MicroPython Documentation

Release 1.8

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Contents

CHAPTER 1

Quick reference for the pyboard

1.1 General board control

See *pyb*.

```
import pyb

pyb.delay(50) # wait 50 milliseconds
pyb.millis() # number of milliseconds since bootup
pyb.repl_uart(pyb.UART(1, 9600)) # duplicate REPL on UART(1)
pyb.wfi() # pause CPU, waiting for interrupt
pyb.freq() # get CPU and bus frequencies
pyb.freq(60000000) # set CPU freq to 60MHz
pyb.stop() # stop CPU, waiting for external interrupt
```

1.2 LEDs

See *pyb.LED*.

```
from pyb import LED

led = LED(1) # red led
led.toggle()
led.on()
led.off()
```

1.3 Pins and GPIO

See *pyb.Pin*.

```
from pyb import Pin

p_out = Pin('X1', Pin.OUT_PP)
p_out.high()
p_out.low()

p_in = Pin('X2', Pin.IN, Pin.PULL_UP)
p_in.value() # get value, 0 or 1
```

1.4 Servo control

See *pyb.Servo*.

```
from pyb import Servo

s1 = Servo(1) # servo on position 1 (X1, VIN, GND)
s1.angle(45) # move to 45 degrees
s1.angle(-60, 1500) # move to -60 degrees in 1500ms
s1.speed(50) # for continuous rotation servos
```

1.5 External interrupts

See *pyb.ExtInt*.

```
from pyb import Pin, ExtInt

callback = lambda e: print("intr")
ext = ExtInt(Pin('Y1'), ExtInt.IRQ_RISING, Pin.PULL_NONE, callback)
```

1.6 Timers

See *pyb.Timer*.

```
from pyb import Timer

tim = Timer(1, freq=1000)
tim.counter() # get counter value
tim.freq(0.5) # 0.5 Hz
tim.callback(lambda t: pyb.LED(1).toggle())
```

1.7 PWM (pulse width modulation)

See *pyb.Pin* and *pyb.Timer*.

```
from pyb import Pin, Timer

p = Pin('X1') # X1 has TIM2, CH1
tim = Timer(2, freq=1000)
ch = tim.channel(1, Timer.PWM, pin=p)
ch.pulse_width_percent(50)
```

1.8 ADC (analog to digital conversion)

See *pyb.Pin* and *pyb.ADC*.

```
from pyb import Pin, ADC

adc = ADC(Pin('X19'))
adc.read() # read value, 0-4095
```

1.9 DAC (digital to analog conversion)

See *pyb.Pin* and *pyb.DAC*.

```
from pyb import Pin, DAC

dac = DAC(Pin('X5'))
dac.write(120) # output between 0 and 255
```

1.10 UART (serial bus)

See *pyb.UART*.

```
from pyb import UART

uart = UART(1, 9600)
uart.write('hello')
uart.read(5) # read up to 5 bytes
```

1.11 SPI bus

See *pyb.SPI*.

```
from pyb import SPI

spi = SPI(1, SPI.MASTER, baudrate=200000, polarity=1, phase=0)
spi.send('hello')
spi.recv(5) # receive 5 bytes on the bus
spi.send_recv('hello') # send a receive 5 bytes
```

1.12 I2C bus

See *pyb.I2C*.

```
from pyb import I2C

i2c = I2C(1, I2C.MASTER, baudrate=100000)
i2c.scan() # returns list of slave addresses
i2c.send('hello', 0x42) # send 5 bytes to slave with address 0x42
i2c.recv(5, 0x42) # receive 5 bytes from slave
i2c.mem_read(2, 0x42, 0x10) # read 2 bytes from slave 0x42, slave memory 0x10
i2c.mem_write('xy', 0x42, 0x10) # write 2 bytes to slave 0x42, slave memory 0x10
```

CHAPTER 2

General information about the pyboard

2.1 Local filesystem and SD card

There is a small internal filesystem (a drive) on the pyboard, called `/flash`, which is stored within the microcontroller's flash memory. If a micro SD card is inserted into the slot, it is available as `/sd`.

When the pyboard boots up, it needs to choose a filesystem to boot from. If there is no SD card, then it uses the internal filesystem `/flash` as the boot filesystem, otherwise, it uses the SD card `/sd`.

(Note that on older versions of the board, `/flash` is called `0:/` and `/sd` is called `1:/`).

The boot filesystem is used for 2 things: it is the filesystem from which the `boot.py` and `main.py` files are searched for, and it is the filesystem which is made available on your PC over the USB cable.

The filesystem will be available as a USB flash drive on your PC. You can save files to the drive, and edit `boot.py` and `main.py`.

Remember to eject (on Linux, unmount) the USB drive before you reset your pyboard.

2.2 Boot modes

If you power up normally, or press the reset button, the pyboard will boot into standard mode: the `boot.py` file will be executed first, then the USB will be configured, then `main.py` will run.

You can override this boot sequence by holding down the user switch as the board is booting up. Hold down user switch and press reset, and then as you continue to hold the user switch, the LEDs will count in binary. When the LEDs have reached the mode you want, let go of the user switch, the LEDs for the selected mode will flash quickly, and the board will boot.

The modes are:

1. Green LED only, *standard boot*: run `boot.py` then `main.py`.
2. Orange LED only, *safe boot*: don't run any scripts on boot-up.
3. Green and orange LED together, *filesystem reset*: resets the flash filesystem to its factory state, then boots in safe mode.

If your filesystem becomes corrupt, boot into mode 3 to fix it. If resetting the filesystem while plugged into your compute doesn't work, you can try doing the same procedure while the board is plugged into a USB charger, or other USB power supply without data connection.

2.3 Errors: flashing LEDs

There are currently 2 kinds of errors that you might see:

1. **If the red and green LEDs flash alternatively, then a Python script** (eg `main.py`) has an error. Use the REPL to debug it.
2. If all 4 LEDs cycle on and off slowly, then there was a hard fault. This cannot be recovered from and you need to do a hard reset.

CHAPTER 3

MicroPython tutorial

This tutorial is intended to get you started with your pyboard. All you need is a pyboard and a micro-USB cable to connect it to your PC. If it is your first time, it is recommended to follow the tutorial through in the order below.

3.1 Introduction to the pyboard

To get the most out of your pyboard, there are a few basic things to understand about how it works.

3.1.1 Caring for your pyboard

Because the pyboard does not have a housing it needs a bit of care:

- Be gentle when plugging/unplugging the USB cable. Whilst the USB connector is soldered through the board and is relatively strong, if it breaks off it can be very difficult to fix.
- Static electricity can shock the components on the pyboard and destroy them. If you experience a lot of static electricity in your area (eg dry and cold climates), take extra care not to shock the pyboard. If your pyboard came in a black plastic box, then this box is the best way to store and carry the pyboard as it is an anti-static box (it is made of a conductive plastic, with conductive foam inside).

As long as you take care of the hardware, you should be okay. It's almost impossible to break the software on the pyboard, so feel free to play around with writing code as much as you like. If the filesystem gets corrupt, see below on how to reset it. In the worst case you might need to reflash the MicroPython software, but that can be done over USB.

3.1.2 Layout of the pyboard

The micro USB connector is on the top right, the micro SD card slot on the top left of the board. There are 4 LEDs between the SD slot and USB connector. The colours are: red on the bottom, then green, orange, and blue on the top. There are 2 switches: the right one is the reset switch, the left is the user switch.

3.1.3 Plugging in and powering on

The pyboard can be powered via USB. Connect it to your PC via a micro USB cable. There is only one way that the cable will fit. Once connected, the green LED on the board should flash quickly.

3.1.4 Powering by an external power source

The pyboard can be powered by a battery or other external power source.

Be sure to connect the positive lead of the power supply to VIN, and ground to GND. There is no polarity protection on the pyboard so you must be careful when connecting anything to VIN.

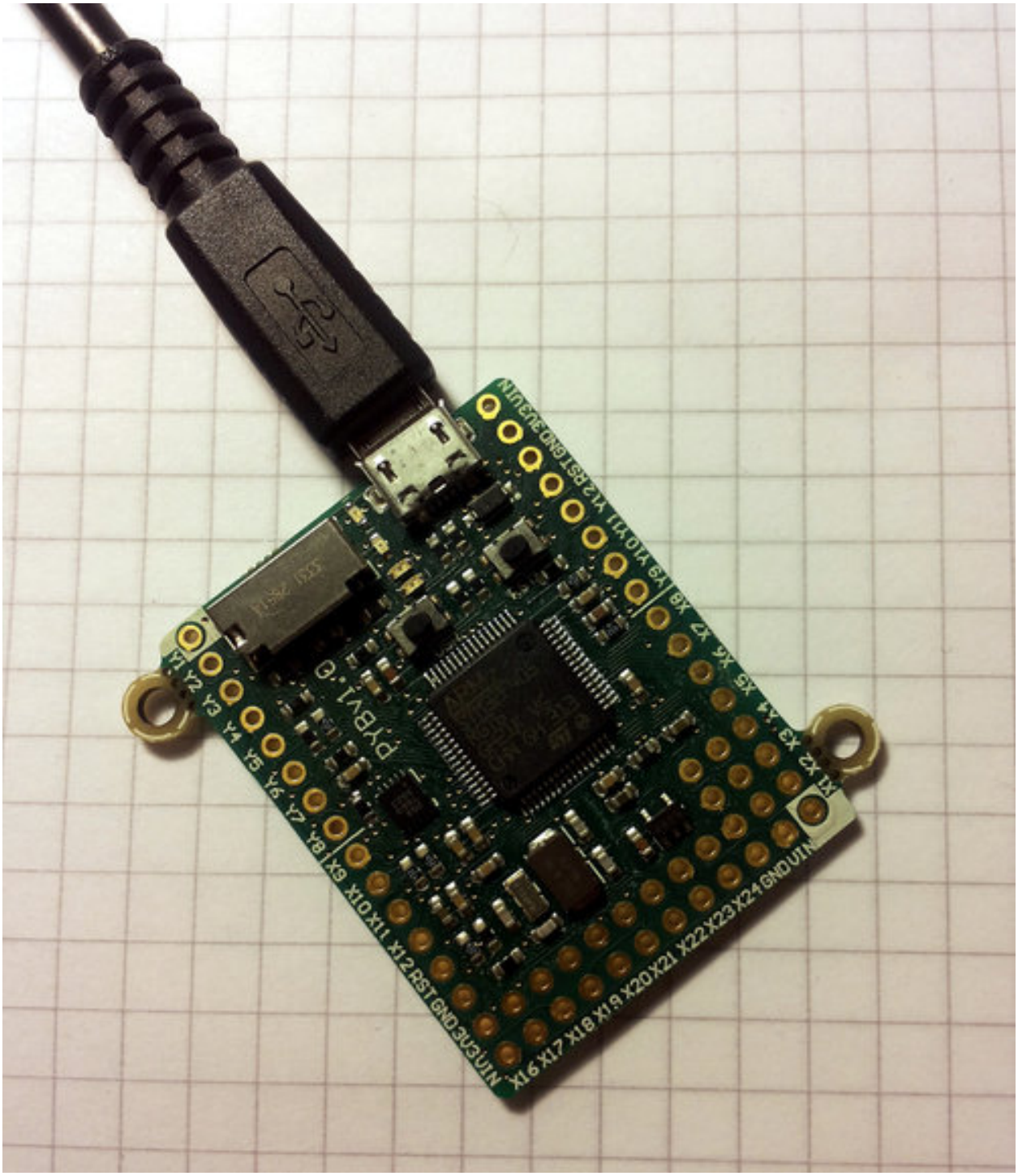
The input voltage must be between 3.6V and 10V.

