

# **ECE 471 – Embedded Systems**

## **Lecture 11**

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25 September 2020

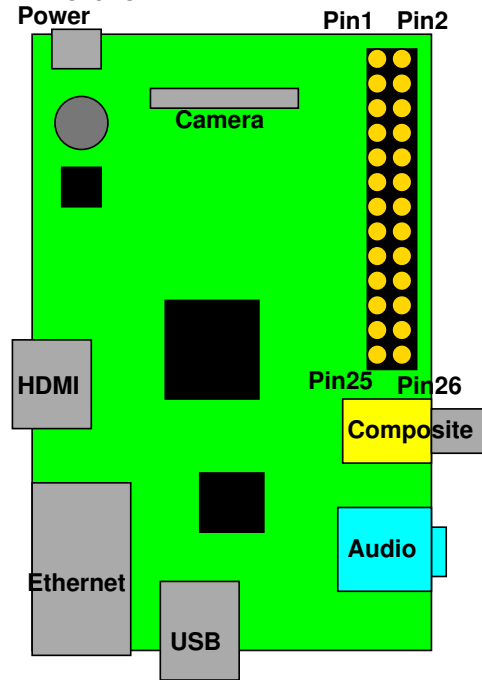
# Announcements

- HW#4 will be posted
- Will require an LED, a breadboard, some resistors and some jumper wires.  
I handed out some GPIO wires in class.
- Remember to comment your code!
- Also be sure your code doesn't crash!

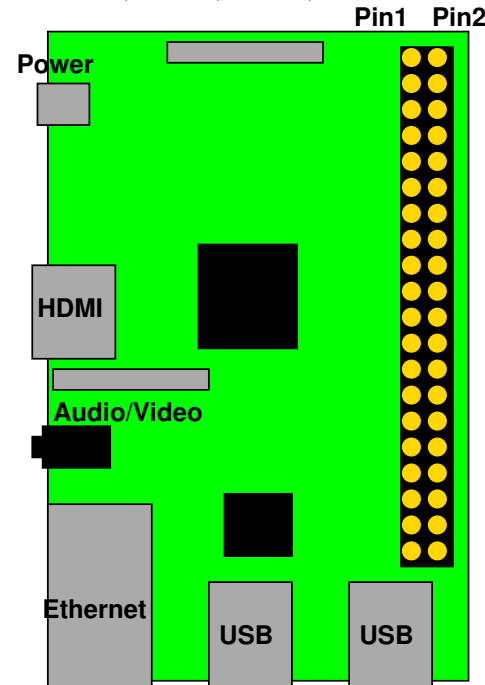


# Brief Overview of the Raspberry Pi Board

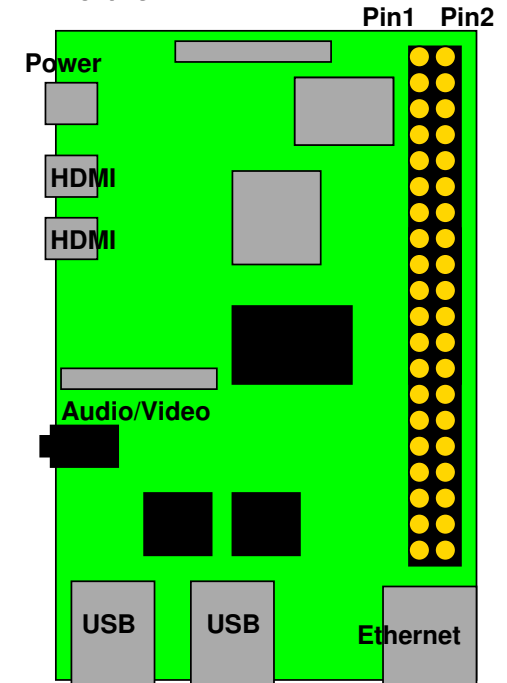
Model 1B



1B+/2B/3B/3B+



Model 4B



# Rasp-pi Header

- Model B has 17 GPIOs (out of 26 pins), B+/2B/3B has 26 (out of 40)
- 3.3V signaling logic. Need level shifter if want 5V or 1.8V
- Linux by default configures some for other purposes (serial, i2c, SPI)



