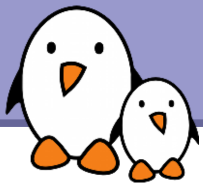

Accessing hardware from userspace

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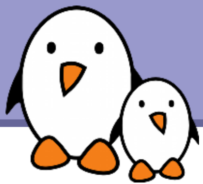

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Latest update: Jul 25, 2018

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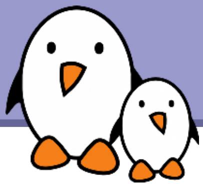
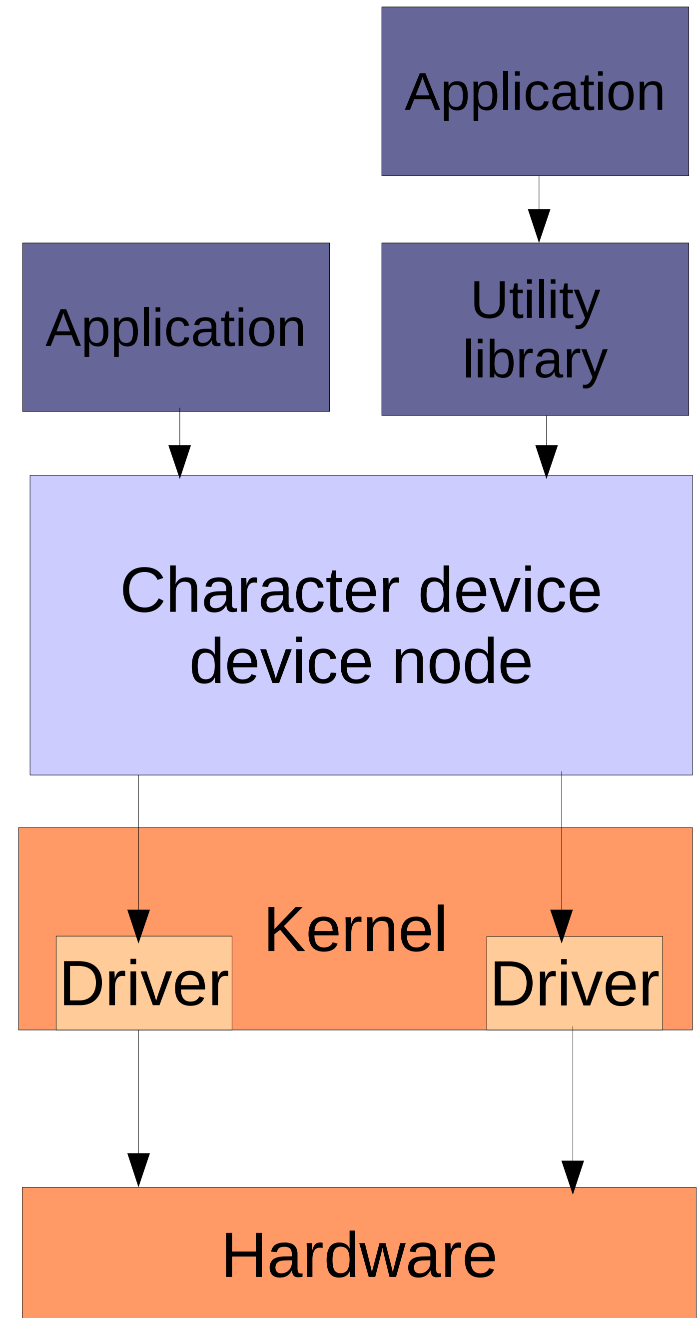
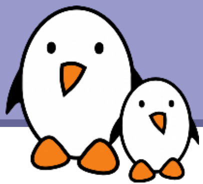


Kernel vs. userspace

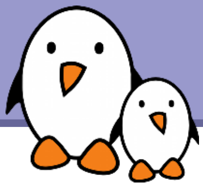
- For most devices, the driver
  - Is inside the kernel
  - Provides an interface for userspace application to communicate with the hardware
- The interface is usually
  - A character device
  - A character device preferably accessed through an utility library
- There are some exceptions: block devices, network interfaces, printers or graphics with X.org.





