

Kernel Course: Lecture 17

Communicating with Hardware (part 2)

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Agenda

1. Kernel Driver: Proper Way
2. User space
3. Assignments
4. Appendixes

Kernel Driver: Proper Way

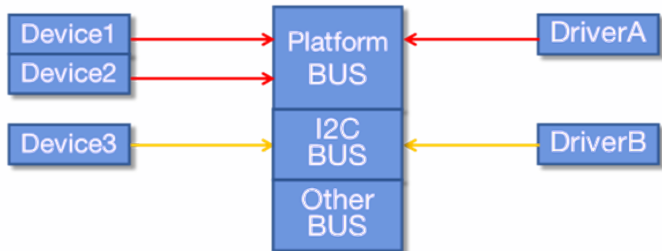
API Overview

Device/driver matching

- In real drivers we rarely use just `module_init()`
- Driver must be platform-independend
- Device-specific data is obtained from Device Tree
- Driver **binding** is the process of associating a device with a device driver that can control it
- Bus drivers (*driver core*) handle this, as bus driver knows about all devices and drivers on this bus

Device/driver matching (cont'd)

- When driver or device is registered, driver core will check their **compatible** strings
- If those strings **match**, driver core will invoke **probe()** function
- Platform devices should be registered very early during system boot
- Drivers usually register later during booting, or by module loading



API: miscdevice

- **miscdevice** = Miscellaneous Character Device
- Easier to implement than regular char dev
- Major number is the same for all misc devices (see `/proc/devices`)

```
#include <linux/miscdevice.h>

struct miscdevice {
    int minor;
    const char *name;
    const struct file_operations *fops;
    ...
};

int misc_register(struct miscdevice *misc);
void misc_deregister(struct miscdevice *misc);
```

API: New GPIO Kernel API

- Similar set of functions as in “Legacy GPIO API”
- GPIO number is usually obtained from device tree
- Operates on **struct gpio_desc** (instead of GPIO number)

```
#include <linux/gpio/consumer.h>

/* Get descriptor structure from dts */
struct gpio_desc *__must_check devm_gpiod_get(struct device *dev,
                                              const char *con_id,
                                              enum gpiod_flags flags);

int gpiod_to_irq(const struct gpio_desc *desc);
void gpiod_set_value(struct gpio_desc *desc, int value);
int gpiod_get_value(const struct gpio_desc *desc);
int gpiod_set_debounce(struct gpio_desc *desc, unsigned debounce); /* usec */
```

For details see [Documentation/driver-api/gpio/consumer.rst](#).

API: Device Tree

```
#include <linux/of.h>

/*
 * - can be obtained from struct device (.of_node field), in probe function
 * - contains matched device properties (can be read using functions below)
 */
struct device_node;

/*
 * - to store "compatible" strings table
 * - provide it to struct device (.of_match_table field)
 */
struct of_device_id;

/* Device Tree access functions */
int of_property_read_u32(const struct device_node *np, const char *propname,
                        u32 *out_value);
bool of_property_read_bool(const struct device_node *np, const char *propname);
```

For details see [Documentation/devicetree/usage-model.txt](#).

API: Managed Device Resources

- **devres** is linked list of memory areas associated with a **struct device**
- Each devres entry is associated with a release function
- All devres entries are released on driver detach
- On release, the associated release function is invoked and then the devres entry is freed

```
void *devm_kzalloc(struct device *dev, size_t size, gfp_t gfp);
struct gpio_desc *devm_gpiod_get(struct device *dev, const char *con_id,
                                enum gpiod_flags flags);
int devm_request_irq(struct device *dev, unsigned int irq,
                    irq_handler_t handler, unsigned long irqflags,
                    const char *devname, void *dev_id);
```

For details see [Documentation/driver-model/devres.txt](#).

Two Flavours of Power Management

Runtime power management (Runtime PM)

Turn off (stop clock or remove power) hardware components that aren't going to be used in the near future, **transparently** from the user space's viewpoint.

System sleep

Knowing in advance that **the whole system** is not going to be used in the near future, turn off **everything** (possibly **by force**) except for the RAM chips.