3.2 Running your first script

Let's jump right in and get a Python script running on the pyboard. After all, that's what it's all about!

3.2.1 Connecting your pyboard

Connect your pyboard to your PC (Windows, Mac or Linux) with a micro USB cable. There is only one way that the cable will connect, so you can't get it wrong.



When the pyboard is connected to your PC it will power on and enter the start up process (the boot process). The green LED should light up for half a second or less, and when it turns off it means the boot process has completed.

3.2.2 Opening the pyboard USB drive

Your PC should now recognise the pyboard. It depends on the type of PC you have as to what happens next:

- **Windows**: Your pyboard will appear as a removable USB flash drive. Windows may automatically pop-up a

window, or you may need to go there using Explorer.

Windows will also see that the pyboard has a serial device, and it will try to automatically configure this device. If it does, cancel the process. We will get the serial device working in the next tutorial.

- **Mac**: Your pyboard will appear on the desktop as a removable disc. It will probably be called "NONAME". Click on it to open the pyboard folder.
- **Linux**: Your pyboard will appear as a removable medium. On Ubuntu it will mount automatically and pop-up a window with the pyboard folder. On other Linux distributions, the pyboard may be mounted automatically, or you may need to do it manually. At a terminal command line, type `lsblk` to see a list of connected drives, and then `mount /dev/sdb1` (replace `sdb1` with the appropriate device). You may need to be root to do this.

Okay, so you should now have the pyboard connected as a USB flash drive, and a window (or command line) should be showing the files on the pyboard drive.

The drive you are looking at is known as `/flash` by the pyboard, and should contain the following 4 files:

- **boot.py – this script is executed when the pyboard boots up. It sets** up various configuration options for the pyboard.
- **main.py – this is the main script that will contain your Python program.** It is executed after `boot.py`.
- **README.txt – this contains some very basic information about getting** started with the pyboard.
- **pybcdc.inf – this is a Windows driver file to configure the serial USB** device. More about this in the next tutorial.

3.2.3 Editing `main.py`

Now we are going to write our Python program, so open the `main.py` file in a text editor. On Windows you can use notepad, or any other editor. On Mac and Linux, use your favourite text editor. With the file open you will see it contains 1 line:

```
# main.py -- put your code here!
```

This line starts with a # character, which means that it is a *comment*. Such lines will not do anything, and are there for you to write notes about your program.

Let's add 2 lines to this `main.py` file, to make it look like this:

```
# main.py -- put your code here!
import pyb
pyb.LED(4).on()
```

The first line we wrote says that we want to use the `pyb` module. This module contains all the functions and classes to control the features of the pyboard.

The second line that we wrote turns the blue LED on: it first gets the `LED` class from the `pyb` module, creates LED number 4 (the blue LED), and then turns it on.

3.2.4 Resetting the pyboard

To run this little script, you need to first save and close the `main.py` file, and then eject (or unmount) the pyboard USB drive. Do this like you would a normal USB flash drive.

When the drive is safely ejected/unmounted you can get to the fun part: press the RST switch on the pyboard to reset and run your script. The RST switch is the small black button just below the USB connector on the board, on the right edge.

When you press RST the green LED will flash quickly, and then the blue LED should turn on and stay on.

Congratulations! You have written and run your very first MicroPython program!

3.3 Getting a MicroPython REPL prompt

REPL stands for Read Evaluate Print Loop, and is the name given to the interactive MicroPython prompt that you can access on the pyboard. Using the REPL is by far the easiest way to test out your code and run commands. You can use the REPL in addition to writing scripts in `main.py`.

To use the REPL, you must connect to the serial USB device on the pyboard. How you do this depends on your operating system.

3.3.1 Windows

You need to install the pyboard driver to use the serial USB device. The driver is on the pyboard's USB flash drive, and is called `pybcdc.inf`.

To install this driver you need to go to Device Manager for your computer, find the pyboard in the list of devices (it should have a warning sign next to it because it's not working yet), right click on the pyboard device, select Properties, then Install Driver. You need to then select the option to find the driver manually (don't use Windows auto update), navigate to the pyboard's USB drive, and select that. It should then install. After installing, go back to the Device Manager to find the installed pyboard, and see which COM port it is (eg COM4). More comprehensive instructions can be found in the Guide for pyboard on Windows (PDF). Please consult this guide if you are having problems installing the driver.

You now need to run your terminal program. You can use HyperTerminal if you have it installed, or download the free program PuTTY: putty.exe. Using your serial program you must connect to the COM port that you found in the previous step. With PuTTY, click on "Session" in the left-hand panel, then click the "Serial" radio button on the right, then enter you COM port (eg COM4) in the "Serial Line" box. Finally, click the "Open" button.

3.3.2 Mac OS X

Open a terminal and run:

```
screen /dev/tty.usbmodem*
```

When you are finished and want to exit screen, type CTRL-A CTRL-\.

3.3.3 Linux

Open a terminal and run:

```
screen /dev/ttyACM0
```

You can also try `picocom` or `minicom` instead of screen. You may have to use `/dev/ttyACM1` or a higher number for `ttyACM`. And, you may need to give yourself the correct permissions to access this devices (eg group `uucp` or `dialout`, or use sudo).

3.3.4 Using the REPL prompt

Now let's try running some MicroPython code directly on the pyboard.

With your serial program open (PuTTY, screen, picocom, etc) you may see a blank screen with a flashing cursor. Press Enter and you should be presented with a MicroPython prompt, i.e. `>>>`. Let's make sure it is working with the obligatory test:

```
>>> print("hello pyboard!")
hello pyboard!
```

In the above, you should not type in the `>>>` characters. They are there to indicate that you should type the text after it at the prompt. In the end, once you have entered the text `print("hello pyboard!")` and pressed Enter, the output on your screen should look like it does above.

If you already know some python you can now try some basic commands here.

If any of this is not working you can try either a hard reset or a soft reset; see below.

Go ahead and try typing in some other commands. For example:

```
>>> pyb.LED(1).on()
>>> pyb.LED(2).on()
>>> 1 + 2
3
>>> 1 / 2
0.5
>>> 20 * 'py'
'pypypypypypypypypypypypypypypypypypypypypypypypypypypypypypypypypypypypy'
```

3.3.5 Resetting the board

If something goes wrong, you can reset the board in two ways. The first is to press CTRL-D at the MicroPython prompt, which performs a soft reset. You will see a message something like

```
>>>
PYB: sync filesystems
PYB: soft reboot
Micro Python v1.0 on 2014-05-03; PYBv1.0 with STM32F405RG
Type "help()" for more information.
>>>
```

If that isn't working you can perform a hard reset (turn-it-off-and-on-again) by pressing the RST switch (the small black button closest to the micro-USB socket on the board). This will end your session, disconnecting whatever program (PuTTY, screen, etc) that you used to connect to the pyboard.

If you are going to do a hard-reset, it's recommended to first close your serial program and eject/unmount the pyboard drive.

3.4 Turning on LEDs and basic Python concepts

The easiest thing to do on the pyboard is to turn on the LEDs attached to the board. Connect the board, and log in as described in tutorial 1. We will start by turning and LED on in the interpreter, type the following

```
>>> myled = pyb.LED(1)
>>> myled.on()
>>> myled.off()
```

These commands turn the LED on and off.

This is all very well but we would like this process to be automated. Open the file MAIN.PY on the pyboard in your favourite text editor. Write or paste the following lines into the file. If you are new to python, then make sure you get the indentation correct since this matters!

```
led = pyb.LED(2)
while True:
    led.toggle()
    pyb.delay(1000)
```

When you save, the red light on the pyboard should turn on for about a second. To run the script, do a soft reset (CTRL-D). The pyboard will then restart and you should see a green light continuously flashing on and off. Success, the first step on your path to building an army of evil robots! When you are bored of the annoying flashing light then press CTRL-C at your terminal to stop it running.

So what does this code do? First we need some terminology. Python is an object-oriented language, almost everything in python is a *class* and when you create an instance of a class you get an *object*. Classes have *methods* associated to them. A method (also called a member function) is used to interact with or control the object.

The first line of code creates an LED object which we have then called led. When we create the object, it takes a single parameter which must be between 1 and 4, corresponding to the 4 LEDs on the board. The pyb.LED class has three important member functions that we will use: on(), off() and toggle(). The other function that we use is pyb.delay() this simply waits for a given time in miliseconds. Once we have created the LED object, the statement while True: creates an infinite loop which toggles the led between on and off and waits for 1 second.

Exercise: Try changing the time between toggling the led and turning on a different LED.

Exercise: Connect to the pyboard directly, create a pyb.LED object and turn it on using the on() method.

3.4.1 A Disco on your pyboard

So far we have only used a single LED but the pyboard has 4 available. Let's start by creating an object for each LED so we can control each of them. We do that by creating a list of LEDS with a list comprehension.

```
leds = [pyb.LED(i) for i in range(1,5)]
```

If you call pyb.LED() with a number that isn't 1,2,3,4 you will get an error message. Next we will set up an infinite loop that cycles through each of the LEDs turning them on and off.

```
n = 0
while True:
  n = (n + 1) % 4
  leds[n].toggle()
  pyb.delay(50)
```

Here, n keeps track of the current LED and every time the loop is executed we cycle to the next n (the % sign is a modulus operator that keeps n between 0 and 3.) Then we access the nth LED and toggle it. If you run this you should see each of the LEDs turning on then all turning off again in sequence.

One problem you might find is that if you stop the script and then start it again that the LEDs are stuck on from the previous run, ruining our carefully choreographed disco. We can fix this by turning all the LEDs off when we initialise the script and then using a try/finally block. When you press CTRL-C, MicroPython generates a VCPInterrupt exception. Exceptions normally mean something has gone wrong and you can use a try: command to "catch" an exception. In this case it is just the user interrupting the script, so we don't need to catch the error but just tell MicroPython what to do when we exit. The finally block does this, and we use it to make sure all the LEDs are off. The full code is:

```
leds = [pyb.LED(i) for i in range(1,5)]
for l in leds:
    l.off()

n = 0
try:
   while True:
      n = (n + 1) % 4
      leds[n].toggle()
      pyb.delay(50)
finally:
    for l in leds:
        l.off()
```

3.4.2 The Fourth Special LED

The blue LED is special. As well as turning it on and off, you can control the intensity using the intensity() method. This takes a number between 0 and 255 that determines how bright it is. The following script makes the blue LED gradually brighter then turns it off again.

```
led = pyb.LED(4)
intensity = 0
while True:
    intensity = (intensity + 1) % 255
    led.intensity(intensity)
    pyb.delay(20)
```

You can call intensity() on the other LEDs but they can only be off or on. 0 sets them off and any other number up to 255 turns them on.

3.5 The Switch, callbacks and interrupts

The pyboard has 2 small switches, labelled USR and RST. The RST switch is a hard-reset switch, and if you press it then it restarts the pyboard from scratch, equivalent to turning the power off then back on.

