Linux Driver Workshop

An introduction to Linux Driver Development

Johannes Roith

16.08.2025

About me

- Embedded Software Developer
- Embedded Linux YouTube Channel
- My website with links to my GitHub, Mastadon, LinkedIn, ...
- One driver of mine made it into the Linux Kernel

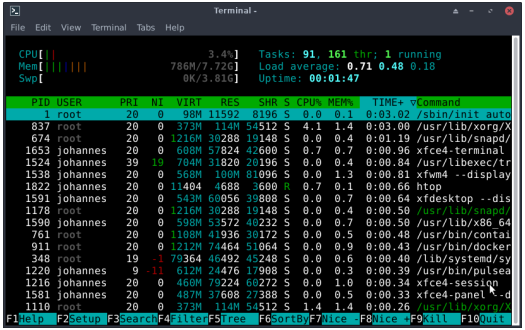
Agenda

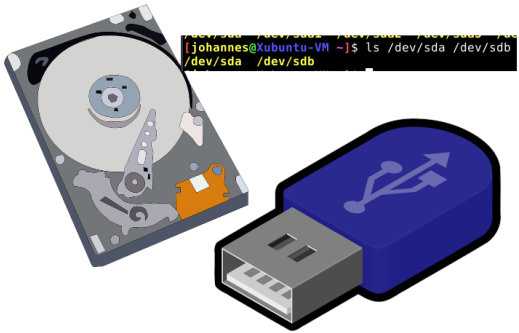
Backup

The Linux Kernel

- Kernel of an operating system: hardware abstraction layer
- Uniform interface (API Systemcalls) independent from PC architecture
- Tasks of the Linux-Kernels:
  - Memory management
  - Process management
  - Multitasking
  - Load balancing
  - Access to hardware over drivers
- Applications are using systemcalls (open, close, read, write, ioctl, ...): they don't need knowledge about the underlying hardware
- Linux: modular monolithic Kernel with loadable modules

The Linux Kernel





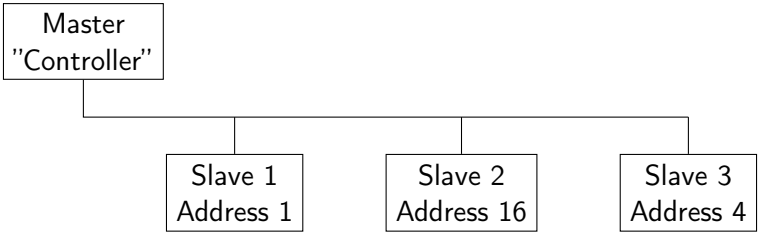
Linux Kernel programming on a Raspberry Pi

- Update packages with: `sudo apt update && sudo apt upgrade -y`
- Install Kernel Headers: `sudo apt install -y raspberrypi-kernel-headers`
- Install build tools like gcc, make, ...: `sudo apt install -y build-essential`
- Reboot, to start updated kernel: `sudo reboot`

The I2C bus

- Simple two wire bus
- Data line: *SDA*
- Clock line: *SCK*
- Supported frequencies: 100kbit/s, 400kbit/s, 1Mbit/s
- Pull-Up resistor on both signals necessary

The I2C bus


Master
"Controller"
Slave 1
Address 1
Slave 2
Address 16
Slave 3
Address 4

A Linux I2C driver

Header and compatible devices

```
/* Required Header */
#include <linux/i2c.h>

/* Name all compatible devices*/
static struct i2c_device_id my_ids[] = {
        {"my_dev"},
        {} /* Empty element signalizes end of list */
};
MODULE_DEVICE_TABLE(i2c, my_ids);
```

A Linux I2C driver

Probe- and Remove functions

```
/* function is called, when a compatible I2C device is added to the system
    */
static int my_probe(struct i2c_client *client)
{
        printk("Hello says I2C client with address: 0x%x\n", client->addr);
        return 0;
}

/* function is called, when a compatible I2C device is removed from the
    system */
static void my_remove(struct i2c_client *client)
{
        printk("Bye, bye, I2C\n");
}
```

A Linux I2C driver

Bundle driver struct

```
/* Bundle compatbile devices, probe and remove functions and driver info
    into driver struct */
static struct i2c_driver my_driver = {
        .probe = my_probe,
        .remove = my_remove,
        .id_table = my_ids,
        .driver = {
                .name = "my-i2c-driver",
        }
};
/* Register driver at the OS */
module_i2c_driver(my_driver);
/* Information about the driver*/
MODULE_LICENSE("GPL");
MODULE_AUTHOR("Johannes Roith");
MODULE_DESCRIPTION("A Hello World I2C driver");
```

Makefile for compiling the I2C driver

```
# Kernel Header Makefile compiles i2c_hello.c to i2c_hello.o file
    automatically
obj-m += i2c_hello.o

all:
        make -C /lib/modules/$(shell uname -r)/build M=$(PWD) modules

clean:
        make -C /lib/modules/$(shell uname -r)/build M=$(PWD) clean
```

Module verwalten in einer Shell

- `lsmod` lists all loaded modules
- `dmesg` shows the kernel's log
- `insmod <modulename>` load the module `<modulename>` into the kernel
- `rmmod <modulename>` removes the module `<modulename>` from the kernel
- `modprobe <modulename>` loads the module `<modulename>` together with all its dependencies
- `modinfo <modulename>` shows the meta-data (author, licence, description, ...) of the module `<modulename>`