- We are only going to use *System sleep* PM API
- For details see “System Sleep vs Runtime Power Management” slides (by Rafael J. Wysocki)

API: Power Management

```
#include <linux/pm.h>

/* Populate it and set to struct driver (.pm field) */
struct dev_pm_ops {
    int (*suspend)(struct device *dev);
    int (*resume)(struct device *dev);
    int (*freeze)(struct device *dev);
    int (*thaw)(struct device *dev);
    int (*poweroff)(struct device *dev);
    int (*restore)(struct device *dev);
};

SIMPLE_DEV_PM_OPS(name, suspend_fn, resume_fn); /* returns struct dev_pm_ops */

int device_init_wakeup(struct device *dev, bool enable);
bool device_may_wakeup(struct device *dev);

int enable_irq_wake(unsigned int irq);
int disable_irq_wake(unsigned int irq);
```

Attempt #3

Platform driver + char dev + new GPIO API + device tree

PRODUCTION READY!

Third Attempt: Device Tree

Listing 1: am335x-boneblack.dts

```
1 &am33xx_pinmux {
2     hw3_pins: hw3_pins {
3         pinctrl-single,pins = <
4             AM33XX_IOPAD(0x82c, PIN_INPUT | MUX_MODE7)      /* gpmc_ad11.gpio0_27 */
5             AM33XX_IOPAD(0x83c, PIN_OUTPUT | MUX_MODE7)     /* gpmc_ad15.gpio1_15 */
6         >;
7     };
8 };
9
10 / {
11     hw3 {
12         compatible = "globallogic,hw3";
13         button-gpios = <&gpio0 27 GPIO_ACTIVE_LOW>;
14         led-gpios = <&gpio1 15 GPIO_ACTIVE_HIGH>;
15         debounce-delay-ms = <5>;
16         wakeup-source;
17         pinctrl-names = "default";
18         pinctrl-0 = <&hw3_pins>;
19     };
20 };
```

Listing 2: hw3.c

```
1 // SPDX-License-Identifier: GPL-2.0
2 /*
3  * Driver for handling externally connected button and LED.
4  */
5
6 #include <linux/module.h>
7 #include <linux/platform_device.h>
8 #include <linux/gpio/consumer.h>
9 #include <linux/interrupt.h>
10 #include <linux/of.h>
11 #include <linux/miscdevice.h>
12 #include <linux/fs.h>
13 #include <linux/spinlock.h>
14 #include <linux/poll.h>
15 #include <linux/sched/signal.h>
16 #include <linux/wait.h>
17 #include <linux/pm.h>
18
19 #include "hw3.h"
20
```

Third Attempt: Code (2/14)

```
21 #define DRIVER_NAME      "hw3"
22 #define WRITE_BUF_LEN    10
23 #define READ_BUF_LEN     2      /* 1 character and \0 */
24
25 struct hw3 {
26     struct miscdevice mdev;
27     struct gpio_desc *btn_gpio;
28     struct gpio_desc *led_gpio;
29     int btn_irq;
30     int led_on;
31     int btn_on;
32     int control;                /* kernel controls LED switching? */
33     spinlock_t lock;
34     wait_queue_head_t wait;
35     bool data_ready;           /* new data ready to read */
36 };
37
38 static inline struct hw3 *to_hw3_struct(struct file *file)
39 {
40     struct miscdevice *miscdev = file->private_data;
41
42     return container_of(miscdev, struct hw3, mdev);
43 }
```


Third Attempt: Code (3/14)

```
44
45 static ssize_t hw3_read(struct file *file, char __user *buf, size_t count,
46                         loff_t *ppos)
47 {
48     struct hw3 *hw3 = to_hw3_struct(file);
49     unsigned long flags;
50     ssize_t ret;
51     const char *val;
52
53     spin_lock_irqsave(&hw3->lock, flags);
54     while (!hw3->data_ready) {
55         spin_unlock_irqrestore(&hw3->lock, flags);
56         if (file->f_flags & O_NONBLOCK)
57             return -EAGAIN;
58         if (wait_event_interruptible(hw3->wait, hw3->data_ready))
59             return -ERESTARTSYS;
60         spin_lock_irqsave(&hw3->lock, flags);
61     }
62
63     val = hw3->btn_on ? "1" : "0";
64     hw3->data_ready = false;
65     spin_unlock_irqrestore(&hw3->lock, flags);
66
```