The USR switch is for general use, and is controlled via a Switch object. To make a switch object do:

```
>>> sw = pyb.Switch()
```

Remember that you may need to type `import pyb` if you get an error that the name `pyb` does not exist.

With the switch object you can get its status:

```
>>> sw()
False
```

This will print `False` if the switch is not held, or `True` if it is held. Try holding the USR switch down while running the above command.

3.5.1 Switch callbacks

The switch is a very simple object, but it does have one advanced feature: the `sw.callback()` function. The callback function sets up something to run when the switch is pressed, and uses an interrupt. It's probably best to start with an example before understanding how interrupts work. Try running the following at the prompt:

```
>>> sw.callback(lambda:print('press!'))
```

This tells the switch to print `press!` each time the switch is pressed down. Go ahead and try it: press the USR switch and watch the output on your PC. Note that this print will interrupt anything you are typing, and is an example of an interrupt routine running asynchronously.

As another example try:

```
>>> sw.callback(lambda:pyb.LED(1).toggle())
```

This will toggle the red LED each time the switch is pressed. And it will even work while other code is running.

To disable the switch callback, pass `None` to the callback function:

```
>>> sw.callback(None)
```

You can pass any function (that takes zero arguments) to the switch callback. Above we used the `lambda` feature of Python to create an anonymous function on the fly. But we could equally do:

```
>>> def f():
...   pyb.LED(1).toggle()
...
>>> sw.callback(f)
```

This creates a function called `f` and assigns it to the switch callback. You can do things this way when your function is more complicated than a `lambda` will allow.

Note that your callback functions must not allocate any memory (for example they cannot create a tuple or list). Callback functions should be relatively simple. If you need to make a list, make it beforehand and store it in a global variable (or make it local and close over it). If you need to do a long, complicated calculation, then use the callback to set a flag which some other code then responds to.

3.5.2 Technical details of interrupts

Let's step through the details of what is happening with the switch callback. When you register a function with `sw.callback()`, the switch sets up an external interrupt trigger (falling edge) on the pin that the switch is connected to. This means that the microcontroller will listen on the pin for any changes, and the following will occur:

1. When the switch is pressed a change occurs on the pin (the pin goes from low to high), and the microcontroller registers this change.
2. The microcontroller finishes executing the current machine instruction, stops execution, and saves its current state (pushes the registers on the stack). This has the effect of pausing any code, for example your running Python script.
3. The microcontroller starts executing the special interrupt handler associated with the switch's external trigger. This interrupt handler get the function that you registered with `sw.callback()` and executes it.
4. Your callback function is executed until it finishes, returning control to the switch interrupt handler.
5. The switch interrupt handler returns, and the microcontroller is notified that the interrupt has been dealt with.
6. The microcontroller restores the state that it saved in step 2.
7. Execution continues of the code that was running at the beginning. Apart from the pause, this code does not notice that it was interrupted.

The above sequence of events gets a bit more complicated when multiple interrupts occur at the same time. In that case, the interrupt with the highest priority goes first, then the others in order of their priority. The switch interrupt is set at the lowest priority.

3.5.3 Further reading

For further information about using hardware interrupts see *writing interrupt handlers*.

3.6 The accelerometer

Here you will learn how to read the accelerometer and signal using LEDs states like tilt left and tilt right.

3.6.1 Using the accelerometer

The pyboard has an accelerometer (a tiny mass on a tiny spring) that can be used to detect the angle of the board and motion. There is a different sensor for each of the x, y, z directions. To get the value of the accelerometer, create a pyb.Accel() object and then call the x() method.

```
>>> accel = pyb.Accel()
>>> accel.x()
7
```

This returns a signed integer with a value between around -30 and 30. Note that the measurement is very noisy, this means that even if you keep the board perfectly still there will be some variation in the number that you measure. Because of this, you shouldn't use the exact value of the x() method but see if it is in a certain range.

We will start by using the accelerometer to turn on a light if it is not flat.

```
accel = pyb.Accel()
light = pyb.LED(3)
SENSITIVITY = 3

while True:
    x = accel.x()
    if abs(x) > SENSITIVITY:
        light.on()
    else:
        light.off()

    pyb.delay(100)
```

We create Accel and LED objects, then get the value of the x direction of the accelerometer. If the magnitude of x is bigger than a certain value `SENSITIVITY`, then the LED turns on, otherwise it turns off. The loop has a small `pyb.delay()` otherwise the LED flashes annoyingly when the value of x is close to `SENSITIVITY`. Try running this on the pyboard and tilt the board left and right to make the LED turn on and off.

Exercise: Change the above script so that the blue LED gets brighter the more you tilt the pyboard. HINT: You will need to rescale the values, intensity goes from 0-255.

3.6.2 Making a spirit level

The example above is only sensitive to the angle in the x direction but if we use the `y()` value and more LEDs we can turn the pyboard into a spirit level.

```
xlights = (pyb.LED(2), pyb.LED(3))
ylights = (pyb.LED(1), pyb.LED(4))

accel = pyb.Accel()
```

```
SENSITIVITY = 3

while True:
    x = accel.x()
    if x > SENSITIVITY:
        xlights[0].on()
        xlights[1].off()
    elif x < -SENSITIVITY:
        xlights[1].on()
        xlights[0].off()
    else:
        xlights[0].off()
        xlights[1].off()

    y = accel.y()
    if y > SENSITIVITY:
        ylights[0].on()
        ylights[1].off()
    elif y < -SENSITIVITY:
        ylights[1].on()
        ylights[0].off()
    else:
        ylights[0].off()
        ylights[1].off()

    pyb.delay(100)
```

We start by creating a tuple of LED objects for the x and y directions. Tuples are immutable objects in python which means they can't be modified once they are created. We then proceed as before but turn on a different LED for positive and negative x values. We then do the same for the y direction. This isn't particularly sophisticated but it does the job. Run this on your pyboard and you should see different LEDs turning on depending on how you tilt the board.

3.7 Safe mode and factory reset

If something goes wrong with your pyboard, don't panic! It is almost impossible for you to break the pyboard by programming the wrong thing.

The first thing to try is to enter safe mode: this temporarily skips execution of `boot.py` and `main.py` and gives default USB settings.

If you have problems with the filesystem you can do a factory reset, which restores the filesystem to its original state.

3.7.1 Safe mode

To enter safe mode, do the following steps:

1. Connect the pyboard to USB so it powers up.
2. Hold down the USR switch.
3. While still holding down USR, press and release the RST switch.
4. The LEDs will then cycle green to orange to green+orange and back again.
5. Keep holding down USR until *only the orange LED is lit*, and then let go of the USR switch.
6. The orange LED should flash quickly 4 times, and then turn off.

7. You are now in safe mode.

In safe mode, the `boot.py` and `main.py` files are not executed, and so the pyboard boots up with default settings. This means you now have access to the filesystem (the USB drive should appear), and you can edit `boot.py` and `main.py` to fix any problems.

Entering safe mode is temporary, and does not make any changes to the files on the pyboard.

3.7.2 Factory reset the filesystem

If you pyboard's filesystem gets corrupted (for example, you forgot to eject/unmount it), or you have some code in `boot.py` or `main.py` which you can't escape from, then you can reset the filesystem.

Resetting the filesystem deletes all files on the internal pyboard storage (not the SD card), and restores the files `boot.py`, `main.py`, `README.txt` and `pybcdc.inf` back to their original state.

To do a factory reset of the filesystem you follow a similar procedure as you did to enter safe mode, but release USR on green+orange:

1. Connect the pyboard to USB so it powers up.
2. Hold down the USR switch.
3. While still holding down USR, press and release the RST switch.
4. The LEDs will then cycle green to orange to green+orange and back again.
5. Keep holding down USR until *both the green and orange LEDs are lit*, and then let go of the USR switch.
6. The green and orange LEDs should flash quickly 4 times.
7. The red LED will turn on (so red, green and orange are now on).
8. The pyboard is now resetting the filesystem (this takes a few seconds).
9. The LEDs all turn off.
10. You now have a reset filesystem, and are in safe mode.
11. Press and release the RST switch to boot normally.

3.8 Making the pyboard act as a USB mouse

The pyboard is a USB device, and can configured to act as a mouse instead of the default USB flash drive.

To do this we must first edit the `boot.py` file to change the USB configuration. If you have not yet touched your `boot.py` file then it will look something like this:

```
# boot.py -- run on boot-up
# can run arbitrary Python, but best to keep it minimal

import pyb
#pyb.main('main.py') # main script to run after this one
#pyb.usb_mode('CDC+MSC') # act as a serial and a storage device
#pyb.usb_mode('CDC+HID') # act as a serial device and a mouse
```

To enable the mouse mode, uncomment the last line of the file, to make it look like:

```
pyb.usb_mode('CDC+HID') # act as a serial device and a mouse
```

If you already changed your `boot.py` file, then the minimum code it needs to work is:

```
import pyb
pyb.usb_mode('CDC+HID')
```

This tells the pyboard to configure itself as a CDC (serial) and HID (human interface device, in our case a mouse) USB device when it boots up.

Eject/unmount the pyboard drive and reset it using the RST switch. Your PC should now detect the pyboard as a mouse!

3.8.1 Sending mouse events by hand

To get the py-mouse to do anything we need to send mouse events to the PC. We will first do this manually using the REPL prompt. Connect to your pyboard using your serial program and type the following:

```
>>> pyb.hid((0, 10, 0, 0))
```

Your mouse should move 10 pixels to the right! In the command above you are sending 4 pieces of information: button status, x, y and scroll. The number 10 is telling the PC that the mouse moved 10 pixels in the x direction.

Let's make the mouse oscillate left and right:

```
>>> import math
>>> def osc(n, d):
...   for i in range(n):
...     pyb.hid((0, int(20 * math.sin(i / 10)), 0, 0))
...     pyb.delay(d)
...
>>> osc(100, 50)
```

The first argument to the function `osc` is the number of mouse events to send, and the second argument is the delay (in milliseconds) between events. Try playing around with different numbers.

Excercise: make the mouse go around in a circle.

3.8.2 Making a mouse with the accelerometer

Now lets make the mouse move based on the angle of the pyboard, using the accelerometer. The following code can be typed directly at the REPL prompt, or put in the `main.py` file. Here, we'll put in in `main.py` because to do that we will learn how to go into safe mode.

At the moment the pyboard is acting as a serial USB device and an HID (a mouse). So you cannot access the filesystem to edit your `main.py` file.

You also can't edit your `boot.py` to get out of HID-mode and back to normal mode with a USB drive...

To get around this we need to go into *safe mode*. This was described in the [safe mode tutorial](tut-reset), but we repeat the instructions here:

1. Hold down the USR switch.
2. While still holding down USR, press and release the RST switch.
3. The LEDs will then cycle green to orange to green+orange and back again.
4. Keep holding down USR until *only the orange LED is lit*, and then let go of the USR switch.
5. The orange LED should flash quickly 4 times, and then turn off.
6. You are now in safe mode.

In safe mode, the `boot.py` and `main.py` files are not executed, and so the pyboard boots up with default settings. This means you now have access to the filesystem (the USB drive should appear), and you can edit `main.py`. (Leave `boot.py` as-is, because we still want to go back to HID-mode after we finish editting `main.py`.)