Adding I2C devices over sysfs

```
# Change to I2C device folder
cd /sys/bus/i2c/devices/i2c-1

# Add I2C device mydev with address 0x12
echo "mydev 0x12" | sudo tee new_devices

# Removes I2C device with address 0x12
echo "0x12" | sudo tee delete_device
```

Exercise

- Implement the kernel module `rgb_board` on the Raspberry Pi as follows:
  - The name of the compatible device should be `rgb_brd`
  - The probe function should print out the I2C address of the device into the kernel's log
  - Another kernel's log message should be written to the log when removing the device
- Compile the kernel with the Makefile
- Load the module
- Check that the module is loaded
- Add a compatible I2C device
- Check the Kernel's log
- Remove the module

PCF8574 IO Expander

- Write access writes output values P0 - P7
- Read access reads current values P0 - P7
- Button connected to P0
- For input operation: Set Output to 1, Button pulls pin to GND. When reading a 1, the button is not pushed, when reading a 0 it is pushed
- Red LED connected to P1, green to P2, blue to P3
- Set output to 0: LED is On
- Set output to 1: LED is Off

Bit:	0	1	2	3	4	5	6	7
Value for:	P0	P1	P2	P3	P4	P5	P6	P7

Accessing the I2C bus

```
struct i2c_client *my_client;
```

The `struct i2c_client` is used, to manage an I2C device in the kernel. With the pointer `my_client` we can access the device, e.g. for reading or writing data.

```
s32 i2c_smbus_read_byte(struct i2c_client *my_client);
```

Reads a byte from the I2C device `my_client`. If an error occurs, the function returns a negative error code, else the read byte.

```
s32 i2c_smbus_write_byte(struct i2c_client *my_client, u8 value);
```

Writes the byte `value` to the I2C device `my_client`. If an error occurs, the function returns a negative error code, else 0.

Exercise

- Light up the RGB LED in a color of your choice. You can do so, by writing to P1-P3 of the PCF8574 in the probe function of the driver.
- Turn off the RGB LED in the remove function
- Compile and test the module
- Additional task: Read the state of the button on P0 in the probe function and write it to the Kernel's log.

Creation of sysfs entries

- *sysfs*: Virtual filesystem
- Display and management of *Kernel Objects* (`kobject`)
- Allows interaction with the driver
- *Kernel Object*: Folder in *sysfs*
- *Kernel Object* can have attributes (represented as files) over which the driver can exchange data with user space.
- Procedure: Implement show and store functions, create attribute, create Kernel Object, link sysfs files with Kernel Object

Show and store functions and attribute

```c
/* Required Header */
#include <linux/kobject.h>

static ssize_t mydev_show(struct kobject *kobj, struct kobj_attribute *attr,
     char *buffer)
{
        return sprintf(buffer, "Hello world!\n");
}

static ssize_t mydev_store(struct kobject *kobj, struct kobj_attribute *attr
    , const char *buffer, size_t count)
{
        printk("I got %s\n", buffer);
        return count;
}

static struct kobj_attribute mydev_attr = __ATTR(my_attr, 0660, mydev_show,
    mydev_store);
```

Create kobject and link it with the attribute

```
struct kobject * my_kobj */
/* in init or probe function */
int status;

my_kobj = kobject_create_and_add("my_kobj", my_kobj);
if (!my_kobj) {
        printk("Error creating kernel object\n");
        return -ENOMEM;
}

status = sysfs_create_file(my_kobj, &mydev_attr.attr);
if (status) {
        printk("Error creating /sys/my_kobj/my_attr\n");
        return status;
}
```

Delete kobject and attribute

```
/* in exit or remove function */
sysfs_remove_file(my_kobj, &mydev_attr.attr);
kobject_put(my_kobj);
```

Exercise

- Create the Kernel object *rgb_led*
- Create the attribute *led* of the Kernel object *rgb_led*
- Implement the store function for this attribute, so you can control the RGB LED over it. By writing the string `011` to the attribute, the red LED should be set t0 0, the green LED to 1 and the blue LED to 1.
- Additional Task: Create a second attribute *button* of the Kernel Object *rgb_led*. Implement a show function to read out the current state of the button.

A true Hello World Kernel Module

```c
#include <linux/module.h>
#include <linux/init.h>
int __init my_init(void)
{
        printk("hello_kernel - Module was loaded.\n");
        return 0;
}
void __exit my_exit(void)
{
        printk("hello_kernel - Module was removed\n");
}
MODULE_LICENSE("GPL");
MODULE_AUTHOR("Johannes Roith");
MODULE_DESCRIPTION("A simple hello world LKM");
module_init(my_init);
module_exit(my_exit);
```

The macro module_i2c_driver

The macro `module_i2c_driver(my_driver)` creates the following code:

```
static int i2c_driver_init(void)
{
        return i2c_add_driver(&my_driver);
}
module_init(i2c_driver_init);

static void i2c_driver_exit(void)
{
        i2c_del_driver(&my_driver);
}
module_exit(i2c_driver_exit);
```