Third Attempt: Code (4/14)

```
67      /* Do not advance ppos, do not use simple_read_from_buffer() */
68      if (copy_to_user(buf, val, READ_BUF_LEN))
69          ret = -EFAULT;
70      else
71          ret = READ_BUF_LEN;
72
73      return ret;
74 }
75
76 static ssize_t hw3_write(struct file *file, const char __user *buf,
77                          size_t count, loff_t *ppos)
78 {
79     struct hw3 *hw3 = to_hw3_struct(file);
80     unsigned long flags;
81     char kbuf[WRITE_BUF_LEN];
82     long val;
83     int res;
84
85     /* Do not advance ppos, do not use simple_write_to_buffer() */
86     if (copy_from_user(kbuf, buf, WRITE_BUF_LEN))
87         return -EFAULT;
88
89     kbuf[1] = '\0'; /* get rid of possible \n from "echo" command */
```

Third Attempt: Code (5/14)

```
90     res = kstrtoul(kbuf, 0, &val);
91     if (res)
92         return -EINVAL;
93     val = !!val;
94
95     spin_lock_irqsave(&hw3->lock, flags);
96     if (hw3->led_on != val) {
97         hw3->led_on = val;
98         gpiod_set_value(hw3->led_gpio, hw3->led_on);
99     }
100    spin_unlock_irqrestore(&hw3->lock, flags);
101
102    return count;
103 }
104
105 static __poll_t hw3_poll(struct file *file, poll_table *wait)
106 {
107     struct hw3 *hw3 = to_hw3_struct(file);
108     unsigned long flags;
109     __poll_t mask = 0;
110
111     poll_wait(file, &hw3->wait, wait);
112
```

Third Attempt: Code (6/14)

```
113     spin_lock_irqsave(&hw3->lock, flags);
114     if (hw3->data_ready)
115         mask = EPOLLIN | EPOLLRDNORM;
116     spin_unlock_irqrestore(&hw3->lock, flags);
117
118     return mask;
119 }
120
121 static long hw3_ioctl(struct file *file, unsigned int cmd, unsigned long arg)
122 {
123     struct hw3 *hw3 = to_hw3_struct(file);
124     unsigned long flags;
125     int val;
126
127     switch (cmd) {
128     case HW3IOC_SETLED:
129         if (get_user(val, (int __user *)arg))
130             return -EFAULT;
131
132         spin_lock_irqsave(&hw3->lock, flags);
133         hw3->led_on = !!val;
134         gpiod_set_value(hw3->led_gpio, hw3->led_on);
135         spin_unlock_irqrestore(&hw3->lock, flags);
```

Third Attempt: Code (7/14)

```
136
137     /* Fall through */
138     case HW3IOC_GETLED:
139         spin_lock_irqsave(&hw3->lock, flags);
140         val = hw3->led_on;
141         spin_unlock_irqrestore(&hw3->lock, flags);
142
143         return put_user(val, (int __user *)arg);
144     case HW3IOC_KERN_CONTROL:
145         if (get_user(val, (int __user *)arg))
146             return -EFAULT;
147
148         spin_lock_irqsave(&hw3->lock, flags);
149         hw3->control = !!val;
150         spin_unlock_irqrestore(&hw3->lock, flags);
151
152         break;
153     default:
154         return -ENOTTY;
155 }
156
157 return 0;
158 }
```

Third Attempt: Code (8/14)

```
159
160 static const struct file_operations hw3_fops = {
161     .owner      = THIS_MODULE,
162     .read       = hw3_read,
163     .write      = hw3_write,
164     .poll       = hw3_poll,
165     .unlocked_ioctl = hw3_ioctl,
166     .llseek     = no_llseek,
167 };
168
169 static irqreturn_t hw3_btn_isr(int irq, void *data)
170 {
171     struct hw3 *hw3 = data;
172     unsigned long flags;
173
174     pr_err("### isr\n");
175
176     spin_lock_irqsave(&hw3->lock, flags);
177     hw3->data_ready = true;
178     hw3->btn_on = gpiod_get_value(hw3->btn_gpio);
179     if (hw3->btn_on && hw3->control) {
180         hw3->led_on ^= 0x1;
181         gpiod_set_value(hw3->led_gpio, hw3->led_on);
    }
```