In `main.py` put the following code:

```
import pyb

switch = pyb.Switch()
accel = pyb.Accel()

while not switch():
    pyb.hid((0, accel.x(), accel.y(), 0))
    pyb.delay(20)
```

Save your file, eject/unmount your pyboard drive, and reset it using the RST switch. It should now act as a mouse, and the angle of the board will move the mouse around. Try it out, and see if you can make the mouse stand still!

Press the USR switch to stop the mouse motion.

You'll note that the y-axis is inverted. That's easy to fix: just put a minus sign in front of the y-coordinate in the `pyb.hid()` line above.

3.8.3 Restoring your pyboard to normal

If you leave your pyboard as-is, it'll behave as a mouse everytime you plug it in. You probably want to change it back to normal. To do this you need to first enter safe mode (see above), and then edit the `boot.py` file. In the `boot.py` file, comment out (put a # in front of) the line with the `CDC+HID` setting, so it looks like:

```
#pyb.usb_mode('CDC+HID') # act as a serial device and a mouse
```

Save your file, eject/unmount the drive, and reset the pyboard. It is now back to normal operating mode.

3.9 The Timers

The pyboard has 14 timers which each consist of an independent counter running at a user-defined frequency. They can be set up to run a function at specific intervals. The 14 timers are numbered 1 through 14, but 3 is reserved for internal use, and 5 and 6 are used for servo and ADC/DAC control. Avoid using these timers if possible.

Let's create a timer object:

```
>>> tim = pyb.Timer(4)
```

Now let's see what we just created:

```
>>> tim
Timer(4)
```

The pyboard is telling us that `tim` is attached to timer number 4, but it's not yet initialised. So let's initialise it to trigger at 10 Hz (that's 10 times per second):

```
>>> tim.init(freq=10)
```

Now that it's initialised, we can see some information about the timer:

```
>>> tim
Timer(4, prescaler=624, period=13439, mode=UP, div=1)
```

The information means that this timer is set to run at the peripheral clock speed divided by 624+1, and it will count from 0 up to 13439, at which point it triggers an interrupt, and then starts counting again from 0. These numbers are set to make the timer trigger at 10 Hz: the source frequency of the timer is 84MHz (found by running `tim.source_freq()`) so we get 84MHz / 625 / 13440 = 10Hz.

3.9.1 Timer counter

So what can we do with our timer? The most basic thing is to get the current value of its counter:

```
>>> tim.counter()
21504
```

This counter will continuously change, and counts up.

3.9.2 Timer callbacks

The next thing we can do is register a callback function for the timer to execute when it triggers (see the [switch tutorial](tut-switch) for an introduction to callback functions):

```
>>> tim.callback(lambda t:pyb.LED(1).toggle())
```

This should start the red LED flashing right away. It will be flashing at 5 Hz (2 toggle's are needed for 1 flash, so toggling at 10 Hz makes it flash at 5 Hz). You can change the frequency by re-initialising the timer:

```
>>> tim.init(freq=20)
```

You can disable the callback by passing it the value `None`:

```
>>> tim.callback(None)
```

The function that you pass to callback must take 1 argument, which is the timer object that triggered. This allows you to control the timer from within the callback function.

We can create 2 timers and run them independently:

```
>>> tim4 = pyb.Timer(4, freq=10)
>>> tim7 = pyb.Timer(7, freq=20)
>>> tim4.callback(lambda t: pyb.LED(1).toggle())
>>> tim7.callback(lambda t: pyb.LED(2).toggle())
```

Because the callbacks are proper hardware interrupts, we can continue to use the pyboard for other things while these timers are running.

3.9.3 Making a microsecond counter

You can use a timer to create a microsecond counter, which might be useful when you are doing something which requires accurate timing. We will use timer 2 for this, since timer 2 has a 32-bit counter (so does timer 5, but if you use timer 5 then you can't use the Servo driver at the same time).

We set up timer 2 as follows:

```
>>> micros = pyb.Timer(2, prescaler=83, period=0x3fffffff)
```

The prescaler is set at 83, which makes this timer count at 1 MHz. This is because the CPU clock, running at 168 MHz, is divided by 2 and then by prescaler+1, giving a freqency of 168 MHz/2/(83+1)=1 MHz for timer 2. The period is set to a large number so that the timer can count up to a large number before wrapping back around to zero. In this case it will take about 17 minutes before it cycles back to zero.

To use this timer, it's best to first reset it to 0:

```
>>> micros.counter(0)
```

and then perform your timing:

```
>>> start_micros = micros.counter()

... do some stuff ...

>>> end_micros = micros.counter()
```

3.10 Inline assembler

Here you will learn how to write inline assembler in MicroPython.

Note: this is an advanced tutorial, intended for those who already know a bit about microcontrollers and assembly language.

MicroPython includes an inline assembler. It allows you to write assembly routines as a Python function, and you can call them as you would a normal Python function.

3.10.1 Returning a value

Inline assembler functions are denoted by a special function decorator. Let's start with the simplest example:

```
@micropython.asm_thumb
def fun():
    movw(r0, 42)
```

You can enter this in a script or at the REPL. This function takes no arguments and returns the number 42. `r0` is a register, and the value in this register when the function returns is the value that is returned. MicroPython always interprets the `r0` as an integer, and converts it to an integer object for the caller.

If you run `print(fun())` you will see it print out 42.

3.10.2 Accessing peripherals

For something a bit more complicated, let's turn on an LED:

```
@micropython.asm_thumb
def led_on():
    movwt(r0, stm.GPIOA)
    movw(r1, 1 << 13)
    strh(r1, [r0, stm.GPIO_BSRRL])
```

This code uses a few new concepts:

- `stm` is a module which provides a set of constants for easy access to the registers of the pyboard's microcontroller. Try running `import stm` and then `help(stm)` at the REPL. It will give you a list of all the available constants.
- `stm.GPIOA` is the address in memory of the GPIOA peripheral. On the pyboard, the red LED is on port A, pin PA13.
- `movwt` moves a 32-bit number into a register. It is a convenience function that turns into 2 thumb instructions: `movw` followed by `movt`. The `movt` also shifts the immediate value right by 16 bits.

- `strh` stores a half-word (16 bits). The instruction above stores the lower 16-bits of `r1` into the memory location `r0 + stm.GPIO_BSRRL`. This has the effect of setting high all those pins on port A for which the corresponding bit in `r0` is set. In our example above, the 13th bit in `r0` is set, so PA13 is pulled high. This turns on the red LED.

3.10.3 Accepting arguments

Inline assembler functions can accept up to 4 arguments. If they are used, they must be named `r0`, `r1`, `r2` and `r3` to reflect the registers and the calling conventions.

Here is a function that adds its arguments:

```
@micropython.asm_thumb
def asm_add(r0, r1):
    add(r0, r0, r1)
```

This performs the computation `r0 = r0 + r1`. Since the result is put in `r0`, that is what is returned. Try `asm_add(1, 2)`, it should return 3.

3.10.4 Loops

We can assign labels with `label(my_label)`, and branch to them using `b(my_label)`, or a conditional branch like `bgt(my_label)`.

The following example flashes the green LED. It flashes it `r0` times.

```
@micropython.asm_thumb
def flash_led(r0):
    # get the GPIOA address in r1
    movwt(r1, stm.GPIOA)

    # get the bit mask for PA14 (the pin LED #2 is on)
    movw(r2, 1 << 14)

    b(loop_entry)

    label(loop1)

    # turn LED on
    strh(r2, [r1, stm.GPIO_BSRRL])

    # delay for a bit
    movwt(r4, 5599900)
    label(delay_on)
    sub(r4, r4, 1)
    cmp(r4, 0)
    bgt(delay_on)

    # turn LED off
    strh(r2, [r1, stm.GPIO_BSRRH])

    # delay for a bit
    movwt(r4, 5599900)
    label(delay_off)
    sub(r4, r4, 1)
    cmp(r4, 0)
    bgt(delay_off)
```

```
    # loop r0 times
    sub(r0, r0, 1)
    label(loop_entry)
    cmp(r0, 0)
    bgt(loop1)
```

3.10.5 Further reading

For further information about supported instructions of the inline assembler, see the *reference documentation*.

3.11 Power control

pyb.wfi() is used to reduce power consumption while waiting for an event such as an interrupt. You would use it in the following situation:

```
while True:
    do_some_processing()
    pyb.wfi()
```

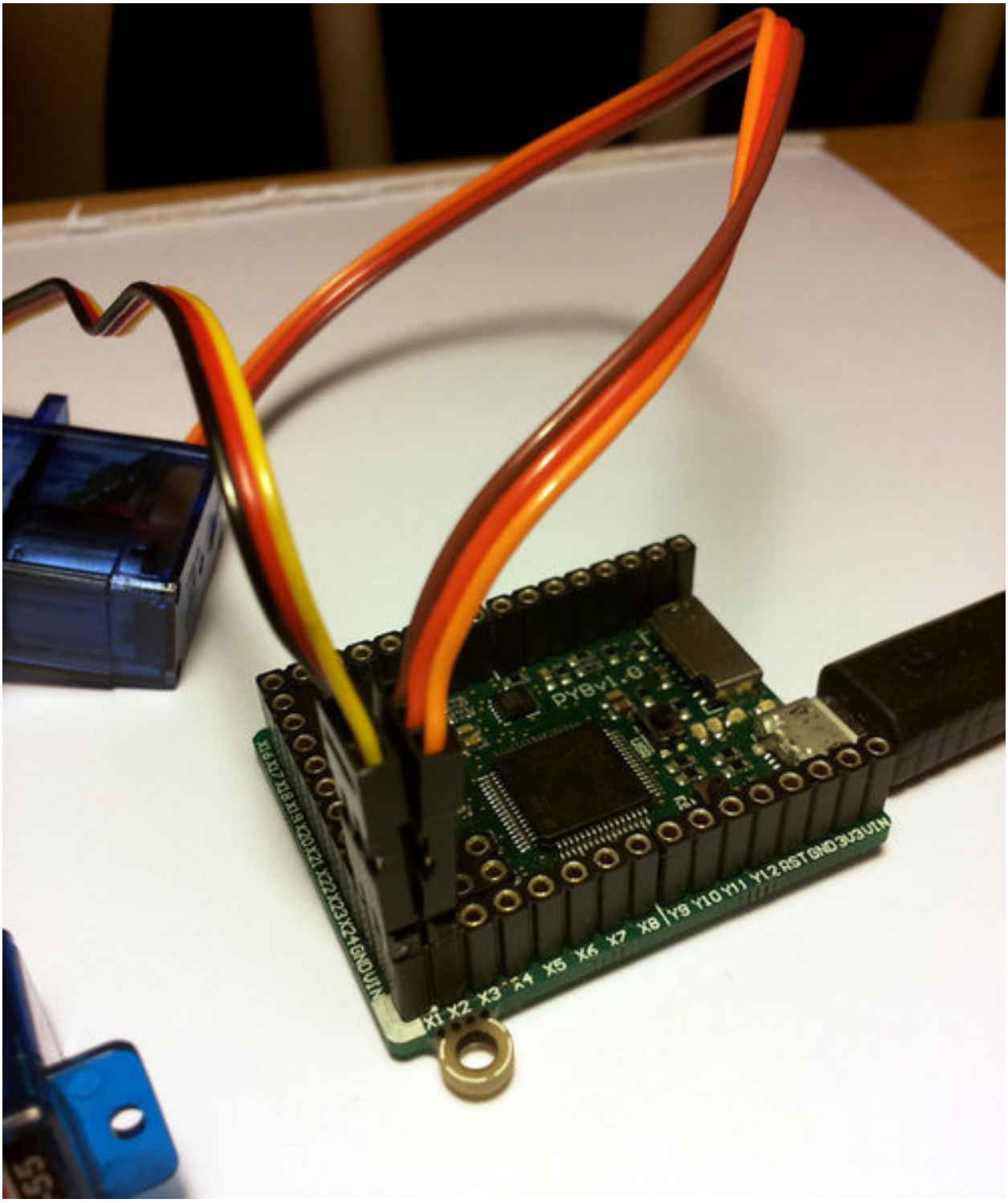
Control the frequency using *pyb.freq()*:

```
pyb.freq(30000000) # set CPU frequency to 30MHz
```

3.12 Tutorials requiring extra components

3.12.1 Controlling hobby servo motors

There are 4 dedicated connection points on the pyboard for connecting up hobby servo motors (see eg [Wikipedia](http://en.wikipedia.org/wiki/Servo_%28radio_control%29)). These motors have 3 wires: ground, power and signal. On the pyboard you can connect them in the bottom right corner, with the signal pin on the far right. Pins X1, X2, X3 and X4 are the 4 dedicated servo signal pins.



