How to avoid writing kernel drivers

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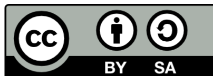

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About Chris Simmonds

- Consultant and trainer
- Author of *Mastering Embedded Linux Programming*
- Working with embedded Linux since 1999
- Android since 2009
- Speaker at many conferences and workshops

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Agenda

- Device drivers in kernel space
- Device drivers in user space
- Some examples:
    - GPIO
    - PWM
    - I2C

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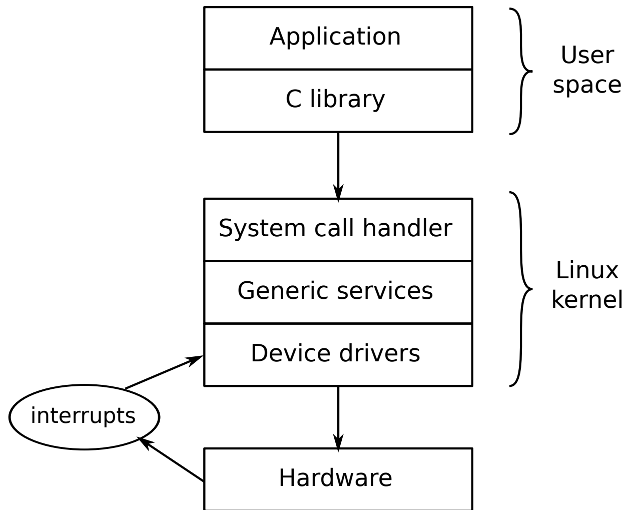
Conventional device driver model



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How applications interact device drivers

- In Linux, everything is a file [1]
- Applications interact with drivers via POSIX functions open(2), read(2), write(2), ioctl(2), etc
- Two main types of interface:

1. Device nodes in `/dev`
   - For example, the serial driver, `ttyS`. Device nodes are named `/dev/ttyS0`, `/dev/ttyS1` ...
2. Driver attributes, exported via *sysfs*
   - For example `/sys/class/gpio`

[1] Except network interfaces, which are sockets

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Userspace drivers

- Writing kernel device drivers can be difficult
- Luckily, there are generic drivers that that allow you to write most of the code in userspace
- We will look at three
  - GPIO
  - PWM
  - I2C

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A note about device trees

- Even though you are writing userspace drivers, you still need to make sure that the hardware is accessible to the kernel
- On ARM based systems, this may mean changing the device tree or adding a device tree overlay (which is outside the scope of this talk)

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GPIO: General Purpose Input/Output

- Pins that can be configured as inputs or outputs
- As outputs:
  - used to control LEDs, relays, control chip selects, etc.
- As inputs:
  - used to read a switch or button state, etc.
  - some GPIO hardware can generate an interrupt when the input changes

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Two userspace drivers!

- **gpiolib**[1]: old, but scriptable interface using sysfs
- **gpio-cdev**: new, higher performance method using character device nodes `/dev/gpiochip*`

[1] it's **not** a library

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The gpiolib sysfs interface

- GPIO pins grouped into registers, named **gpiochipNN**
- Each pin is assigned a number from 0 to XXX

```
# ls /sys/class/gpio/
export   gpiochip0   gpiochip32   gpiochip64   gpiochip96   unexport
```

This device has 4 gpio chips
each with 32 pins

Write to this
file to export
a GPIO pin
to user space

Write to this
file to unexport
a GPIO pin
to user space

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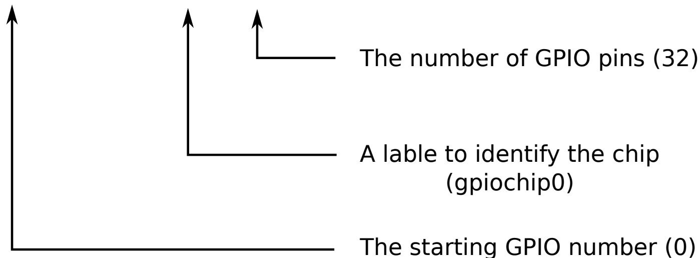
Inside a gpiochip



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Exporting a GPIO pin

```
# echo 42 > /sys/class/gpio/export
# ls /sys/class/gpio
export   gpio42  gpiochip0   gpiochip32   gpiochip64   gpiochip96   unexport
```

If the export is successful, a new directory is created

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Inputs and outputs

```
# ls /sys/class/gpio/gpio42
active_low  device  direction  edge  power  subsystem  uevent  value
```

active_low: Set to 1 to invert input and ouput

direction: Set direction by writing "out" or "in". Default "in"

value: The logic level of the pin. Change the level of outputs by writing "0" or "1"

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Interrupts

- If the GPIO can generate interrupts, the file **edge** can be used to control interrupt handling
- edge = ["none", "rising", "falling","both"]
- For example, to make GPIO60 interrupt on a falling edge:
  - `echo falling > /sys/class/gpio/gpio60/edge`
- To wait for an interrupt, use the poll(2) function

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The gpio-cdev interface

- One device node per GPIO register named `/dev/gpiochip*`
- Access the GPIO pins using `ioctl(2)`
- Advantages
  - Naming scheme gpiochip/pin rather than uniform but opaque name space from 0 to XXX
  - Multiple pin transitions in single function call without glitches
  - More robust handling of interrupts

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gpio-cdev example 1/2

```
/*
 * Demonstrate using gpio cdev to output a single bit
 * On a BeagleBone Black, GPIO1_21 is user LED 1
 */

#include <unistd.h>
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <fcntl.h>
#include <sys/ioctl.h>
#include <linux/gpio.h>

int main(void)
{
    int f;
    int ret;
    struct gpiohandle_request req;
    struct gpiohandle_data data;
```


