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

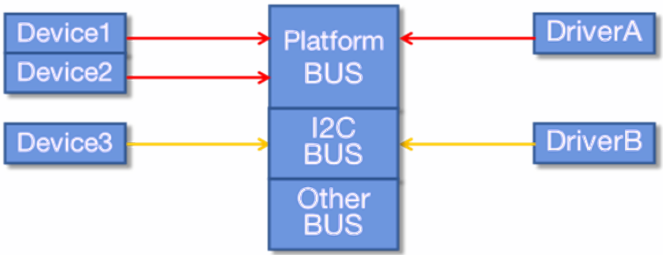
API Overview

Device/driver matching

- Driver must be platform-independend
- Device-specific data is obtained from Device Tree
- In real drivers we rarely use just `module_init()`
- Driver **binding** is the process of associating a device with a driver
- Bus drivers (*driver core*) handle the binding
  (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
- Major number is the same for all misc devices (see `/proc/devices`)
- Easier to implement than regular char dev

```
#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”
- Operates on `struct gpio_desc` (instead of GPIO number)
- GPIO descriptor is usually obtained from device tree

```
#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

```c
#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

```c
#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!

Decisions Overview

- Previous attempts are fine for experiments and low-level platform drivers (e.g. GPIO controller driver)
- For our device we have to use either:
  - Special frameworks for device classes (like IIO, RTC, etc)
  - or generic kernel devices (char devs, block devs, etc)
- We don’t have any special frameworks in kernel for our device class
- So we will use:
  - Character device (misc): for user space interface
  - Platform device: for integration in device tree and PM ops

Driver Features

- User space interface (file operations):
  - read: button state (0 or 1); blocking/non-blocking read
  - write: LED state (0 or 1)
  - poll: wait for button to be pressed
  - ioctl: `SETLED`, `GETLED`, `KERN_CONTROL`
- Proper integration with Device Tree
- Power Management: button can wake up BBB from suspend
- Button is handled via interrupt
- Kernel can implement device's logic, or delegate it to user space
- Handle multi-threading scenarios
- Expose ioctl constants to user space

Third Attempt: Device Tree

Listing 1: am335x-boneblack.dts

```
&am33xx_pinmux {
        hw3_pins: hw3_pins {
                pinctrl-single,pins = <
                        AM33XX_IOPAD(0x82c, PIN_INPUT | MUX_MODE7)              /* gpmc_ad11.gpio0_27 */
                        AM33XX_IOPAD(0x83c, PIN_OUTPUT | MUX_MODE7)             /* gpmc_ad15.gpio1_15 */
                >;
        };
};

/ {
        hw3 {
                compatible = "globallogic,hw3";
                button-gpios = <&gpio0 27 GPIO_ACTIVE_LOW>;
                led-gpios = <&gpio1 15 GPIO_ACTIVE_HIGH>;
                debounce-delay-ms = <5>;
                wakeup-source;
                pinctrl-names = "default";
                pinctrl-0 = <&hw3_pins>;
        };
};
```

Third Attempt: Code (1/14)

Listing 2: hw3.c

```c
// SPDX-License-Identifier: GPL-2.0
/*
 * Driver for handling externally connected button and LED.
 */

#include <linux/module.h>
#include <linux/platform_device.h>
#include <linux/gpio/consumer.h>
#include <linux/interrupt.h>
#include <linux/of.h>
#include <linux/miscdevice.h>
#include <linux/fs.h>
#include <linux/spinlock.h>
#include <linux/poll.h>
#include <linux/sched/signal.h>
#include <linux/wait.h>
#include <linux/pm.h>

#include "hw3.h"