In this picture there are male-male double adaptors to connect the servos to the header pins on the pyboard.

The ground wire on a servo is usually the darkest coloured one, either black or dark brown. The power wire will most likely be red.

The power pin for the servos (labelled VIN) is connected directly to the input power source of the pyboard. When powered via USB, VIN is powered through a diode by the 5V USB power line. Connect to USB, the pyboard can power at least 4 small to medium sized servo motors.

If using a battery to power the pyboard and run servo motors, make sure it is not greater than 6V, since this is the maximum voltage most servo motors can take. (Some motors take only up to 4.8V, so check what type you are using.)

Creating a Servo object

Plug in a servo to position 1 (the one with pin X1) and create a servo object using:

```
>>> servo1 = pyb.Servo(1)
```

To change the angle of the servo use the `angle` method:

```
>>> servo1.angle(45)
>>> servo1.angle(-60)
```

The angle here is measured in degrees, and ranges from about -90 to +90, depending on the motor. Calling `angle` without parameters will return the current angle:

```
>>> servo1.angle()
-60
```

Note that for some angles, the returned angle is not exactly the same as the angle you set, due to rounding errors in setting the pulse width.

You can pass a second parameter to the `angle` method, which specifies how long to take (in milliseconds) to reach the desired angle. For example, to take 1 second (1000 milliseconds) to go from the current position to 50 degrees, use

```
>>> servo1.angle(50, 1000)
```

This command will return straight away and the servo will continue to move to the desired angle, and stop when it gets there. You can use this feature as a speed control, or to synchronise 2 or more servo motors. If we have another servo motor (`servo2 = pyb.Servo(2)`) then we can do

```
>>> servo1.angle(-45, 2000); servo2.angle(60, 2000)
```

This will move the servos together, making them both take 2 seconds to reach their final angles.

Note: the semicolon between the 2 expressions above is used so that they are executed one after the other when you press enter at the REPL prompt. In a script you don't need to do this, you can just write them one line after the other.

Continuous rotation servos

So far we have been using standard servos that move to a specific angle and stay at that angle. These servo motors are useful to create joints of a robot, or things like pan-tilt mechanisms. Internally, the motor has a variable resistor (potentiometer) which measures the current angle and applies power to the motor proportional to how far it is from the desired angle. The desired angle is set by the width of a high-pulse on the servo signal wire. A pulse width of 1500 microsecond corresponds to the centre position (0 degrees). The pulses are sent at 50 Hz, ie 50 pulses per second.

You can also get **continuous rotation** servo motors which turn continuously clockwise or counterclockwise. The direction and speed of rotation is set by the pulse width on the signal wire. A pulse width of 1500 microseconds corresponds to a stopped motor. A pulse width smaller or larger than this means rotate one way or the other, at a given speed.

On the pyboard, the servo object for a continuous rotation motor is the same as before. In fact, using `angle` you can set the speed. But to make it easier to understand what is intended, there is another method called `speed` which sets the speed:

```
>>> servo1.speed(30)
```

`speed` has the same functionality as `angle`: you can get the speed, set it, and set it with a time to reach the final speed.

```
>>> servo1.speed()
30
>>> servo1.speed(-20)
>>> servo1.speed(0, 2000)
```

The final command above will set the motor to stop, but take 2 seconds to do it. This is essentially a control over the acceleration of the continuous servo.

A servo speed of 100 (or -100) is considered maximum speed, but actually you can go a bit faster than that, depending on the particular motor.

The only difference between the `angle` and `speed` methods (apart from the name) is the way the input numbers (angle or speed) are converted to a pulse width.

Calibration

The conversion from angle or speed to pulse width is done by the servo object using its calibration values. To get the current calibration, use

```
>>> servo1.calibration()
(640, 2420, 1500, 2470, 2200)
```

There are 5 numbers here, which have meaning:

1. Minimum pulse width; the smallest pulse width that the servo accepts.
2. Maximum pulse width; the largest pulse width that the servo accepts.
3. Centre pulse width; the pulse width that puts the servo at 0 degrees or 0 speed.
4. The pulse width corresponding to 90 degrees. This sets the conversion in the method `angle` of angle to pulse width.
5. The pulse width corresponding to a speed of 100. This sets the conversion in the method `speed` of speed to pulse width.

You can recalibrate the servo (change its default values) by using:

```
>>> servo1.calibration(700, 2400, 1510, 2500, 2000)
```

Of course, you would change the above values to suit your particular servo motor.

3.12.2 Fading LEDs

In addition to turning LEDs on and off, it is also possible to control the brightness of an LED using Pulse-Width Modulation (PWM), a common technique for obtaining variable output from a digital pin. This allows us to fade an LED:

Components

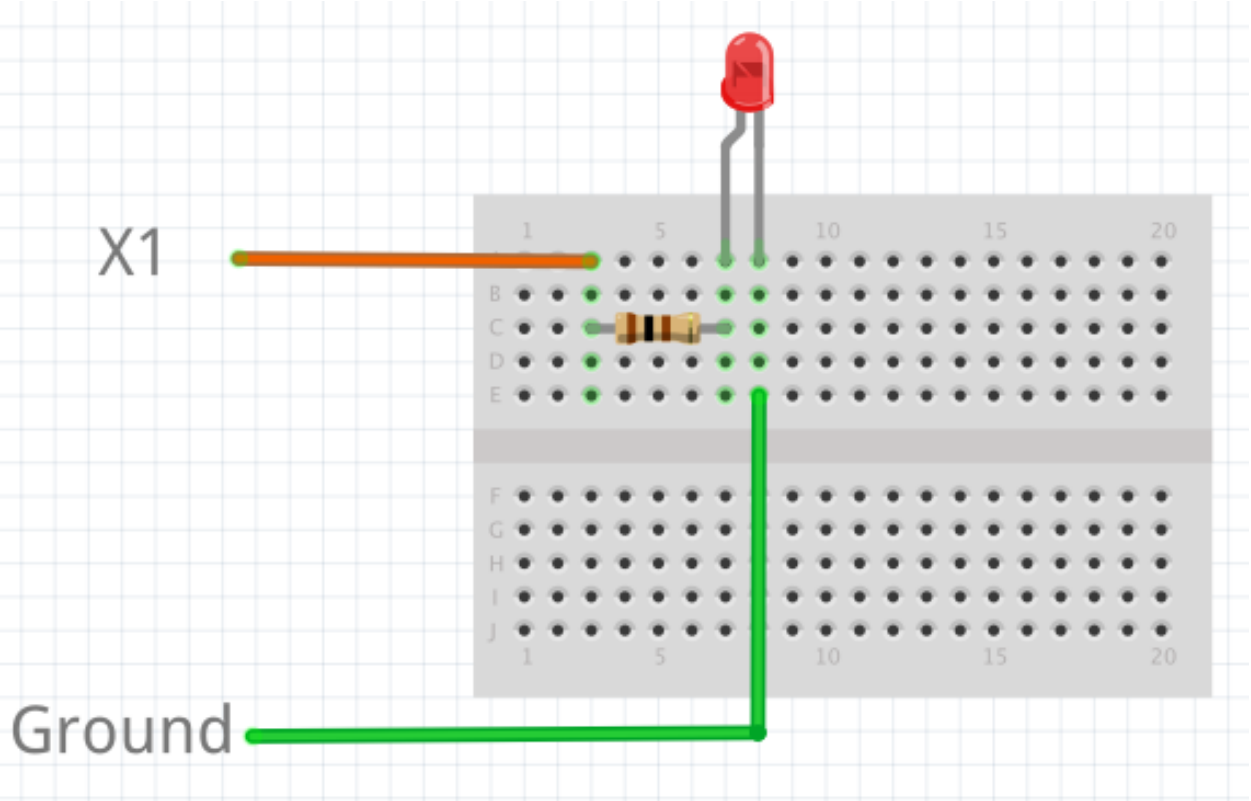
You will need:

- Standard 5 or 3 mm LED
- 100 Ohm resistor

- Wires
- Breadboard (optional, but makes things easier)

Connecting Things Up

For this tutorial, we will use the `X1` pin. Connect one end of the resistor to `X1`, and the other end to the **anode** of the LED, which is the longer leg. Connect the **cathode** of the LED to ground.



Code

By examining the *Quick reference for the pyboard*, we see that `X1` is connected to channel 1 of timer 5 (`TIM5 CH1`). Therefore we will first create a `Timer` object for timer 5, then create a `TimerChannel` object for channel 1:

```
from pyb import Timer
from time import sleep

# timer 5 will be created with a frequency of 100 Hz
tim = pyb.Timer(5, freq=100)
tchannel = tim.channel(1, Timer.PWM, pin=pyb.Pin.board.X1, pulse_width=0)
```

Brightness of the LED in PWM is controlled by controlling the pulse-width, that is the amount of time the LED is on every cycle. With a timer frequency of 100 Hz, each cycle takes 0.01 second, or 10 ms.