Third Attempt: Code (9/14)

```
182     }
183     spin_unlock_irqrestore(&hw3->lock, flags);
184
185     wake_up_interruptible(&hw3->wait);
186
187     return IRQ_HANDLED;
188 }
189
190 static int hw3_probe(struct platform_device *pdev)
191 {
192     struct device *dev = &pdev->dev;
193     struct device_node *node = pdev->dev.of_node;
194     struct hw3 *hw3;
195     u32 debounce;
196     bool wakeup_source;
197     int ret;
198
199     pr_err("### probe\n");
200
201     hw3 = devm_kzalloc(&pdev->dev, sizeof(*hw3), GFP_KERNEL);
202     if (!hw3)
203         return -ENOMEM;
204 }
```

Third Attempt: Code (10/14)

```
205     hw3->control = 1;
206
207     /* "button-gpios" in dts */
208     hw3->btn_gpio = devm_gpiod_get(dev, "button", GPIOD_IN);
209     if (IS_ERR(hw3->btn_gpio))
210         return PTR_ERR(hw3->btn_gpio);
211
212     /* "led-gpios" in dts */
213     hw3->led_gpio = devm_gpiod_get(dev, "led", GPIOD_OUT_LOW);
214     if (IS_ERR(hw3->led_gpio))
215         return PTR_ERR(hw3->led_gpio);
216
217     hw3->btn_irq = gpiod_to_irq(hw3->btn_gpio);
218     if (hw3->btn_irq < 0)
219         return hw3->btn_irq;
220
221     ret = of_property_read_u32(node, "debounce-delay-ms", &debounce);
222     if (ret == 0) {
223         ret = gpiod_set_debounce(hw3->btn_gpio, debounce * 1000);
224         if (ret < 0)
225             dev_warn(dev, "No HW support for debouncing\n");
226     }
227
```


Third Attempt: Code (11/14)

```
228     wakeup_source = of_property_read_bool(node, "wakeup-source");
229
230     ret = devm_request_irq(dev, hw3->btn_irq, hw3_btn_isr,
231                          IRQF_TRIGGER_FALLING | IRQF_TRIGGER_RISING,
232                          dev_name(dev), hw3);
233     if (ret < 0)
234         return ret;
235
236     device_init_wakeup(dev, wakeup_source);
237     platform_set_drvdata(pdev, hw3);
238     spin_lock_init(&hw3->lock);
239     init_waitqueue_head(&hw3->wait);
240
241     hw3->mdev.minor      = MISC_DYNAMIC_MINOR;
242     hw3->mdev.name       = DRIVER_NAME;
243     hw3->mdev.fops       = &hw3_fops;
244     hw3->mdev.parent     = dev;
245     ret = misc_register(&hw3->mdev);
246     if (ret)
247         return ret;
248
249     gpiod_set_value(hw3->led_gpio, 0);
250
```

Third Attempt: Code (12/14)

```
251     pr_err("### probe finished OK\n");
252     return 0;
253 }
254
255 static int hw3_remove(struct platform_device *pdev)
256 {
257     struct hw3 *hw3 = platform_get_drvdata(pdev);
258
259     misc_deregister(&hw3->mdev);
260     return 0;
261 }
262
263 #ifdef CONFIG_PM_SLEEP
264 static int hw3_suspend(struct device *dev)
265 {
266     struct hw3 *hw3 = dev_get_drvdata(dev);
267
268     if (device_may_wakeup(dev))
269         enable_irq_wake(hw3->btn_irq);
270
271     return 0;
272 }
273
```

Third Attempt: Code (13/14)

```
274 static int hw3_resume(struct device *dev)
275 {
276     struct hw3 *hw3 = dev_get_drvdata(dev);
277
278     if (device_may_wakeup(dev))
279         disable_irq_wake(hw3->btn_irq);
280
281     return 0;
282 }
283 #endif /* CONFIG_PM_SLEEP */
284
285 static SIMPLE_DEV_PM_OPS(hw3_pm, hw3_suspend, hw3_resume);
286
287 static const struct of_device_id hw3_of_match[] = {
288     { .compatible = "globallogic,hw3" },
289     { .compatible = "globallogic,hw4" },
290     { .compatible = "globallogic,hw5" },
291     {}, /* sentinel */
292 };
293 MODULE_DEVICE_TABLE(of, hw3_of_match);
294
295 static struct platform_driver hw3_driver = {
296     .probe = hw3_probe,
```

