248  2 bufferclass_ti,omaplfb
rfcomm                 33484  0
ircomm_tty             30305  0
ircomm                 16429  1 ircomm_tty
irda                  162973  2 ircomm_tty,ircomm
ipv6                  249063  14
hidp                   11193  0
l2cap                  30104  4 rfcomm,hidp
bluetooth              49221  3 rfcomm,hidp,l2cap
…
```

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


module name
module parameter name
module parameter value

Useful reading

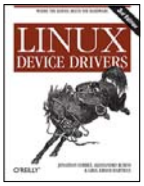
Linux Kernel in a Nutshell, Dec 2006

- 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/
- In **`exercises/pptx`**

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?)
- In **`exercises/pptx`**