To achieve the fading effect shown at the beginning of this tutorial, we want to set the pulse-width to a small value, then slowly increase the pulse-width to brighten the LED, and start over when we reach some maximum brightness:

```
# maximum and minimum pulse-width, which corresponds to maximum
# and minimum brightness
max_width = 200000
```

```
min_width = 20000

# how much to change the pulse-width by each step
wstep = 1500
cur_width = min_width

while True:
  tchannel.pulse_width(cur_width)

  # this determines how often we change the pulse-width. It is
  # analogous to frames-per-second
  sleep(0.01)

  cur_width += wstep

  if cur_width > max_width:
    cur_width = min_width
```

Breathing Effect

If we want to have a breathing effect, where the LED fades from dim to bright then bright to dim, then we simply need to reverse the sign of `wstep` when we reach maximum brightness, and reverse it again at minimum brightness. To do this we modify the `while` loop to be:

```
while True:
  tchannel.pulse_width(cur_width)

  sleep(0.01)

  cur_width += wstep

  if cur_width > max_width:
    cur_width = max_width
    wstep *= -1
  elif cur_width < min_width:
    cur_width = min_width
    wstep *= -1
```

Advanced Exercise

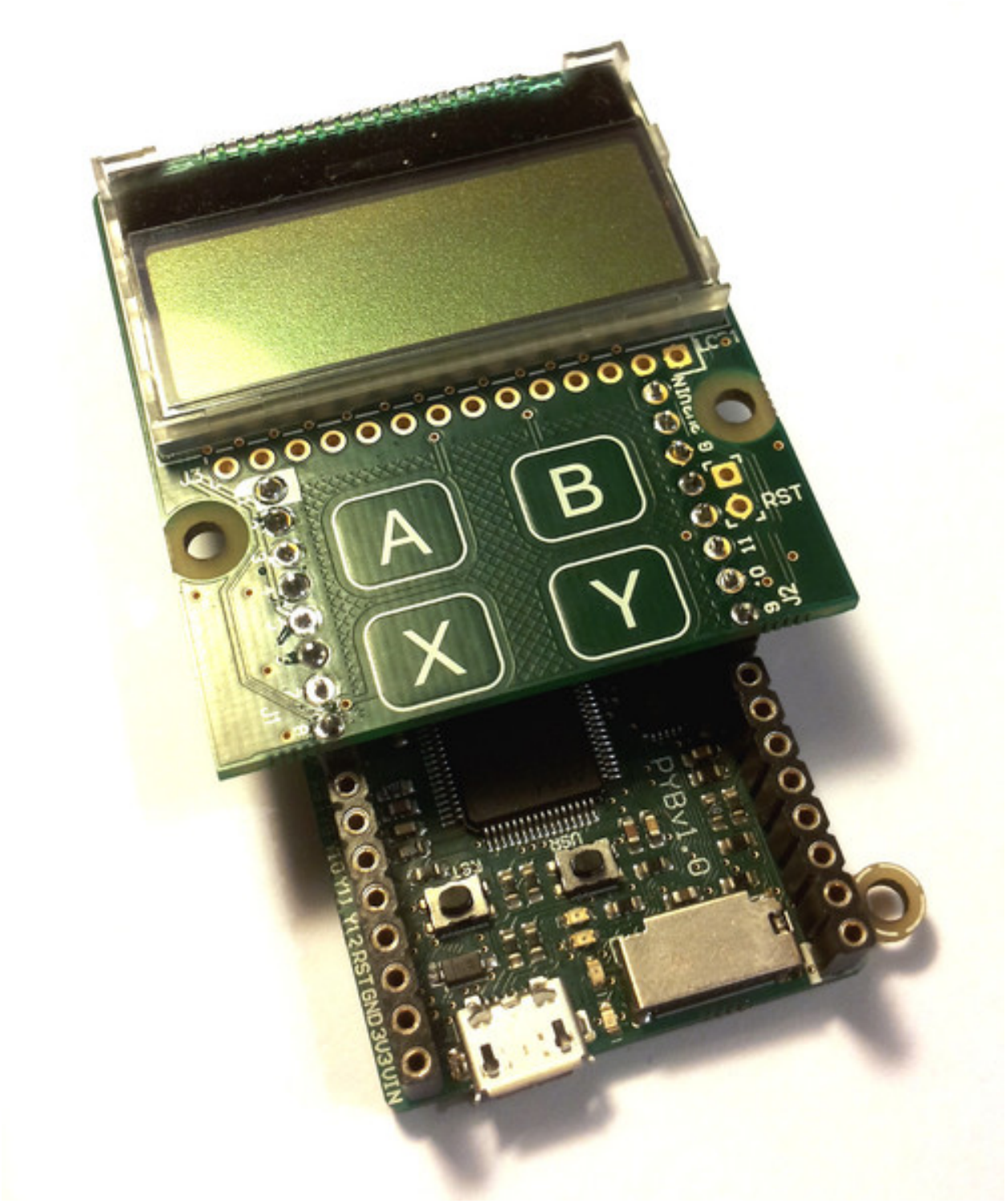
You may have noticed that the LED brightness seems to fade slowly, but increases quickly. This is because our eyes interprets brightness logarithmically (Weber's Law), while the LED's brightness changes linearly, that is by the same amount each time. How do you solve this problem? (Hint: what is the opposite of the logarithmic function?)

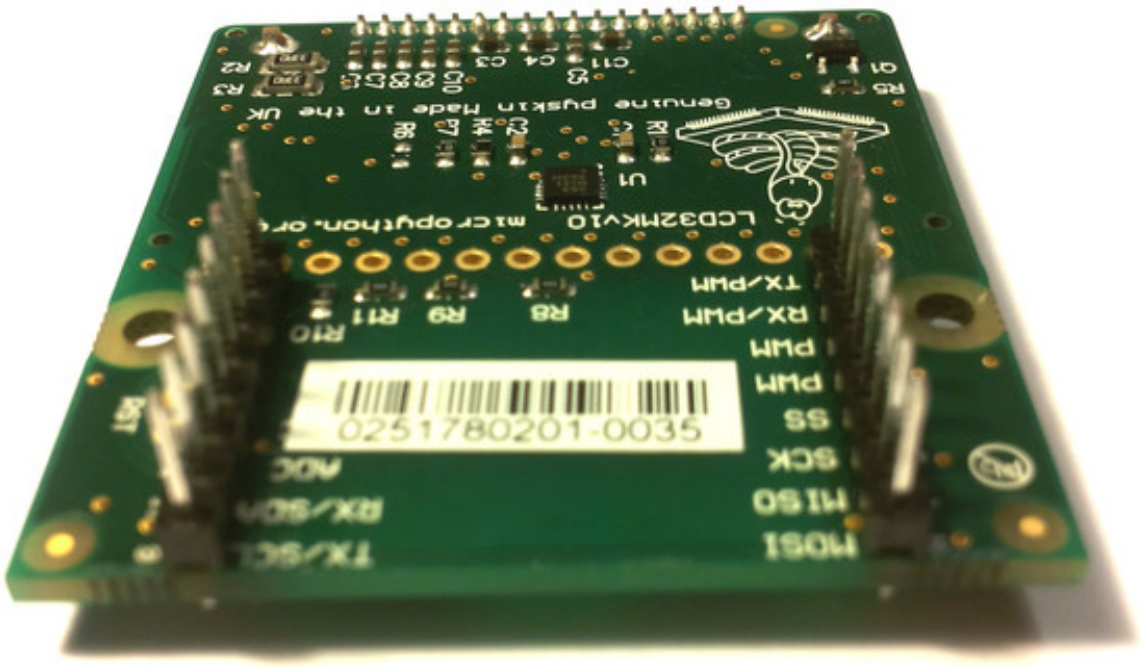
Addendum

We could have also used the digital-to-analog converter (DAC) to achieve the same effect. The PWM method has the advantage that it drives the LED with the same current each time, but for different lengths of time. This allows better control over the brightness, because LEDs do not necessarily exhibit a linear relationship between the driving current and brightness.

3.12.3 The LCD and touch-sensor skin

Soldering and using the LCD and touch-sensor skin.





The following video shows how to solder the headers onto the LCD skin. At the end of the video, it shows you how to correctly connect the LCD skin to the pyboard.

For circuit schematics and datasheets for the components on the skin see *The pyboard hardware*.

Using the LCD

To get started using the LCD, try the following at the MicroPython prompt. Make sure the LCD skin is attached to the pyboard as pictured at the top of this page.

```
>>> import pyb
>>> lcd = pyb.LCD('X')
>>> lcd.light(True)
>>> lcd.write('Hello uPy!\n')
```

You can make a simple animation using the code:

```
import pyb
lcd = pyb.LCD('X')
lcd.light(True)
for x in range(-80, 128):
    lcd.fill(0)
    lcd.text('Hello uPy!', x, 10, 1)
    lcd.show()
    pyb.delay(25)
```

Using the touch sensor

To read the touch-sensor data you need to use the I2C bus. The MPR121 capacitive touch sensor has address 90.

To get started, try:

```
>>> import pyb
>>> i2c = pyb.I2C(1, pyb.I2C.MASTER)
>>> i2c.mem_write(4, 90, 0x5e)
>>> touch = i2c.mem_read(1, 90, 0)[0]
```

The first line above makes an I2C object, and the second line enables the 4 touch sensors. The third line reads the touch status and the `touch` variable holds the state of the 4 touch buttons (A, B, X, Y).

There is a simple driver here which allows you to set the threshold and debounce parameters, and easily read the touch status and electrode voltage levels. Copy this script to your pyboard (either flash or SD card, in the top directory or `lib/` directory) and then try:

```
>>> import pyb
>>> import mpr121
>>> m = mpr121.MPR121(pyb.I2C(1, pyb.I2C.MASTER))
>>> for i in range(100):
...   print(m.touch_status())
...   pyb.delay(100)
...
```

This will continuously print out the touch status of all electrodes. Try touching each one in turn.

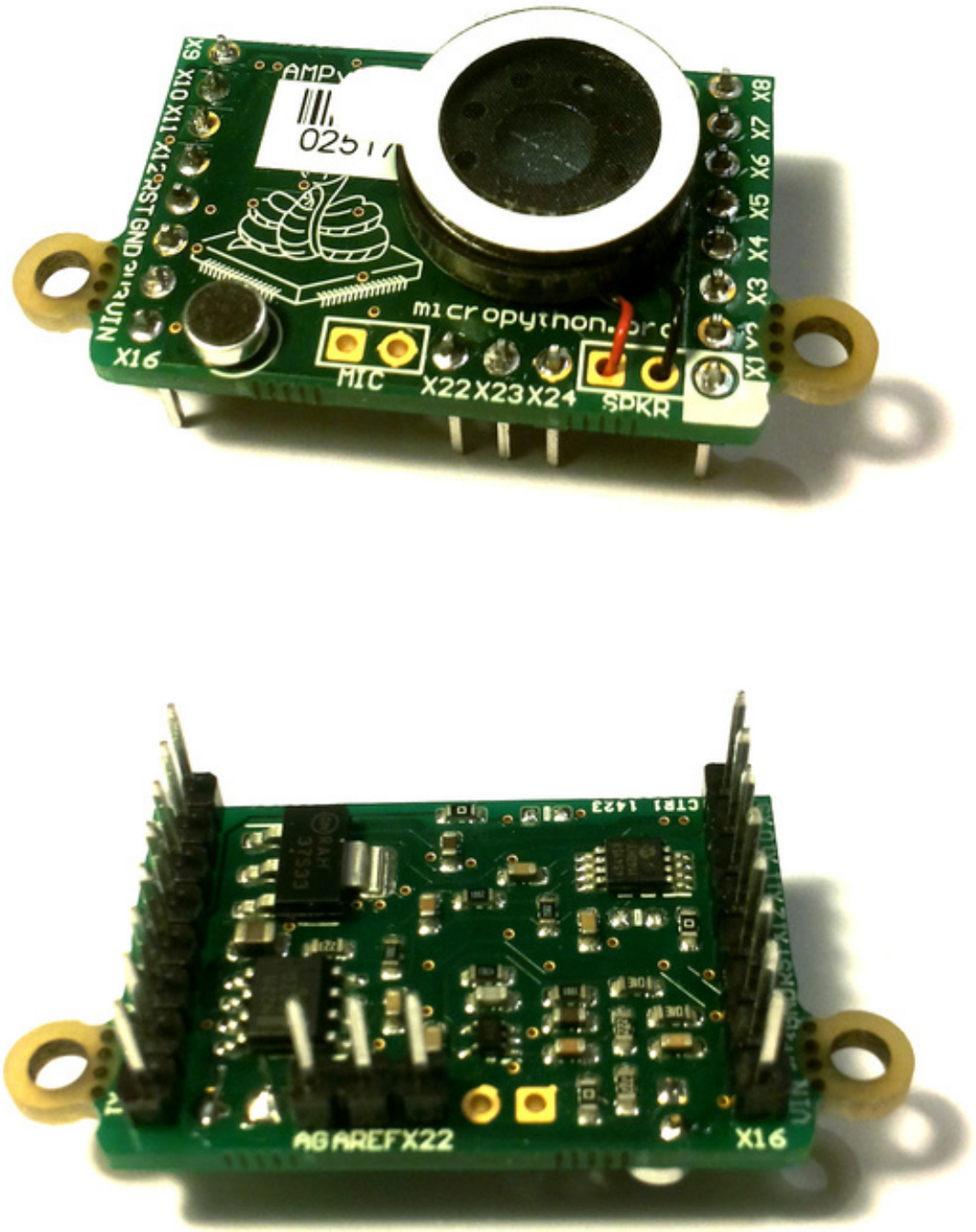
Note that if you put the LCD skin in the Y-position, then you need to initialise the I2C bus using:

```
>>> m = mpr121.MPR121(pyb.I2C(2, pyb.I2C.MASTER))
```