Third Attempt: Code (14/14)

```
297         .remove = hw3_remove,
298         .driver = {
299             .name = DRIVER_NAME,
300             .pm = &hw3_pm,
301             .of_match_table = hw3_of_match,
302         },
303     };
304
305     module_platform_driver(hw3_driver);
306
307     MODULE_ALIAS("platform:hw3");
308     MODULE_AUTHOR("Sam Protsenko <semen.protsenko@globallogic.com>");
309     MODULE_DESCRIPTION("Test module 3");
310     MODULE_LICENSE("GPL");
```

Third Attempt: Header

Listing 3: hw3.h

```
1  /* SPDX-License-Identifier: GPL-2.0 */
2  #ifndef _UAPI_LINUX_HW3_H
3  #define _UAPI_LINUX_HW3_H
4
5  #include <linux/ioctl.h>
6  #include <linux/types.h>
7
8  /* Chosen to be unique w.r.t. Documentation/ioctl/ioctl-number */
9  #define HW3_IOCTL_MAGIC      0x91
10
11 #define HW3IOC_SETLED         _IOWR(HW3_IOCTL_MAGIC, 0, int)
12 #define HW3IOC_GETLED         _IOR(HW3_IOCTL_MAGIC, 1, int)
13 #define HW3IOC_KERN_CONTROL   _IOW(HW3_IOCTL_MAGIC, 2, int)
14
15 #endif /* _UAPI_LINUX_HW3_H */
```

Take five

User space

Listing 4: hw3-app.c

```
1  #include <sys/types.h>
2  #include <sys/ioctl.h>
3  #include <fcntl.h>
4  #include <unistd.h>
5  #include <poll.h>
6  #include <stdio.h>
7  #include <stdlib.h>
8  #include <string.h>
9
10 #include "hw3.h"
11
12 #define DEV_FILE      "/dev/hw3"
13 #define TIMEOUT       10000      /* msec */
14 #define BUF_SIZE      4096
15 #define COUNT         20
16
17 int main(int argc, char *argv[])
18 {
19     int fd;
20     int ret = EXIT_FAILURE;
```


User Space Application (2/4)

```
21     int i;
22     struct pollfd pfd;
23     int ready;
24     int led_on;
25     char buf[BUF_SIZE];
26
27     fd = open(DEV_FILE, O_RDWR | O_NONBLOCK);
28     if (fd == -1) {
29         perror("Failed to open dev file");
30         return EXIT_FAILURE;
31     }
32
33     i = 0;
34     if (ioctl(fd, HW3IOC_KERN_CONTROL, &i) == -1) {
35         perror("Error occurred on ioctl");
36         goto end;
37     }
38
39     ioctl(fd, HW3IOC_GETLED, &led_on);
40
41     pfd.fd = fd;
42     pfd.events = POLLIN;
43     for (i = 0; i < COUNT; ++i) {
```

User Space Application (3/4)

```
44     printf("Waiting for button interrupt [%d/%d]...\n", i+1, COUNT);
45     ready = poll(&pfd, 1, TIMEOUT);
46     if (ready < 0) {
47         perror("poll() error");
48         goto end;
49     } else if (ready == 0) {
50         fprintf(stderr, "poll() timeout\n");
51         goto end;
52     }
53     if (!(pfd.revents & POLLIN)) {
54         fprintf(stderr, "poll() returned with no POLLIN\n");
55         goto end;
56     }
57
58     ret = read(fd, buf, BUF_SIZE);
59     if (ret == -1)
60         perror("read() error");
61     else
62         printf("read: %s\n", buf);
63
64     /* Handle "release button" event */
65     if (buf[0] == '0') {
66         led_on ^= 0x1;
```

User Space Application (4/4)

```
67             //ioctl(fd, HW3IOC_SETLED, &led_on);
68             sprintf(buf, "%d", led_on);
69             write(fd, buf, 2);
70         }
71     }
72
73     i = 1;
74     ioctl(fd, HW3IOC_KERN_CONTROL, &i);
75     ret = EXIT_SUCCESS;
76
77 end:
78     close(fd);
79     return ret;
80 }
```