# Rasp-pi Header

3.3V	1	2	5V
GPIO2 (SDA)	3	4	5V
GPIO3 (SCL)	5	6	GND
GPIO4 (1-wire)	7	8	GPIO14 (UART_TXD)
GND	9	10	GPIO15 (UART_RXD)
GPIO17	11	12	GPIO18 (PCM_CLK)
GPIO27	13	14	GND
GPIO22	15	16	GPIO23
3.3V	17	18	GPIO24
GPIO10 (MOSI)	19	20	GND
GPIO9 (MISO)	21	22	GPIO25
GPIO11 (SCLK)	23	24	GPIO8 (CE0)
GND	25	26	GPIO7 (CE1)
ID_SD (EEPROM)	27	28	ID_SC (EEPROM)
GPIO5	29	30	GND
GPIO6	31	32	GPIO12
GPIO13	33	34	GND
GPIO19	35	36	GPIO16
GPIO26	37	38	GPIO20
GND	39	40	GPIO21



# How you enable GPIO on STM32L

A lot of read/modify/write instructions to read current register values and then to shift/mask to write out updated bitfields.

- Enable GPIO Clock
- Set output mode for GPIO.
- Set GPIO type.
- Set pin clock speed.
- Set pin pull-up/pull-down
- Set or clear GPIO pin.

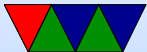


# “Bare Metal” on BCM2835 (Rasp-pi)

- Documented in BCM2835 ARM Peripherals Manual
- 53 GPIOs (not all available on board)
- Can use Wiring-Pi or libbcm2835 if you need speed
- Similar to how done on STM32L... but we have an operating system



# Letting the OS handle it for you





# “Old” Linux sysfs GPIO interface

- See the Appendix to these notes for details
- Deprecated with Linux 4.8 in October 2016
- Still there; supposedly to be removed in 2020
- Benefits
  - Could call from shell script
- Downsides
  - String based, had to remember to convert from ASCII
  - If crash/forget to close, GPIO left active
  - Multiple processes at same time, conflict



- Some things (like open-drain) couldn't be set
- Slow, especially if writing multiple (lots of syscalls)



# “New” Linux GPIO interface

- Introduced with Linux 4.8 (October 2016)
- New way uses ioctls and structs
  - Faster
  - Automatically releases GPIO when program ends
  - Can set parameters (i.e. pull-up/down) couldn't before



# GPIOD utils

- If you have gpiod utilities installed you can get info
- If not installed, if on network you can `sudo apt-get`

`install gpiod`

- `gpiodetect`

`gpiochip0 [pinctrl-bcm2835] (54 lines)`

`gpiochip1 [raspberrypi-exp-gpio] (8 lines)`

- `gpioinfo`

`gpiochip0 - 54 lines:`

line	0:	unnamed	unused	input	active-high
------	----	---------	--------	-------	-------------

line	1:	unnamed	unused	input	active-high
------	----	---------	--------	-------	-------------

...



# There is a library

- Some Linux interfaces (perf, ALSA, ) assume library
- libgpiod library
- We will avoid it
  - embedded systems: may not be room for a library
  - sometimes good to code directly to operating system



# A few low-level Linux Coding Instructions

- Linux, “everything is a file”
- File descriptors
- `open()`, `close()` what happens if forget to close?
- `read()`, `write()`
- `lseek()`
- `ioctl()`



# gpio – getting interface info

```
#include "linux/gpio.h"

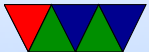
// struct gpiochip_info {
//     char name[32];
//     char label[32];
//     __u32 lines; }

int fd,rv;
struct gpiochip_info chip_info;

/* open first gpio device read/write, check for error */
fd=open("/dev/gpiochip0",O_RDWR);
if (fd<0) printf("Error opening %s\n",strerror(errno));

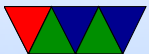
/* ask for chipinfo from open file descriptor, put in chip_info struct */
rv=ioctl(fd,GPIO_GET_CHIPINFO_IOCTL,&chip_info);
if (rv<0 ) printf("Error ioctl %s\n",strerror(errno));

/* print summary of what was returned */
printf("Found %s, %s, %d lines\n",
        chip_info.name,chip_info.label,chip_info.lines);
```