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gpio-cdev example 2/2

```
    f = open("/dev/gpiochip1", O_RDONLY);
    req.lineoffsets[0] = 21;
    req.flags = GPIOHANDLE_REQUEST_OUTPUT; /* Request as output */
    req.default_values[0] = 0;
    strcpy(req.consumer_label, "gpio-output"); /* up to 31 characters */
    req.lines = 1;

    ret = ioctl(f, GPIO_GET_LINEHANDLE_IOCTL, &req);

    /* Note that there is a new file descriptor in req.fd to handle the
       GPIO lines */
    data.values[0] = 1;
    ret = ioctl(req.fd, GPIOHANDLE_SET_LINE_VALUES_IOCTL, &data);
    close(f);
    return 0;
}
```


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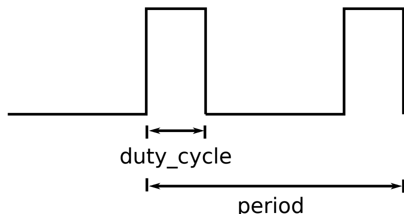
PWM: Pulse-Width Modulation



- Most SoCs have dedicated circuits that can produce a wave with **period** and **duty cycle**
- Two main use cases:
  - Dimmable LEDs and backlights
  - Servo motors: deflection is proportional to duty cycle

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The PWM sysfs interface

```
# ls /sys/class/pwm/pwmchip0
device  export  npwm  power  subsystem  uevent  unexport
```

Write to this
file to export
a PWM
to user space

Write to this
file to unexport
a PWM
to user space

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Exporting a PWM

```
# echo 0 > /sys/class/pwm/pwmchip0/export
# ls /sys/class/pwm/pwmchip0
device  export  npwm  power  pwm0  subsystem  uevent  unexport
```

If the export is successful, a new directory is created

```
# ls /sys/class/pwm/pwmchip0/pwm0
capture  duty_cycle  export  period    power      uevent
device   enable      npwm    polarity  subsystem  unexport
```


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PWM example

- For example, set period to 1 ms (1,000,000 ns) ...
- and duty to 0.5 ms (500,000 ns) ...
- then enable it

```
echo 1000000 > /sys/class/pwm/pwmchip0/pwm0/period
echo 500000 > /sys/class/pwm/pwmchip0/pwm0/duty_cycle
echo 1 > /sys/class/pwm/pwmchip0/pwm0/enable
```


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I2C: the Inter-IC bus

- Simple 2-wire serial bus, commonly used to connect sensor devices
- Each I2C device has a 7-bit address, usually hard wired
- 16 bus addresses are reserved, giving a maximum of 112 nodes per bus
- The master controller manages read/write transfers with slave nodes

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The i2c-dev driver

- **i2c-dev** exposes I2C master controllers
- Need to load/configure the i2c-dev driver (`CONFIG_I2C_CHARDEV`)
- There is one device node per i2c master controller

```
# ls -l /dev/i2c*
crw-rw---T 1 root i2c 89, 0 Jan  1  2000 /dev/i2c-0
crw-rw---T 1 root i2c 89, 1 Jan  1  2000 /dev/i2c-1
```

- You access I2C slave nodes using read(2), write(2) and ioctl(2)
- Structures defined in `usr/include/linux/i2c-dev.h`

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Detecting i2c slaves using i2cdetect

- **i2cdetect**, from i2c-tools package, lists i2c adapters and probes devices
    - Example: detect devices on bus 1 (`/dev/i2c-1`)

```
# i2cdetect -y -r 1
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00:          -- -- -- -- -- -- -- -- -- -- -- -- --
10: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
20: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
30: -- -- -- -- -- -- -- -- -- 39 -- -- -- -- -- --
40: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
50: -- -- -- -- UU UU UU UU -- -- -- -- -- -- -- --
60: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
70: -- -- -- -- -- -- -- --
```

UU = device already handled by kernel driver

0x39 = device discovered at address 0x39

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i2cget/i2cset

- `i2cget <bus> <chip> <register>`: read data from an I2C device
  - Example: read register 0x8a from device at 0x39

```
# i2cget -y 1 0x39 0x8a
0x50
```

- `i2cset <bus> <chip> <register>`: writedata to an I2C device
  - Example: Write 0x03 to register 0x80:

```
# i2cset -y 1 0x39 0x80 3
```


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I2C code example - light sensor, addr 0x39

```
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <sys/ioctl.h>
#include <linux/i2c-dev.h>

int main(int argc, char **argv)
    int f;
    char buf[4];

    f = open("/dev/i2c-1", O_RDWR);
    ioctl(f, I2C_SLAVE, 0x39) < 0) {

    buf[0] = 0x8a;              /* Chip ID register */
    write(f, buf, 1);
    read(f, buf, 1);
    printf("ID 0x%x\n", buf [0]);
}
```

Code: https://github.com/csimmonds/userspace-io-ew2016

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Other examples

- SPI: access SPI devices via device nodes `/dev/spidev*`
- USB: access USB devices via libusb
- User defined I/O: UIO
  - Generic kernel driver that allows you to write userspace drivers
  - access device registers and handle interrupts from userspace

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What are you missing?

- User-space drivers are not always the best solution
  - User-space programs can be killed; kernel drivers cannot
  - Kernel drivers can use advanced locking techniques - spinlocks, rwlocks, rcu, etc
  - Kernel drivers have direct access to DMA channels and interrupts
  - A kernel driver can fit in to a subsystem
    - Example: controlling an LCD backlight is better done as a kernel PWM driver so that it can use the common backlight infrastructure

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- Questions?

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