Listing 5: Makefile

```
1  ifneq ($(KERNELRELEASE),) # kbuild part of makefile
2  CFLAGS_hw3.o := -DDEBUG
3  obj-m := hw3.o
4  else # normal makefile
5  KDIR ?= /lib/modules/$(shell uname -r)/build
6
7  default: module app
8  module:
9      $(MAKE) -C $(KDIR) M=$(PWD) C=1 modules
10 clean:
11     $(MAKE) -C $(KDIR) M=$(PWD) C=1 clean
12     rm -f hw3-app
13
14 CC = $(CROSS_COMPILE)gcc
15 CFLAGS = -O2 -Wall
16
17 app:
18     $(CC) $(CFLAGS) hw3-app.c -o hw3-app
19
20 .PHONY: module clean app
21 endif
```

Building Everything (On Host)

Setup environment:

```
$ export PATH=/opt/gcc-linaro-7.3.1-2018.05-x86_64_arm-linux-gnueabihf/bin:$PATH
$ export CROSS_COMPILE=arm-linux-gnueabihf-
$ export ARCH=arm
$ export KDIR=~/repos/linux-stable
```

Build new dtb:

```
$ cd $KDIR
$ make am335x-boneblack.dtb
$ cp arch/arm/boot/dts/am335x-boneblack.dtb $TFTP_DIR
$ cd -
```

Build module and app:

```
$ cd $MODULE_DIR
$ make
$ cp hw3.ko hw3-app $NFS_DIR/root
```

Testing Driver From Bash (On Target)

```
# insmod hw3.ko           # load module
# echo 0 > /dev/hw3        # set LED off
# echo 1 > /dev/hw3        # set LED on
# cat /dev/hw3             # poll button

010010...                # press Ctrl-C to interrupt

# rmmod hw3.ko            # unload module
```

Notice that when driver is in control, LED will toggle on button **press**.

Testing Driver Using App (On Target)

```
# insmod hw3.ko
# ./hw3-app

Waiting for button interrupt [1/20]...
read: 1
Waiting for button interrupt [2/20]...
read: 0
...

# rmmod hw3.ko
```

Notice that when app is in control, LED will toggle on button **release**.

Testing Power Management (On Target)

```
# insmod hw3.ko
# echo mem > /sys/power/state      # issue suspend

PM: suspend entry (deep)
PM: Syncing filesystems ... done.
Freezing user space processes ... (elapsed 0.001 seconds) done.
OOM killer disabled.
Freezing remaining freezable tasks ... (elapsed 0.001 seconds) done.
Suspending console(s) (use no_console_suspend to debug)

=== PRESS OUR BUTTON FOR RESUME ===

Disabling non-boot CPUs ...
pm33xx pm33xx: PM: Successfully put all powerdomains to target state
OOM killer enabled.
Restarting tasks ... done.
PM: suspend exit

# rmmod hw3.ko
```

Kernel Introspection (On Target)

```
# cat /proc/interrupts | grep hw3
63: 18 44e07000.gpio 27 Edge hw3

# cat /sys/kernel/debug/gpio
gpiochip0: GPIOs 0-31, parent: platform/44e07000.gpio, gpio-0-31:
  gpio-27 ( |button ) in hi IRQ
gpiochip1: GPIOs 32-63, parent: platform/4804c000.gpio, gpio-32-63:
  gpio-47 ( |led ) out hi

# find /sys/kernel/debug/pinctrl/ -exec grep -Hn hw3 {} \;
...

# ls -l /sys/firmware/devicetree/base/hw3/
button-gpios
compatible
debounce-delay-ms
led-gpios
wakeup-source
...

# cat /sys/firmware/devicetree/base/hw3/debounce-delay-ms | hexdump
```

