Embedded systems 2b/7

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Communicating from userspace with the kernel

Through `/dev`

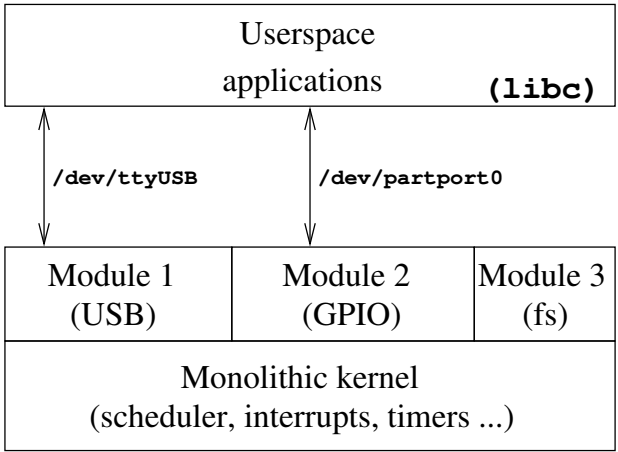
- write, read, or control (`ioctl`)
- each kernel module implements its own answer to the system calls
- each peripheral is identified by its class (*major number*) [1] and its index (*minor number*)

```
brw-rw----  1 root     disk      8,   0 Feb 28 06:21 sda
brw-rw----  1 root     disk      8,   1 Feb 28 06:21 sda1
brw-rw----  1 root     disk      8,   2 Feb 28 06:21 sda2
brw-rw----  1 root     disk      8,   3 Feb 28 06:21 sda3
[...]
crw-rw----  1 root     dialout   4,  64 Feb 28 07:21 ttyS0
crw-rw----  1 root     dialout   4,  65 Feb 28 07:21 ttyS1
crw-rw----  1 root     dialout   4,  66 Feb 28 07:21 ttyS2
crw-rw----  1 root     dialout   4,  67 Feb 28 07:21 ttyS3
```

In case an entry is missing (e.g. created by `udev`) in `/dev` : `mknod`

[1] see `linux.../include/linux/kdev_t.h` for their definition: major number defined on 12 bits and minor on 20 bits)

Architecture of a POSIX [2] compliant OS



system fonctions, networking, process scheduling and memory sharing, vfs

[2] /dev directory: pubs.opengroup.org/onlinepubs/009695399/basedefs/xbd_chap10.html

The /dev directory

- includes pseudo-files linking the kernel with the user space
- each device is defined with a *major number* and, within each class, a *minor number*
- on the kernel side, a *driver* links to the same major number and provides implementations of the system calls
  - `open()`
  - `close()`
  - `write()`
  - `read()`
  - `ioctl()`

```
static int dev_open (struct inode *inod, struct file *fil)
{// initialize ADC: static to avoid polluting namespace
}

static ssize_t qadc_read (struct file *f, char *buf, size_t len, loff_t *off)
{// read from ADC...
}

static struct file_operations fops=
{.read=           qadc_read,
 .open=           qadc_open,
 .unlocked_ioctl= qadc_ioctl,
 .release=        qadc_release,
// no .write on an ADC !
};

static int qadc_init (void)
{register_chrdev (qadc_major, "ppp", &fops);
 ...}

static void qadc_exit (void)
{unregister_chrdev(90,"ppp");
 ...}

module_init (qadc_init);
module_exit (qadc_exit);
```

Input/Output Control (ioctl)

- mechanism breaking the "Everything is a file" philosophy
- configures a peripheral by providing "what" index and as an argument the "value"
- no standardized command: the header file common to the driver and the userspace program provides the list of IOCTL calls
- example: OSS (Open Sound System [3]) in `include/uapi/linux/soundcard.h` of the kernel source:

```
/* Use ioctl(fd, OSS_GETVERSION, &int) to get the
   version number of the currently active driver.  */
...
/* IOCTL commands for /dev/dsp and /dev/audio
 */
#define SNDCTL_DSP_RESET          _SIO  ('P', 0)
#define SNDCTL_DSP_SYNC           _SIO  ('P', 1)
#define SNDCTL_DSP_SPEED          _SIOWR('P', 2, int)
#define SNDCTL_DSP_STEREO         _SIOWR('P', 3, int)
...
```