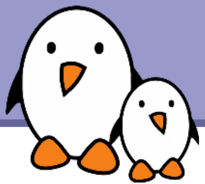
Character device API

- Character devices are seen by userspace applications as files, so the traditional Unix file API is available
  - `open()` and `close()` on the device file
  - `read()` to get data from the device
  - `write()` to send data through the device
  - `ioctl()` to perform special operations on the device
  - `poll()` and `select()` to wait for events
  - `mmap()` to remap the device memory into the process address space
- The kernel driver is responsible for implementing this API, so that from the perspective of the userspace application, communicating with the hardware is very simple.



ioctl()

- `ioctl()` is a function of the C library, a system call, and an operation of character device driver
- It is used to implement operations specific to the device or device type, such as setting the serial port speed, changing the screen resolution, adjusting the video capture format, etc.
- Prototype of the function in userspace
  `int ioctl(int d, int request, ...)`
  - d is the file descriptor
  - `request` is a number identifying the operation. This number is device or device-type specific.
  - `...` is an unlimited number of arguments. The number of arguments, their type and semantic depend on the ioctl operation
- See `man ioctl`



Example with the serial port

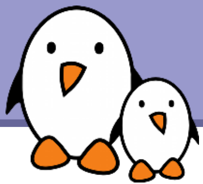
```
#include <termios.h>
#include <fcntl.h>
#include <sys/ioctl.h>

int main(void)
{
   int fd, serial;
   fd = open("/dev/ttyS0", O_RDWR);
   write(fd, “Hello”, 5);
   ioctl(fd, TIOCMGET, &serial);
   if (serial & TIOCM_DTR)
      printf("TIOCM_DTR is not set");
   else
      printf("TIOCM_DTR is set");
   close(fd);
}
```

Open the device

Write to it

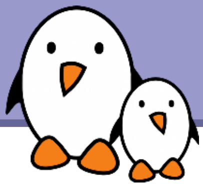
Perform a special operation on it : get the status bits

Warning: error checking omitted!



ioctl operations for serial ports

- There are many ioctl operations for serial ports, as defined by the `tty_ioctl` manual page. For some of them, POSIX also specifies functions to wrap ioctl operations
  - `TCGETS` operation is similar to the `tcgetattr()` function, it gets a termios structure
  - `TCSETS` operation is similar to the `tcsetattr()` function, it sets a termios structure
  - `TCSBRK` similar to `tcsendbreak()`, it sends a break
  - `TCXONC` similar to `tcflow()`, to control the software flow control
  - `TCFLSH` similar to `tcflush()`, to flush the input or output buffers
  - `TIOCMGET` to get the status of the modem bits
  - `TIOCMSET` to set the status of the modem bits
- See the `termios` manual page for more details



Termios example

```
struct termios options;

fd = open(“/dev/ttyS0”, O_RDWR);

tcgetattr(fd, &options);

cfsetispeed(&options, B19200);
cfsetospeed(&options, B19200);
options.c_cflag |= (CLOCAL | CREAD);

tcsetattr(fd, TCSANOW, &options);
```

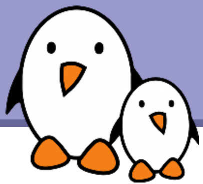
Get current value of the termios structure

Modify the settings

Set the new termios structure

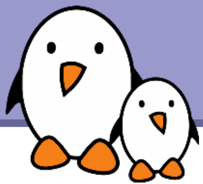
Warning: error checking omitted!