# gpio – get info about line gpio17

```
// struct gpioline_info {  
//     __u32 line_offset;  
//     __u32 flags;  
//     char name[32];  
//     char consumer[32]; }  
  
struct gpioline_info line_info;  
  
/* clear struct to 0 before using it */  
/* kernel might not like uninitialized values */  
memset(&line_info,0,sizeof(line_info));  
  
/* get line info for gpio17 */  
line_info.line_offset=17;    // set GPIO17  
rv=ioctl(fd,GPIO_GET_LINEINFO_IOCTL,&line_info);  
if (rv<0) printf("Error ioctl %s\n",strerror(errno));  
  
/* print summary of what we learned */  
printf("Offset %d, flags %x, name %s, consumer %s\n",line_info.line_offset,  
        line_info.flags, line_info.name, line_info.consumer);
```





# gpio – configure request structure

```
// struct gpiohandle_request {
//     __u32 lineoffsets[GPIOHANDLES_MAX];
//     __u32 flags;
//     __u8 default_values[GPIOHANDLES_MAX];
//     char consumer_label[32];
//     __u32 lines;int fd;}

// configuration values we can or together
// BIAS values added later

// #define GPIOHANDLE_REQUEST_INPUT(1UL << 0)
// #define GPIOHANDLE_REQUEST_OUTPUT(1UL << 1)
// #define GPIOHANDLE_REQUEST_ACTIVE_LOW(1UL << 2)
// #define GPIOHANDLE_REQUEST_OPEN_DRAIN(1UL << 3)
// #define GPIOHANDLE_REQUEST_OPEN_SOURCE(1UL << 4)
// #define GPIOHANDLE_REQUEST_BIAS_PULL_UP (1UL << 5)
// #define GPIOHANDLE_REQUEST_BIAS_PULL_DOWN (1UL << 6)
// #define GPIOHANDLE_REQUEST_BIAS_DISABLE (1UL << 7)
```



# gpio – actually do request

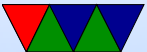
```
struct gpiohandle_request req;

/* clear out struct */
memset(&req,0,sizeof(struct gpiohandle_request));

req.flags = GPIOHANDLE_REQUEST_OUTPUT; // want it to be output
req.lines =1; // can group multiple lines together
req.lineoffsets[0] =17; // gpio number we want
req.default_values[0]=0; // default value
strcpy(req.consumer_label, "ECE471"); // helpful label

/* get a handle for our requested config */
rv = ioctl(fd, GPIO_GET_LINEHANDLE_IOCTL, &req);
if (rv<0 ) printf("Error ioctl %s\n",strerror(errno));

// req.fd is now a handle for this gpio setup
```



# gpio – change value of gpio17

```
// struct gpiohandle_data {  
//     __u8 values[GPIOHANDLES_MAX]; }  
  
struct gpiohandle_data data;  
  
/* set output to 0 */  
data.values[0]=0;  
  
/* send this data struct to the handle for gpio17 we created */  
rv=ioctl(req.fd,GPIOHANDLE_SET_LINE_VALUES_IOCTL,&data);  
if (rv<0) printf("Error setting value %s\n",strerror(errno));  
  
/* set output to 1 */  
data.values[0]=1;  
  
/* send this data struct to the handle for gpio17 we created */  
rv=ioctl(req.fd,GPIOHANDLE_SET_LINE_VALUES_IOCTL,&data);  
if (rv<0) printf("Error setting value %s\n",strerror(errno));
```