```

Third Attempt: Code (2/14)

```
21 #define DRIVER_NAME     "hw3"
22 #define WRITE_BUF_LEN   10
23 #define READ_BUF_LEN    2       /* one 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         unsigned long copy_len;
51         ssize_t ret;
52         const char *val;
53
54         spin_lock_irqsave(&hw3->lock, flags);
55         while (!hw3->data_ready) {
56                 spin_unlock_irqrestore(&hw3->lock, flags);
57                 if (file->f_flags & O_NONBLOCK)
58                         return -EAGAIN;
59                 if (wait_event_interruptible(hw3->wait, hw3->data_ready))
60                         return -ERESTARTSYS;
61                 spin_lock_irqsave(&hw3->lock, flags);
62         }
63
64         val = hw3->btn_on ? "1" : "0";
65         hw3->data_ready = false;
66         spin_unlock_irqrestore(&hw3->lock, flags);
```

Third Attempt: Code (4/14)

```
67
68          /* Handle case when user requested 1 byte read */
69          copy_len = min(count, (size_t)READ_BUF_LEN);
70
71          /* Do not advance ppos, do not use simple_read_from_buffer() */
72          if (copy_to_user(buf, val, copy_len))
73                  ret = -EFAULT;
74          else
75                  ret = copy_len;
76
77          return ret;
78  }
79
80  static ssize_t hw3_write(struct file *file, const char __user *buf,
81                           size_t count, loff_t *ppos)
82  {
83          struct hw3 *hw3 = to_hw3_struct(file);
84          unsigned long flags;
85          char kbuf[WRITE_BUF_LEN];
86          long val;
87          int res;
88
89          /* Do not advance ppos, do not use simple_write_to_buffer() */
```

Third Attempt: Code (5/14)

```
90          if (copy_from_user(kbuf, buf, WRITE_BUF_LEN))
91                  return -EFAULT;
92
93          kbuf[1] = '\0'; /* get rid of possible \n from "echo" command */
94          res = kstrtol(kbuf, 0, &val);
95          if (res)
96                  return -EINVAL;
97          val = !!val;
98
99          spin_lock_irqsave(&hw3->lock, flags);
100         if (hw3->led_on != val) {
101                 hw3->led_on = val;
102                 gpiod_set_value(hw3->led_gpio, hw3->led_on);
103         }
104         spin_unlock_irqrestore(&hw3->lock, flags);
105
106         return count;
107 }
108
109 static __poll_t hw3_poll(struct file *file, poll_table *wait)
110 {
111         struct hw3 *hw3 = to_hw3_struct(file);
112         unsigned long flags;
```

Third Attempt: Code (6/14)

```
113         __poll_t mask = 0;
114
115         poll_wait(file, &hw3->wait, wait);
116
117         spin_lock_irqsave(&hw3->lock, flags);
118         if (hw3->data_ready)
119                 mask = EPOLLIN | EPOLLRDNORM;
120         spin_unlock_irqrestore(&hw3->lock, flags);
121
122         return mask;
123 }
124
125 static long hw3_ioctl(struct file *file, unsigned int cmd, unsigned long arg)
126 {
127         struct hw3 *hw3 = to_hw3_struct(file);
128         unsigned long flags;
129         int val;
130
131         switch (cmd) {
132         case HW3IOC_SETLED:
133                 if (get_user(val, (int __user *)arg))
134                         return -EFAULT;
135
```

Third Attempt: Code (7/14)

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

Third Attempt: Code (8/14)

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

Third Attempt: Code (9/14)

```
182                 hw3->led_on ^= 0x1;
183                 gpiod_set_value(hw3->led_gpio, hw3->led_on);
184         }
185         spin_unlock_irqrestore(&hw3->lock, flags);
186
187         wake_up_interruptible(&hw3->wait);
188
189         return IRQ_HANDLED;
190 }
191
192 static int hw3_probe(struct platform_device *pdev)
193 {
194         struct device *dev = &pdev->dev;
195         struct device_node *node = pdev->dev.of_node;
196         struct hw3 *hw3;
197         u32 debounce;
198         bool wakeup_source;
199         int ret;
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         return 0;
252 }
253
254 static int hw3_remove(struct platform_device *pdev)
255 {
256         struct hw3 *hw3 = platform_get_drvdata(pdev);
257
258         misc_deregister(&hw3->mdev);
259         return 0;
260 }
261
262 #ifdef CONFIG_PM_SLEEP
263 static int hw3_suspend(struct device *dev)
264 {
265         struct hw3 *hw3 = dev_get_drvdata(dev);
266
267         if (device_may_wakeup(dev))
268                 enable_irq_wake(hw3->btn_irq);
269
270         return 0;
271 }
272
273 static int hw3_resume(struct device *dev)
```