I2C



I2C from userspace

- Some I2C devices have directly a driver in the kernel
  - In this case, the driver is tied to the appropriate kernel infrastructure, depending on the device type
  - It is made available to userspace through this infrastructure
- The `i2c-dev` driver allows an userspace application to directly interact on the I2C bus
  - Character devices are created in userspace for each I2C adapter
  - Major is 89, the minor is the adapter number
  - Conventional name is `/dev/i2c-0`, `/dev/i2c-1`, etc.
  - See `/sys/class/i2c-dev/` or run `i2cdetect -l` for a list
  - `i2cdetect` is part of the `i2c-tools` package in Ubuntu/Debian distributions



i2c-dev

- Open the i2c-dev device

```
fd = open(“/dev/i2c-0”, O_RDWR);
```

- Specify the device with which you want to communicate

```
ioctl(fd, I2C_SLAVE, 0x40);
```

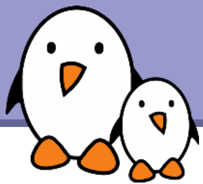
- Write to the bus

```
buf[0] = register;
buf[1] = data1;
buf[2] = data2;
write(fd, buf, 3);
```

- Read from the bus

```
read(fd, buf, 1);
```

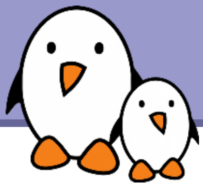
- See `Documentation/i2c/dev-interface` for details



Accessing hardware directly (1)

- The `/dev/mem` character device allows to access directly to the physical memory, including I/O memory
  - read() or write() operations are possible
  - mmap() operation is also possible, to remap specific parts of the physical memory to the address space of the application.
  - Obviously, access rights to this device must be properly set, as it allows to do anything with the system
    `crw-r----- 1 root kmem 1, 1 2009-04-28 10:37 /dev/mem`
- Exemple from the X.org server

```
fd = open ("/dev/mem", O_RDWR);
a = mmap (0, size, PROT_READ|PROT_WRITE,
          MAP_SHARED, fd, addr);
close(fd);
```

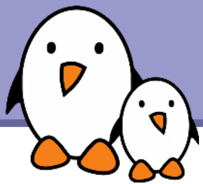


Accessing hardware directly (2)

- Other character device drivers can also provide a mmap() operation which can be used by userspace applications
- For example, in DirectFB, a library that relies on the kernel framebuffer driver :

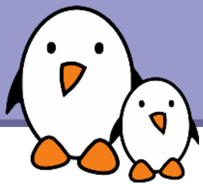
```
int fd;
char *fbbase;
fd = open(“/dev/fb0”, O_RDWR);
fbbase = mmap(NULL, shared->fix.smem_len,
            PROT_READ | PROT_WRITE,
            MAP_SHARED, fd, 0);
```

- Then the fbbase pointer can be used to directly read and write to the framebuffer.



GPIOs

- GPIOs can be directly accessed through `/dev/mem` or a specific character driver implementing the `mmap()` operation
- If the board code supports the `gpiolib` kernel framework, GPIOs are made available to userspace through sysfs
  - `/sys/class/gpio/gpioN/` directory for each GPIO
    - `direction` file to configure the direction (either in and out)
    - `value` file to configure the value (0 or 1)
  - `/sys/class/gpio/`
    - `export` allows to export GPIO to userspace that haven't been explicitly exported by the kernel. Writing the GPIO number is sufficient
    - `unexport` allows to unexport GPIOs that have previously been exported
  - See `Documentation/gpio.txt` in kernel sources for details.



Utility libraries

- Most of the device drivers in the kernel fit inside a framework, that unifies the set of operations that can be performed on a device of a given type
- Some of these device types must be used directly as character devices by userspace applications
- For other device types, an utility library is available to ease usage of the device
  - ALSA sound devices, represented as character devices in userspace, are better used through `libasound`
  - Video 4 Linux devices through libv4l
  - Framebuffer devices through DirectFB
- Don't forget to check if an utility library exists for your case, or write your own !