# gpio – read from gpio17

```
struct gpiohandle_data data;

/* clear out our data */
memset(&data, 0, sizeof(data));

/* read current value into data struct */
rv = ioctl(req.fd, GPIOHANDLE_GET_LINE_VALUES_IOCTL, &data);
if (rv<0) printf("Error! %s\n",strerror(errno));

/* print the result */
printf("%d\n",data[0]);
```



# Delay

- Busy delay (like in ECE271).  
`for(i=0;i<1000000;i++);`  
Harder to do in C. Why?  
Compiler optimizes away.
- `usleep()` puts process to sleep for a number of microseconds. But can have issues if want exact delay.  
Why? OS potentially context switches every 100ms.
- Other ways to implement: Set up PWM? Timers?



# Waiting for Input

- Busy loop. Bad, burns CPU / power
- `usleep()` in loop. Can delay response time.
- Interrupt when ready! `poll()`



# gpio – using poll()

```
// struct gpioevent_request {
//     __u32 lineoffset;
//     __u32 handleflags;
//     __u32 eventflags;
//     char consumer_label[32];
//     int fd; }

// struct gpioevent_data {
//     __u64 timestamp;
//     __u32 id; }

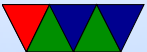
struct gpioevent_request ereq;
struct gpioevent_data edata;
struct pollfd pfd;
ssize_t rd;

/* do this instead of request_line */
memset(&ereq, 0, sizeof(struct gpioevent_request));
req.lineoffset=17;
req.handleflags = GPIOHANDLE_REQUEST_INPUT;
req.eventflags = GPIOEVENT_REQUEST_BOTH_EDGES;
```



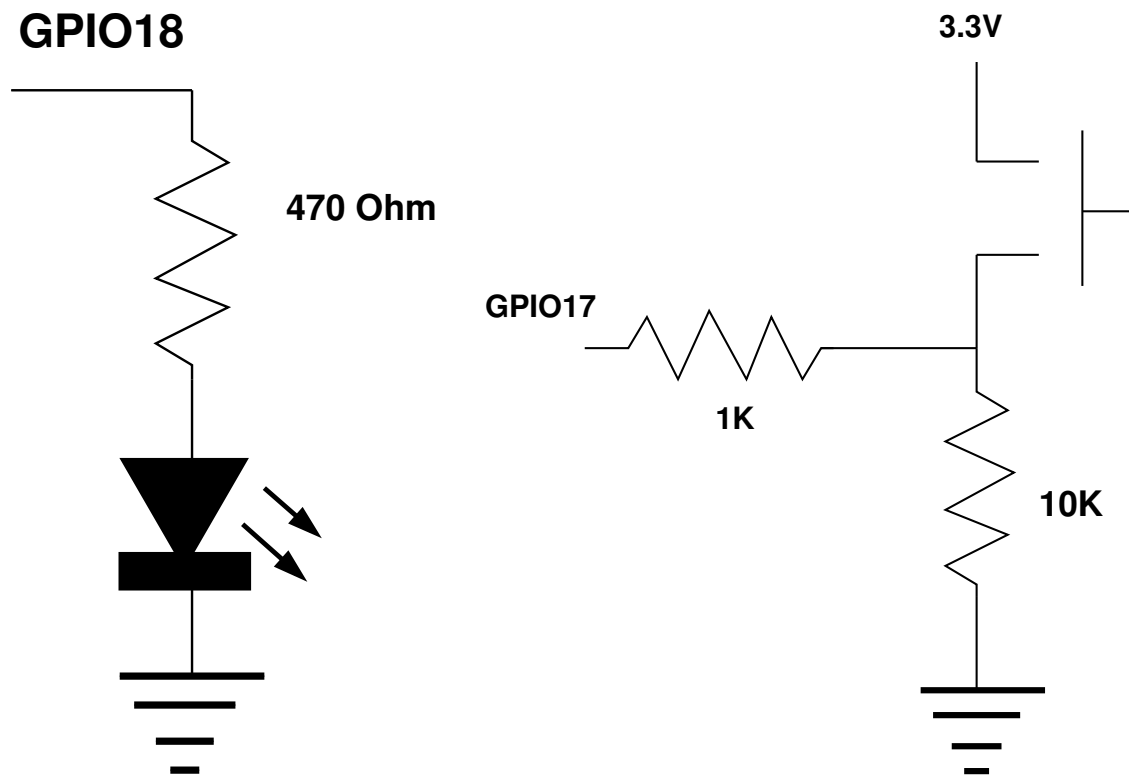
```
rv = ioctl(fd, GPIO_GET_LINEEVENT_IOCTL, &req);

pfd.fd = ereq.fd;
pfd.events = POLLIN | POLLPRI;
rv = poll(&pfd, 1, 1000);    // 1000 = timeout 1s
if (rv > 0) {
    rd = read(req.fd, &event, sizeof(event));
    printf("Timestamp: %lld    id %d\n",
           edata.timestamp, edata.id);
}
```