- Userspace:

```
sample_rate = 48000;
if (ioctl (fd, SNDCTL_DSP_SPEED, &sample_rate) == -1)
    {perror ("SNDCTL_DSP_SPEED");exit (-1);}
```

[3] http://www.linuxdevcenter.com/pub/a/linux/2007/08/02/an-introduction-to-linux-audio.html

IOCTL: kernel

```
static long dev_ioctl(struct file*,unsigned int,unsigned long);

static struct file_operations fops=
{.read=dev_read,
 .open=dev_open,
 .unlocked_ioctl=dev_ioctl,
 .write=dev_write,
 .release=dev_rls,};

static long dev_ioctl(struct file *f, unsigned int cmd, unsigned long arg)
{static char var[10]; // DON'T read arg which is located
 int dummy;           // ... in userspace: copy_from_user
 printk(KERN_ALERT "ioctl CMD%d",cmd);
 switch ( cmd )       // one of the known ioctl
 {case 0: dummy=copy_from_user(var,(char*)arg,5);
          printk(KERN_ALERT "ioctl0: %s\n",(char*)var);
          break;
  case 1: printk(KERN_ALERT "ioctl1: %s\n",(char*)var);
          dummy=copy_to_user((char*)arg,var,5);
          break;
  default:printk(KERN_ALERT "unknown ioctl");break;
 }
 return 0;}
```

IOCTL: userspace

No shell command line instruction: requires a dedicated compiled (C) program:

```
#include <sys/ioctl.h>  /* ioctl */
#define IOCTL_SET_MSG 0
#define IOCTL_GET_MSG 1

main(int argc,char **argv)
{ int file_desc, ret_val;
  char msg[30] = "Message passed by ioctl\n";

  file_desc = open("/dev/jmf", 0);
  msg[4]=0;
  ret_val = ioctl(file_desc, IOCTL_SET_MSG, msg);
  ret_val = ioctl(file_desc, IOCTL_GET_MSG, msg);
}
```

donne (dmesg)

```
[  943.551282] Hello ioctl
[  946.385700] ioctl open
[  946.385757] ioctl CMD0
[  946.385758] ioctl0: Mess
[  946.385762] ioctl CMD1
[  946.385763] ioctl1: Mess
[  946.385766] bye
```

Kernel timer: configuration and callback function

Timer configuration and releasing resources when leaving the module

```
 timer_setup(&exp_timer,do_something,0);  // since 4.14
 exp_timer.expires = jiffies + delay * HZ;
// HZ specifies number of clock ticks generated per second
 add_timer(&exp_timer);
}

void hello_end() // cleanup_module(void)
{release_mem_region(IO_BASE2, 0x2e4);
 del_timer(&exp_timer);
}
```

Callback function:

```
static void do_something(struct timer_list *data) // was unsigned long data)
{[...]
 mod_timer(&exp_timer, jiffies + HZ); // relaunch timer
}
```

Accessing kernel functions requires compliance with the GPL License [4]:

```
MODULE_LICENSE("GPL");
```

[4] J. Corbet, *Unexporting kallsyms_lookup_name()*, 28/02/2020 @ https://lwn.net/Articles/813350/