Third Attempt: Code (13/14)

```
274 {
275         struct hw3 *hw3 = dev_get_drvdata(dev);
276
277         if (device_may_wakeup(dev))
278                 disable_irq_wake(hw3->btn_irq);
279
280         return 0;
281 }
282 #endif /* CONFIG_PM_SLEEP */
283
284 static SIMPLE_DEV_PM_OPS(hw3_pm, hw3_suspend, hw3_resume);
285
286 static const struct of_device_id hw3_of_match[] = {
287         { .compatible = "globallogic,hw3" },
288         { .compatible = "globallogic,hw4" },
289         { .compatible = "globallogic,hw5" },
290         {}, /* sentinel */
291 };
292 MODULE_DEVICE_TABLE(of, hw3_of_match);
293
294 static struct platform_driver hw3_driver = {
295         .probe = hw3_probe,
296         .remove = hw3_remove,
```

Third Attempt: Code (14/14)

```
297         .driver = {
298                 .name = DRIVER_NAME,
299                 .pm = &hw3_pm,
300                 .of_match_table = hw3_of_match,
301         },
302 };
303
304 module_platform_driver(hw3_driver);
305
306 MODULE_ALIAS("platform:hw3");
307 MODULE_AUTHOR("Sam Protsenko <joe.skb7@gmail.com>");
308 MODULE_DESCRIPTION("Test module 3");
309 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

User Space Application (1/4)

Listing 4: hw3-app.c

```c
#include <sys/types.h>
#include <sys/ioctl.h>
#include <fcntl.h>
#include <unistd.h>
#include <poll.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

#include "hw3.h"

#define DEV_FILE        "/dev/hw3"
#define TIMEOUT         10000           /* msec */
#define BUF_SIZE        4096
#define COUNT           20

int main(int argc, char *argv[])
{
        int fd;
        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 ($(KERNELRELEASE),) # kbuild part of makefile
2
3  CFLAGS_hw3.o := -DDEBUG
4  obj-m := hw3.o
5
6  else # normal makefile
7
8  KDIR ?= /lib/modules/$(shell uname -r)/build
9
10 default: module app
11 module:
12         $(MAKE) -C $(KDIR) M=$(PWD) C=1 modules
13 clean:
14         $(MAKE) -C $(KDIR) M=$(PWD) C=1 clean
15         rm -f hw3-app
16 app: CC = $(CROSS_COMPILE)gcc
17 app: CFLAGS = -O2 -Wall
18 app:
19         $(CC) $(CFLAGS) hw3-app.c -o hw3-app
20
21 .PHONY: module clean app
22
23 endif
```

Building Everything (On Host)

Setup environment:

```
$ export PATH=/opt/gcc-arm-8.3-2019.03-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 -1 /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