# Circuit



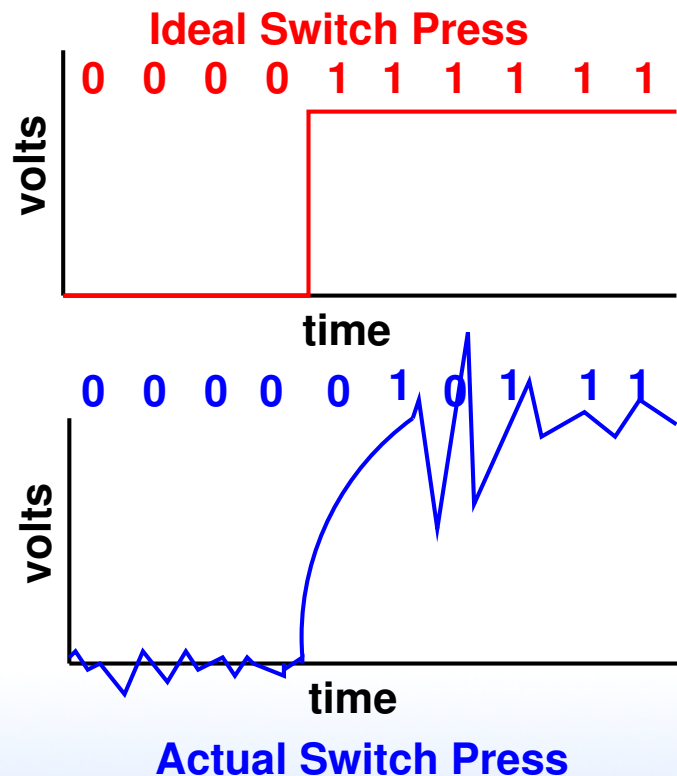
# Circuit Discussion

- Pull-up / Pull-down resistor. Why?
- Why the extra 1k resistor? (avoid short if set to output by accident)



# Debouncing! Noisy Switches

- Noisy switches, have to debounce



# Debouncing!

- Can you fix in hardware? Capacitors?
- Can you fix in software? No built-in debounce like on STM32L
- Algorithms
  - Wait until you get  $X$  consecutive values before changing
  - Get new value, wait short time and check again



# Permissions!

- Unless your user is configured to have gpio permissions you'll have to run as root or use sudo.
- raspbian there's a "gpio" group which has permissions  
`sudo addgroup vince gpio`
- What should your code do if permission is denied?  
Not crash, ideally.



# Bypassing Linux for speed

<http://codeandlife.com/2012/07/03/benchmarking-raspberry-pi-gpio-speed/>

Trying to generate fastest GPIO square wave.

shell	gpio util	40Hz
shell	sysfs	2.8kHz
Python	WiringPi	28kHz
Python	RPi.GPIO	70kHz
C	sysfs (vmw)	400kHz
C	WiringPi	4.6MHz
C	libbcm2835	5.4MHz
C	Rpi Foundation "Native"	22MHz



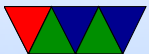
# Appendix: Linux userspace sysfs interface