Kernel timer: direct GPIO access

```
#define mio 0

int hello_start()
{int delay = 1;
 unsigned int s;

 if (request_mem_region(IO_BASE1,0x12c,"GPIO cfg")==NULL)
     printk(KERN_ALERT "mem request failed");
 jmf_gpio = (void __iomem*)ioremap(IO_BASE1, 0x4);
 s=readl(jmf_gpio+0x12c);// PAS assignation (crash): mask
 s|=(1<<22);             //  ... GPIO clock
 writel(s,jmf_gpio+0x12c);
 release_mem_region(IO_BASE1, 0x12c);

 if (request_mem_region(IO_BASE2,0x2E4,"GPIO test")==NULL)
     printk(KERN_ALERT "mem request failed");
 jmf_gpio = (void __iomem*)ioremap(IO_BASE2, 0x2E4);
 writel(1<<mio,jmf_gpio+0x204); // direction
 writel(1<<mio,jmf_gpio+0x208); // enable
 writel(1<<mio,jmf_gpio+0x40);  // value
```

User Guide : Appendix B (Register Details) p.785 → gpio @ 0xE000A000 → DATA_0 en 0x040, DIRM_0 en 0x204 et OEN_0 en 0x208.

Kernel timer: gpiolib

- Rather than accessing the low level registers, use existing kernel functions
- GPIO access: gpiolib
- kernel configuration (make linux-menuconfig)

```
CONFIG_GPIO_XILINX:
Say yes here to support the Xilinx FPGA GPIO device

Symbol: GPIO_XILINX [=m]
Type  : tristate
Prompt: Xilinx GPIO support
  Location:
    -> Device Drivers
      -> GPIO Support (GPIOLIB [=y])
        -> Memory mapped GPIO drivers
```

- we have selected *not to* compile static libraries but to use modules in order to keep the ability to deactivate the libraries by removing the module from the kernel (rmmod)
- as was seen in userspace, MIOx is refered to by the index 906+x

Kernel timer – gpiolib

```
int hello_start(void);
void hello_end(void);

int hello_start()
{int jmf_gpio=906+0;  // 0 = orange, 7 = red (heartbeat)
 err=gpio_is_valid(jmf_gpio);
 err=gpio_request_one(jmf_gpio, GPIOF_OUT_INIT_LOW, "jmf_gpio");
 // see linux-XXX/linux/gpio.h for available functions

 timer_setup(&exp_timer,do_something,0);  // since 4.14
 exp_timer.expires = jiffies + delay * HZ;
// HZ specifies number of clock ticks generated per second
 add_timer(&exp_timer);
 return 0;
}

void hello_end() // cleanup_module(void)
{gpio_free(jmf_gpio); del_timer(&exp_timer);
}
```

output pin handling: `gpio_set_value(jmf_gpio,jmf_stat);`
Using `gpiolib`: the licence (GPL) of the module matters !

Summary

- Two input and output functions (notice the **different prototypes** !):
  `int module_init (beginning_function);` and
  `void module_exit (final_function);`
- initialize the link between the module and userspace (make sure the major number is free [5]):
  `register_chrdev (90 , "jmf" ,&fops );`
- print message in /var/log/syslog by
  `printk (KERN_ALERT "formated message");` (*no coma !*)
- ability to dynamically create the dev entry point
  `insmod module` creates /dev/jmf by

```
struct miscdevice jmfdev;

{jmfdev.name = "jmf";  // /dev/jmf: major=misc class
 jmfdev.minor = MISC_DYNAMIC_MINOR;
 jmfdev.fops = &fops;
 misc_register(&jmfdev); // dyanmic creation /dev/jmf
}
```

  which concludes with (`rmmod module`):

```
misc_deregister(&jmfdev);
```

[5] see /proc/devices for a list of allocated major numbers

Lab session

1. compile a simple module (`init`, `exit`) on the PC – `Makefile` linking to the kernel source,

```
obj-m +=mon_module.o
all:
    make -C /lib/modules/$(shell uname -r)/build M=$(PWD) modules
```

since

```
$ ls -l /lib/modules/4.12.0-1-amd64/
 build -> /usr/src/linux-headers-4.12.0-1-amd64
```