Assignments

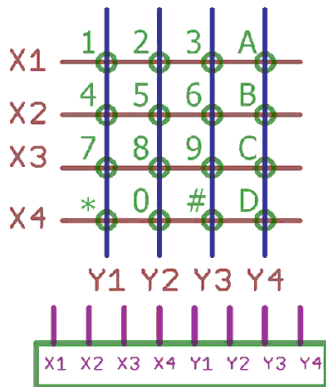
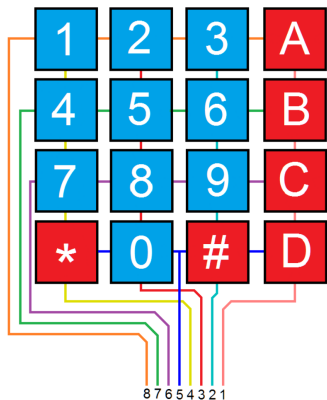
Assignment 1

- Assemble LED + button device on the breadboard
- Build **hw3.ko**, **hw3-app** and modified **am335x-boneblack.dtb**
- Boot kernel with new **dtb** and load **hw3.ko**
- Test it with Bash commands
- Test it with **hw3-app**
- Inspect **hw3.ko** driver using kernel introspection capabilities
- Make sure you are using NFS for development
- Make sure you are able to jump between both kernel functions and your driver code functions

Assignment 2

- Connect matrix keypad to BBB (directly or using breadboard)
- Implement driver for detecting pressed buttons
- Report detected buttons to kernel log (**dmesg**)
- Use work queue for scanning columns
- Obtain scan interval from device tree definition
- Perform reading rows on interrupt
- Configure debouncing for rows lines
- Use platform driver and device tree

Assignment 2 (cont'd)



Assignment 2 (cont'd)

GPIO line	Pin name	BBB pin
gpio0_26	gpmc_ad10	P8.14
gpio0_27	gpmc_ad11	P8.17
gpio1_12	gpmc_ad12	P8.12
gpio1_13	gpmc_ad13	P8.11
gpio1_14	gpmc_ad14	P8.16
gpio1_15	gpmc_ad15	P8.15
gpio1_17	gpmc_a1	P9.23
gpio1_29	gpmc_csn0	P8.26

Assignment 2 (cont'd)

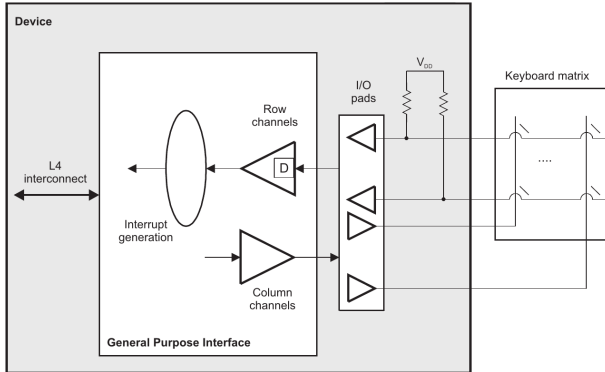


Figure 1: Internal connections

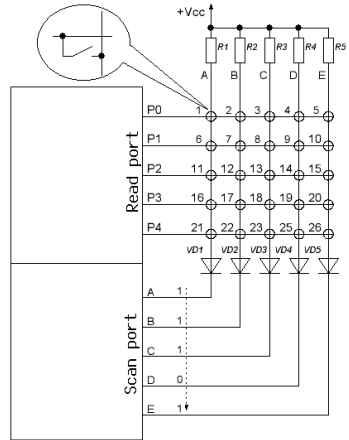


Figure 2: External connections
(safe)

Assignment 2 (cont'd)

Initialization:

- Pull-up all scan and read lines
- Set all scan and read lines into input
- Configure debouncing on read lines

Polling:

- Set all scan lines into input (Hi-Z)
- Set one scan line into "0"
- Repeat for next scan line

Scanning (on interrupt):

- Read the state of all read lines
- Detect which button was pressed

Assignment 3 (advanced)

- Find existing driver for matrix keypad in kernel
- Find device tree bindings documentation for it
- Use this driver instead of your own, make it work
- Read and understand that driver's code (especially `input_dev` API)

Thank you!