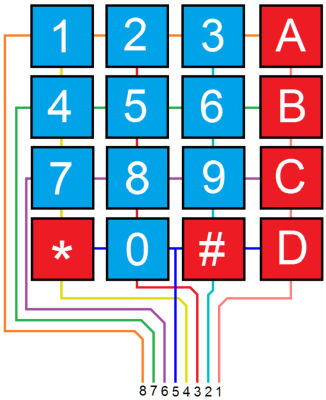
Assignment 1

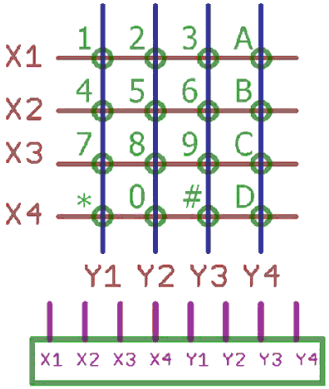
- Assemble LED + button device on the breadboard
- Build `hw3.ko`, `hw3-app` and modified `am335x-boneblack.dtb`
- Boot kernel with new `dtb` and load `hw3.ko`
- Test it with Bash commands
- Test it with `hw3-app`
- Inspect `hw3.ko` driver using kernel introspection capabilities
- Make sure you are using 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)

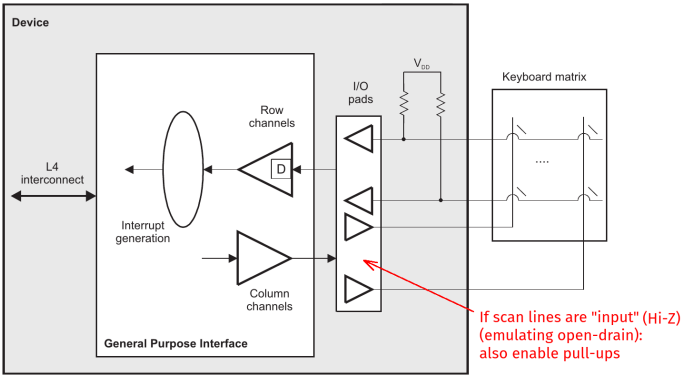


Figure 1: Using internal pull-ups

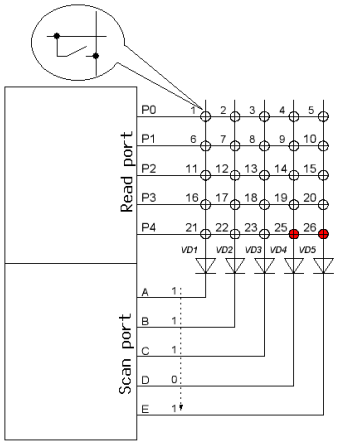


Figure 2: Short circuit protection (external)

Assignment 2 (cont'd)

Initialization:

- Pull-up all lines ("scan" and "read")
- 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

```
/dts-v1/;
/plugin/;

#include <dt-bindings/gpio/gpio.h>
#include <dt-bindings/pinctrl/am33xx.h>

/ {
        compatible = "ti,beaglebone", "ti,beaglebone-black";
        part_number = "GLOBALLOGIC-HW3";
        version = "A1";

        fragment@0 {
                target = <&am33xx_pinmux>;
                __overlay__ {
                        hw3_pins: hw3_pins {
                        pinctrl-single,pins = <
                                /* gpmc_ad11.gpio0_27 */
                                AM33XX_IOPAD(0x82c, PIN_INPUT | MUX_MODE7)
                                /* gpmc_ad15.gpio1_15 */
                                AM33XX_IOPAD(0x83c, PIN_OUTPUT | MUX_MODE7)
```

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

```
                        >;
                        };
                };
        };

        fragment@1 {
                target-path = "/";
                __overlay__ {
                        hw3 {
                                compatible = "globallogic,hw3";
                                button-gpios = <&gpio0 27 GPIO_ACTIVE_LOW>;
                                led-gpios = <&gpio1 15 GPIO_ACTIVE_HIGH>;
                                debounce-delay-ms = <5>;
                                wakeup-source;
                                pinctrl-names = "default";
                                pinctrl-0 = <&hw3_pins>;
                        };
                };
        };
};
```

Commands to build `.dtso` → `.dtbo`

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

rm -f $out
gcc $gcc_flags -o $gen $in
dtc $dtc_flags -o $out $gen
rm -f $gen
```