2. compile the *same* module for the Redpitaya by linking with the kernel sources found in `buildroot` – transfer and execute on the Zynq
3. add communication functions `open`, `close` – create the `/dev` entry point with `mknod` and test from shell and a C program
4. add IOCTL function and call from a C program using `ioctl()`

Use conditional compilation x86 v.s ARM : `#ifdef __ARMEL__`[6]

[6] J.-M Friedt, *Modification des appels systèmes du noyau Linux : manipulation de la mémoire du noyau*, GNU/Linux Magazine Hors Série 87 (Nov.-Déc 2016)

Diverting system calls

```
$ strace mkdir toto
[...]
mkdir("toto", 0777)                     = 0
```

- A system call [7] provides the means by the kernel to access resources managed by the system (POSIX standard: `open`, `close`, `read`, `write`, `mkdir` ...)
- a userspace program requests a system call...
- ... matching a corresponding function in kernel space.
- A system call table matches userspace and kernelspace requests.

$\Rightarrow$ manipulating system calls consists inn

1. identifying the memory address where the look up table is located,
2. modify the address of the called function towards our own function or...
3. ... modify the content of memory at the called destination address.

[7] list of POSIX system calls in `/usr/include/x86_64-linux-gnu/asm/unistd_64.h`

Diverting system calls

Obvious attack against which protections include

- prevent writing in the memory page holding the system clal lookup table

```
/boot/System.map-4.6.0-1-amd64: ffffffff816001e0 R sys_call_table
/proc/kallsyms                : ffffffff816001e0 R sys_call_table
```

- not exporting symbols of the system calls (range of the function: `static` within the file, `EXPORT_SYMBOL`)

Question: what are the functions exported by the kernel to the modules?

```
linux-4.4.2$ grep -r EXPORT_SYMBOL * | grep \(sys_
[...]
fs/open.c:EXPORT_SYMBOL(sys_close);
kernel/time/time.c:EXPORT_SYMBOL(sys_tz);
```

Only sys_close() is exported

Diverting system calls

```
#include <linux/module.h>
#include <linux/syscalls.h>

static unsigned long* cherche_table(void)
{unsigned long int offset = PAGE_OFFSET;   // debut kernel
 unsigned long *sct;
 printk(KERN_INFO "PAGE_OFFSET=%lx\n",PAGE_OFFSET);
 while (offset < ULLONG_MAX)      // recherche toute la mem
  {sct = (unsigned long *)offset;
   if (*sct == (unsigned long)&sys_close)   // @ sys_close
      return sct;              // on a trouve' l'@ de debut
   offset += sizeof(void *);
  }
 return NULL;
}
[...]
```

```
[100266.370251] PAGE_OFFSET=ffff880000000000
[100266.433568] table: ffff880016001f8
[100266.433570] NR close: 3
[100266.433571] NR mkdir: 83 => ffffffff812020d0
```

consistent (16001f8-24=16001e0 since sys_close is call 3) with

```
/boot/System.map-4.6.0-1-amd64: ffffffff816001e0 R sys_call_table
/proc/kallsyms                : ffffffff816001e0 R sys_call_table
```

Diverting system calls

Function pointer

```
#include <linux/module.h>
#include <linux/syscalls.h>

asmlinkage          // passage params par pile
long (*ref_sys_mkdir)(const char __user*,int);

asmlinkage
long mon_mkdir(const char __user *pnam, int mode)
{printk(KERN_INFO "intercept: %s:%x\n", pnam,mode);
 return 0;
}

static int __init module_start(void)
{addr_table = cherche_table();
 ref_sys_mkdir=(void *)addr_table[__NR_mkdir-__NR_close];
 addr_table[__NR_mkdir-__NR_close]=(unsigned long)mon_mkdir;
 return(0);
}
```

```
$ mkdir toto
[103669.045129] intercept: toto:1ff
```

No longer works since kernel 4.17.0 which no longer exports `sys_close`, cf `https://github.com/f0rb1dd3n/Reptile`