There is also a demo which uses the LCD and the touch sensors together, and can be found here.

3.12.4 The AMP audio skin

Soldering and using the AMP audio skin.



The following video shows how to solder the headers, microphone and speaker onto the AMP skin.

For circuit schematics and datasheets for the components on the skin see *The pyboard hardware*.

Example code

The AMP skin has a speaker which is connected to `DAC(1)` via a small power amplifier. The volume of the amplifier is controlled by a digital potentiometer, which is an I2C device with address 46 on the `IC2(1)` bus.

To set the volume, define the following function:

```
import pyb
def volume(val):
    pyb.I2C(1, pyb.I2C.MASTER).mem_write(val, 46, 0)
```

Then you can do:

```
>>> volume(0)    # minimum volume
>>> volume(127)  # maximum volume
```

To play a sound, use the `write_timed` method of the `DAC` object. For example:

```
import math
from pyb import DAC

# create a buffer containing a sine-wave
buf = bytearray(100)
for i in range(len(buf)):
    buf[i] = 128 + int(127 * math.sin(2 * math.pi * i / len(buf)))

# output the sine-wave at 400Hz
dac = DAC(1)
dac.write_timed(buf, 400 * len(buf), mode=DAC.CIRCULAR)
```

You can also play WAV files using the Python `wave` module. You can get the wave module here and you will also need the chunk module available here. Put these on your pyboard (either on the flash or the SD card in the top-level directory). You will need an 8-bit WAV file to play, such as this one, or to convert any file you have with the command:

```
avconv -i original.wav -ar 22050 -codec pcm_u8 test.wav
```

Then you can do:

```
>>> import wave
>>> from pyb import DAC
>>> dac = DAC(1)
>>> f = wave.open('test.wav')
>>> dac.write_timed(f.readframes(f.getnframes()), f.getframerate())
```

This should play the WAV file.

3.13 Tips, tricks and useful things to know

3.13.1 Debouncing a pin input

A pin used as input from a switch or other mechanical device can have a lot of noise on it, rapidly changing from low to high when the switch is first pressed or released. This noise can be eliminated using a capacitor (a debouncing circuit). It can also be eliminated using a simple function that makes sure the value on the pin is stable.

The following function does just this. It gets the current value of the given pin, and then waits for the value to change. The new pin value must be stable for a continuous 20ms for it to register the change. You can adjust this time (to say 50ms) if you still have noise.

```
import pyb

def wait_pin_change(pin):
    # wait for pin to change value
    # it needs to be stable for a continuous 20ms
    cur_value = pin.value()
    active = 0
    while active < 20:
        if pin.value() != cur_value:
            active += 1
        else:
            active = 0
        pyb.delay(1)
```

Use it something like this:

```
import pyb

pin_x1 = pyb.Pin('X1', pyb.Pin.IN, pyb.Pin.PULL_DOWN)
while True:
    wait_pin_change(pin_x1)
    pyb.LED(4).toggle()
```

3.13.2 Making a UART - USB pass through

It's as simple as:

```
import pyb
import select

def pass_through(usb, uart):
    usb.setinterrupt(-1)
    while True:
        select.select([usb, uart], [], [])
        if usb.any():
            uart.write(usb.read(256))
        if uart.any():
            usb.write(uart.read(256))

pass_through(pyb.USB_VCP(), pyb.UART(1, 9600))
```

CHAPTER 4

MicroPython libraries

The following standard Python libraries are built in to MicroPython.

For additional libraries, please download them from the micropython-lib repository.

4.1 Python standard libraries and micro-libraries

The following standard Python libraries have been "micro-ified" to fit in with the philosophy of MicroPython. They provide the core functionality of that module and are intended to be a drop-in replacement for the standard Python library.

The modules are available by their u-name, and also by their non-u-name. The non-u-name can be overridden by a file of that name in your package path. For example, `import json` will first search for a file `json.py` or directory `json` and load that package if it is found. If nothing is found, it will fallback to loading the built-in `ujson` module.

4.2 MicroPython-specific libraries

Functionality specific to the MicroPython implementation is available in the following libraries.

4.2.1 `machine` — functions related to the board

The `machine` module contains specific functions related to the board.

Reset related functions

`machine.`**`reset`**`()`
Resets the device in a manner similar to pushing the external RESET button.

`machine.`**`reset_cause`**`()`
Get the reset cause. See *constants* for the possible return values.

Power related functions

`machine.`**`freq`**`()`
Returns CPU frequency in hertz.

machine.**idle**()
: Gates the clock to the CPU, useful to reduce power consumption at any time during short or long periods. Peripherals continue working and execution resumes as soon as any interrupt is triggered (on many ports this includes system timer interrupt occuring at regular intervals on the order of millisecond).

machine.**sleep**()
: Stops the CPU and disables all peripherals except for WLAN. Execution is resumed from the point where the sleep was requested. For wake up to actually happen, wake sources should be configured first.

machine.**deepsleep**()
: Stops the CPU and all peripherals (including networking interfaces, if any). Execution is resumed from the main script, just as with a reset. The reset cause can be checked to know that we are coming from `machine.DEEPSLEEP`. For wake up to actually happen, wake sources should be configured first, like `Pin` change or `RTC` timeout.

Miscellaneous functions

machine.**unique_id**()
: Returns a byte string with a unique idenifier of a board/SoC. It will vary from a board/SoC instance to another, if underlying hardware allows. Length varies by hardware (so use substring of a full value if you expect a short ID). In some MicroPython ports, ID corresponds to the network MAC address.

Constants

machine.**IDLE**

machine.**SLEEP**

machine.**DEEPSLEEP**
: irq wake values

machine.**POWER_ON**

machine.**HARD_RESET**

machine.**WDT_RESET**

machine.**DEEPSLEEP_RESET**

machine.**SOFT_RESET**
: reset causes

machine.**WLAN_WAKE**

machine.**PIN_WAKE**

machine.**RTC_WAKE**
: wake reasons

Classes

class ADC – analog to digital conversion

Usage:

```
import machine

adc = machine.ADC()             # create an ADC object
apin = adc.channel(pin='GP3')   # create an analog pin on GP3
val = apin()                    # read an analog value
```

Constructors

class machine.**ADC**(*id=0*, ***, *bits=12*)

Create an ADC object associated with the given pin. This allows you to then read analog values on that pin. For more info check the pinout and alternate functions table.

> **Warning:** ADC pin input range is 0-1.4V (being 1.8V the absolute maximum that it can withstand). When GP2, GP3, GP4 or GP5 are remapped to the ADC block, 1.8 V is the maximum. If these pins are used in digital mode, then the maximum allowed input is 3.6V.

Methods

adc.**channel**(*id*, ***, *pin*)

Create an analog pin. If only channel ID is given, the correct pin will be selected. Alternatively, only the pin can be passed and the correct channel will be selected. Examples:

```
    # all of these are equivalent and enable ADC channel 1 on GP3
    apin = adc.channel(1)
    apin = adc.channel(pin='GP3')
    apin = adc.channel(id=1, pin='GP3')
```

adc.**init**()

Enable the ADC block.

adc.**deinit**()

Disable the ADC block.

class ADCChannel — read analog values from internal or external sources

ADC channels can be connected to internal points of the MCU or to GPIO pins. ADC channels are created using the ADC.channel method.

adcchannel()

Fast method to read the channel value.

adcchannel.**value**()

Read the channel value.

adcchannel.**init**()

Re-init (and effectively enable) the ADC channel.

adcchannel.**deinit**()

Disable the ADC channel.

class I2C – a two-wire serial protocol

I2C is a two-wire protocol for communicating between devices. At the physical level it consists of 2 wires: SCL and SDA, the clock and data lines respectively.

I2C objects are created attached to a specific bus. They can be initialised when created, or initialised later on.

Printing the i2c object gives you information about its configuration.

Constructors

General Methods

i2c.**deinit**()
Turn off the I2C bus.

Availability: WiPy.

i2c.**scan**()
Scan all I2C addresses between 0x08 and 0x77 inclusive and return a list of those that respond. A device responds if it pulls the SDA line low after its address (including a read bit) is sent on the bus.

Note: on WiPy the I2C object must be in master mode for this method to be valid.

Primitive I2C operations The following methods implement the primitive I2C master bus operations and can be combined to make any I2C transaction. They are provided if you need more control over the bus, otherwise the standard methods (see below) can be used.

i2c.**start**()
Send a start bit on the bus (SDA transitions to low while SCL is high).

Availability: ESP8266.

i2c.**stop**()
Send a stop bit on the bus (SDA transitions to high while SCL is high).

Availability: ESP8266.

i2c.**readinto**(*buf*)
Reads bytes from the bus and stores them into *buf*. The number of bytes read is the length of *buf*. An ACK will be sent on the bus after receiving all but the last byte, and a NACK will be sent following the last byte.

Availability: ESP8266.

i2c.**write**(*buf*)
Write all the bytes from *buf* to the bus. Checks that an ACK is received after each byte and raises an OSError if not.

Availability: ESP8266.

Standard bus operations The following methods implement the standard I2C master read and write operations that target a given slave device.

i2c.**readfrom**(*addr*, *nbytes*)
Read *nbytes* from the slave specified by *addr*. Returns a *bytes* object with the data read.

i2c.**readfrom_into**(*addr*, *buf*)
Read into *buf* from the slave specified by *addr*. The number of bytes read will be the length of *buf*.