THIS IS INCLUDED FOR HISTORICAL PURPOSES



# Linux GPIO interface

- `Documentation/gpio/sysfs.txt`
- sysfs and string based





# A few low-level Linux Coding Instructions



# Enable a GPIO for use

To enable GPIO 17:

write "17" to /sys/class/gpio/export

To disable GPIO 17:

write "17" to /sys/class/gpio/unexport

```
char buffer[10];  
fd=open("/sys/class/gpio/export",O_WRONLY);  
if (fd<0) fprintf(stderr,"\tError enabling\n");  
strcpy(buffer,"17");  
write(fd,buffer,2);  
close(fd);
```



# Set GPIO Direction

To make GPIO 17 an input:

write "in" to /sys/class/gpio/gpio17/direction

To make GPIO 17 an output:

write "out" to /sys/class/gpio/gpio17/direction

```
fd=open("/sys/class/gpio/gpio17/direction",O_WRONLY);  
if (fd<0) fprintf(stderr,"Error!\n");  
write(fd,"in",2);  
close(fd);
```



# Write GPIO Value

To write value of GPIO 17:

`write /sys/class/gpio/gpio17/value`

```
fd=open("/sys/class/gpio/gpio17/value",O_WRONLY);  
if (fd<0) fprintf(stderr,"Error opening!\n");  
write(fd,"1",1);  
close(fd);
```



# Read GPIO Value

To read value of GPIO 17:

`read /sys/class/gpio/gpio17/value`

```
char buffer[16];
fd=open("/sys/class/gpio/gpio17/value",O_RDONLY);
if (fd<0) fprintf(stderr,"Error opening!\n");
read(fd,buffer,16);
printf("Read %c from GPIO17\n",buffer[0]);
close(fd);
```

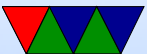
Note: the value you read is ASCII, not an integer.

Also Note, if reading and you do not close after read you will have to rewind using `lseek(fd,0,SEEK_SET);` after your read.



# Delay

- Busy delay (like in ECE271).  
`for(i=0;i<1000000;i++);`  
Harder to do in C. Why?  
Compiler optimizes away.
- `usleep()` puts process to sleep for a number of microseconds. But can have issues if want exact delay.  
Why? OS potentially context switches every 100ms.
- Other ways to implement: Set up PWM? Timers?



# Using fopen instead?

- Need to `fflush()` after writes (linefeed not enough?)
- Need to `frewind()` after reads?



# C Pitfalls

- Be careful cut and pasting! Especially the size of strings you are sending with `write()`
- Know the difference between `'C'` and `"C"`
- Remember the strings we are reading/writing are ASCII  
'0' and '1' not integers





# Waiting for Input

- Busy loop. Bad, burns CPU / power
- `usleep()` in loop. Can delay response time.
- Interrupt when ready! `poll()`



# GPIO Interrupts on Linux

May need a recent version of Raspbian.

First write "rising", "falling", or "both" to  
/sys/class/gpio/gpio17/edge.

Then open and poll /sys/class/gpio/gpio17/value.

```
struct pollfd fds;  
int result;  
  
fd=open("/sys/class/gpio/gpio18/value",O_RDONLY);  
fds.fd=fd;  
fds.events=POLLPRI|POLLERR;  
while(1) {  
    result=poll(&fds,1, -1);  
    if (result<0) printf("Error!\n");  
    lseek(fd,0,SEEK_SET);  
    read(fd,buffer,1); }
```



# Buffered “Stream” I/O

- Slightly higher-level I/O routines in C library
- Buffered I/O
- Still use open/close/read/write underneath  
Can find file descriptor with `fileno()`

- ```
FILE *f;  
f=fopen("filename","r");  
if (f==NULL) fprintf(stderr,"Error!\n");  
fwrite(buffer,size,members,f);  
fclose(f);
```

- Buffered I/O (saves overhead, fewer syscalls, maybe makes I/O faster, but also adds potential delay)
- Use `fflush()` to force buffer flush



- Use `rewind()` to rewind to beginning of file