Appendixes

Appendix A: Power Management on BBB

Appendix A: Power Management on BBB

- Cortex-M3 core is used as a power supervisor
- Make sure your kernel has **CONFIG_AMX3_PM** option
- Obtain firmware for Cortex-M3 and copy it to kernel dir:

```
$ git clone git://git.ti.com/processor-firmware/ti-amx3-cm3-pm-firmware.git
$ cd ti-amx3-cm3-pm-firmware
$ git checkout ti2018.05
$ cp bin/am335x-pm-firmware.elf ~/repos/linux-stable/firmware
```

Appendix A: Power Management on BBB (cont'd)

- Add next options to `bbb.cfg` fragment and build the kernel:

```
# --- PM (see sprac74a.pdf) ---  
# Embed firmware in kernel  
CONFIG_EXTRA_FIRMWARE="am335x-pm-firmware.elf"  
CONFIG_EXTRA_FIRMWARE_DIR="firmware"  
# AMx3 Power Config Options  
CONFIG_MAILBOX=y  
CONFIG_OMAP2PLUS_MBOX=y  
CONFIG_REMOTEPROC=y  
CONFIG_WKUP_M3_RPROC=y  
CONFIG_WKUP_M3_IPC=y  
CONFIG_SOC_TI=y  
CONFIG_TI_EMIF_SRAM=y  
CONFIG_AMX3_PM=y  
# RTC  
CONFIG_RTC_DRV_OMAP=y
```

Appendix A: Power Management on BBB (cont'd)

- Kernel will upload the firmware to Cortex-M3
- Now it's possible to issue PM operations (suspend/resume)
- Don't try to load the firmware from user space (using `CONFIG_FW_LOADER_USER_HELPER*`), mdev doesn't support it
- For details see:

<http://www.ti.com/lit/an/sprac74a/sprac74a.pdf>

Appendix B: Device Tree Overlays

Appendix B: Device Tree Overlays

- Instead of messing with `am335x-boneblack.dtb`, it would be nice to load Device Tree definitions for external devices incrementally
- Device Tree Overlays (`.dtbo`) to the rescue!
- **Bad news:** `CONFIG_OF_CONFIGFS` is still not merged in kernel, so we can't merge overlays in kernel (via ConfigFS)
- **Good news:** we still can merge overlays into `dtb` in U-Boot
- See `fdt apply` command in U-Boot shell

Appendix B: Device Tree Overlays (cont'd) (1/2)

Listing 6: hw3.dtso

```
1 /dts-v1/;
2 /plugin/;
3
4 #include <dt-bindings/gpio/gpio.h>
5 #include <dt-bindings/pinctrl/am33xx.h>
6
7 / {
8     compatible = "ti,beaglebone", "ti,beaglebone-black";
9     part_number = "GLOBALLOGIC-HW3";
10    version = "A1";
11
12    fragment@0 {
13        target = <&am33xx_pinmux>;
14        __overlay__ {
15            hw3_pins: hw3_pins {
16                pinctrl-single,pins = <
17                    /* gpmc_ad11.gpio0_27 */
18                    AM33XX_IOPAD(0x82c, PIN_INPUT | MUX_MODE7)
19                    /* gpmc_ad15.gpio1_15 */
20                    AM33XX_IOPAD(0x83c, PIN_OUTPUT | MUX_MODE7)
```

Appendix B: Device Tree Overlays (cont'd) (2/2)

```
21         >;
22     };
23 };
24 };
25
26 fragment@1 {
27     target-path = "/";
28     __overlay__ {
29         hw3 {
30             compatible = "globallogic,hw3";
31             button-gpios = <&gpio0 27 GPIO_ACTIVE_LOW>;
32             led-gpios = <&gpio1 15 GPIO_ACTIVE_HIGH>;
33             debounce-delay-ms = <5>;
34             wakeup-source;
35             pinctrl-names = "default";
36             pinctrl-0 = <&hw3_pins>;
37         };
38     };
39 };
40 };
```

Appendix B: Device Tree Overlays (cont'd)

Commands to build .dtso → .dtbo

```
input=hw3.dtso
gen=hw3_gen.dtso
output=hw3.dtbo
kernel_dir=~/.repos/linux-stable
gcc_flags="-E -P -x assembler-with-cpp -I$kernel_dir/include -o $gen"
dtc_flags="-W no-unit_address_vs_reg -I dts -O dtb -o $output -b 0 -@"

gcc $gcc_flags $input
dtc $dtc_flags $gen
```