On WiPy the return value is the number of bytes read. Otherwise the return value is *None*.

i2c.**writeto**(*addr*, *buf*, *, *stop=True*)
Write the bytes from *buf* to the slave specified by *addr*.

The *stop* argument (only available on WiPy) tells if a stop bit should be sent at the end of the transfer. If *False* the transfer should be continued later on.

On WiPy the return value is the number of bytes written. Otherwise the return value is *None*.

Memory operations Some I2C devices act as a memory device (or set of registers) that can be read from and written to. In this case there are two addresses associated with an I2C transaction: the slave address and the memory address. The following methods are convenience functions to communicate with such devices.

`i2c.`**`readfrom_mem`**(*addr*, *memaddr*, *nbytes*, ***, *addrsize=8*)
Read *nbytes* from the slave specified by *addr* starting from the memory address specified by *memaddr*. The argument *addrsize* specifies the address size in bits (on ESP8266 this argument is not recognised and the address size is always 8 bits). Returns a *bytes* object with the data read.

`i2c.`**`readfrom_mem_into`**(*addr*, *memaddr*, *buf*, ***, *addrsize=8*)
Read into *buf* from the slave specified by *addr* starting from the memory address specified by *memaddr*. The number of bytes read is the length of *buf*. The argument *addrsize* specifies the address size in bits (on ESP8266 this argument is not recognised and the address size is always 8 bits).

On WiPy the return value is the number of bytes read. Otherwise the return value is *None*.

`i2c.`**`writeto_mem`**(*addr*, *memaddr*, *buf*, ***, *addrsize=8*)
Write *buf* to the slave specified by *addr* starting from the memory address specified by *memaddr*. The argument *addrsize* specifies the address size in bits (on ESP8266 this argument is not recognised and the address size is always 8 bits).

On WiPy the return value is the number of bytes written. Otherwise the return value is *None*.

Constants

`I2C.`**`MASTER`**
for initialising the bus to master mode

Availability: WiPy.

class Pin – control I/O pins

A pin is the basic object to control I/O pins. It has methods to set the mode of the pin (input, output, etc) and methods to get and set the digital logic level. For analog control of a pin, see the ADC class.

Usage Model:

Constructors

class `machine.`**`Pin`**(*id*, *...*)
Create a new Pin object associated with the id. If additional arguments are given, they are used to initialise the pin. See *pin.init()*.

Methods

`pin.`**`value`**([*value*])
Get or set the digital logic level of the pin:

- With no argument, return 0 or 1 depending on the logic level of the pin.
- With `value` given, set the logic level of the pin. `value` can be anything that converts to a boolean. If it converts to `True`, the pin is set high, otherwise it is set low.

`pin`([*value*])
Pin objects are callable. The call method provides a (fast) shortcut to set and get the value of the pin. See **pin.value** for more details.

`pin.`**`alt_list`**()
Returns a list of the alternate functions supported by the pin. List items are a tuple of the form: `('ALT_FUN_NAME', ALT_FUN_INDEX)`

Availability: WiPy.

Attributes

class `Pin.`**`board`**

Contains all `Pin` objects supported by the board. Examples:

```
Pin.board.GP25
led = Pin(Pin.board.GP25, mode=Pin.OUT)
Pin.board.GP2.alt_list()
```

Availability: WiPy.

Constants The following constants are used to configure the pin objects. Note that not all constants are available on all ports.

`IN`
`OUT`
`OPEN_DRAIN`
`ALT`
`ALT_OPEN_DRAIN`

Selects the pin mode.

`PULL_UP`
`PULL_DOWN`

Selects the whether there is a pull up/down resistor.

`LOW_POWER`
`MED_POWER`
`HIGH_POWER`

Selects the pin drive strength.

`IRQ_FALLING`
`IRQ_RISING`
`IRQ_LOW_LEVEL`
`IRQ_HIGH_LEVEL`

Selects the IRQ trigger type.

class RTC – real time clock

The RTC is and independent clock that keeps track of the date and time.

Example usage:

```
rtc = machine.RTC()
rtc.init((2014, 5, 1, 4, 13, 0, 0, 0))
print(rtc.now())
```

Constructors

class `machine.`**`RTC`**(*id=0, ...*)

Create an RTC object. See init for parameters of initialization.

Methods

`rtc.`**`init`**(*datetime*)

Initialise the RTC. Datetime is a tuple of the form:

(year, month, day[, hour[, minute[, second[, microsecond[, tzinfo]]]]])

rtc.**now**()
Get get the current datetime tuple.

rtc.**deinit**()
Resets the RTC to the time of January 1, 2015 and starts running it again.

rtc.**alarm**(*id*, *time*, */*, *repeat=False*)
Set the RTC alarm. Time might be either a millisecond value to program the alarm to current time + time_in_ms in the future, or a datetimetuple. If the time passed is in milliseconds, repeat can be set to `True` to make the alarm periodic.

rtc.**alarm_left**(*alarm_id=0*)
Get the number of milliseconds left before the alarm expires.

rtc.**cancel**(*alarm_id=0*)
Cancel a running alarm.

rtc.**irq**(*, *trigger*, *handler=None*, *wake=machine.IDLE*)
Create an irq object triggered by a real time clock alarm.

- `trigger` must be `RTC.ALARM0`
- `handler` is the function to be called when the callback is triggered.
- `wake` specifies the sleep mode from where this interrupt can wake up the system.

Constants

RTC.**ALARM0**
irq trigger source

class SD – secure digital memory card

The SD card class allows to configure and enable the memory card module of the WiPy and automatically mount it as `/sd` as part of the file system. There are several pin combinations that can be used to wire the SD card socket to the WiPy and the pins used can be specified in the constructor. Please check the pinout and alternate functions table. for more info regarding the pins which can be remapped to be used with a SD card.

Example usage:

```
from machine import SD
import os
# clk cmd and dat0 pins must be passed along with
# their respective alternate functions
sd = machine.SD(pins=('GP10', 'GP11', 'GP15'))
os.mount(sd, '/sd')
# do normal file operations
```

Constructors

class machine.**SD**(*id*, ...)
Create a SD card object. See `init()` for parameters if initialization.

Methods

sd.**init**(*id=0*, *pins=('GP10', 'GP11', 'GP15')*)
Enable the SD card. In order to initalize the card, give it a 3-tuple: `(clk_pin, cmd_pin, dat0_pin)`.

sd.**deinit**()
Disable the SD card.

class SPI – a master-driven serial protocol

SPI is a serial protocol that is driven by a master. At the physical level there are 3 lines: SCK, MOSI, MISO.

Constructors

Methods

spi.**init**(*mode*, *baudrate=1000000*, ***, *polarity=0*, *phase=0*, *bits=8*, *firstbit=SPI.MSB*, *pins=(CLK*, *MOSI*, *MISO)*)
Initialise the SPI bus with the given parameters:

- `mode` must be `SPI.MASTER`.
- `baudrate` is the SCK clock rate.
- `polarity` can be 0 or 1, and is the level the idle clock line sits at.
- `phase` can be 0 or 1 to sample data on the first or second clock edge respectively.
- `bits` is the width of each transfer, accepted values are 8, 16 and 32.
- `firstbit` can be `SPI.MSB` only.
- `pins` is an optional tupple with the pins to assign to the SPI bus.

spi.**deinit**()
Turn off the SPI bus.

spi.**write**(*buf*)
Write the data contained in `buf`. Returns the number of bytes written.

spi.**read**(*nbytes*, ***, *write=0x00*)
Read the `nbytes` while writing the data specified by `write`. Return the number of bytes read.

spi.**readinto**(*buf*, ***, *write=0x00*)
Read into the buffer specified by `buf` while writing the data specified by `write`. Return the number of bytes read.

spi.**write_readinto**(*write_buf*, *read_buf*)
Write from `write_buf` and read into `read_buf`. Both buffers must have the same length. Returns the number of bytes written

Constants

SPI.**MASTER**
for initialising the SPI bus to master

SPI.**MSB**
set the first bit to be the most significant bit

class Timer – control internal timers

Note: Memory can't be allocated inside irq handlers (an interrupt) and so exceptions raised within a handler don't give much information. See *micropython.alloc_emergency_exception_buf()* for how to get around this limitation.

Constructors

class machine.**Timer**(*id*, ...)

Methods

timer.**deinit**()

Deinitialises the timer. Disables all channels and associated IRQs. Stops the timer, and disables the timer peripheral.

class TimerChannel — setup a channel for a timer

Timer channels are used to generate/capture a signal using a timer.

TimerChannel objects are created using the Timer.channel() method.

Methods

Constants

Timer.**ONE_SHOT**

Timer.**PERIODIC**

Timer.**PWM**

Selects the timer operating mode.

Timer.**A**

Timer.**B**

Selects the timer channel. Must be ORed (Timer.A | Timer.B) when using a 32-bit timer.

Timer.**POSITIVE**

Timer.**NEGATIVE**

Timer channel polarity selection (only relevant in PWM mode).

Timer.**TIMEOUT**

Timer.**MATCH**

Timer channel IRQ triggers.

class UART – duplex serial communication bus

UART implements the standard UART/USART duplex serial communications protocol. At the physical level it consists of 2 lines: RX and TX. The unit of communication is a character (not to be confused with a string character) which can be 8 or 9 bits wide.

UART objects can be created and initialised using:

```
from machine import UART

uart = UART(1, 9600)                         # init with given baudrate
uart.init(9600, bits=8, parity=None, stop=1) # init with given parameters
```

A UART object acts like a stream object and reading and writing is done using the standard stream methods:

```
uart.read(10)       # read 10 characters, returns a bytes object
uart.readall()      # read all available characters
uart.readline()     # read a line
uart.readinto(buf)  # read and store into the given buffer
uart.write('abc')   # write the 3 characters
```

Constructors

Methods

`uart.`**`deinit`**`()`
Turn off the UART bus.

`uart.`**`any`**`()`
Return the number of characters available for reading.

`uart.`**`read`**`(`[*nbytes*]`)`
Read characters. If `nbytes` is specified then read at most that many bytes.

Return value: a bytes object containing the bytes read in. Returns `None` on timeout.

`uart.`**`readall`**`()`
Read as much data as possible.

Return value: a bytes object or `None` on timeout.

`uart.`**`readinto`**`(`*buf*[, *nbytes*]`)`
Read bytes into the `buf`. If `nbytes` is specified then read at most that many bytes. Otherwise, read at most `len(buf)` bytes.

Return value: number of bytes read and stored into `buf` or `None` on timeout.

`uart.`**`readline`**`()`
Read a line, ending in a newline character.

Return value: the line read or `None` on timeout.

`uart.`**`write`**`(`*buf*`)`
Write the buffer of bytes to the bus.

Return value: number of bytes written or `None` on timeout.

`uart.`**`sendbreak`**`()`
Send a break condition on the bus. This drives the bus low for a duration of 13 bits. Return value: `None`.

Constants

`UART.`**`EVEN`**
`UART.`**`ODD`**
parity types (anlong with `None`)

`UART.`**`RX_ANY`**
IRQ trigger sources

class WDT – watchdog timer

The WDT is used to restart the system when the application crashes and ends up into a non recoverable state. Once started it cannot be stopped or reconfigured in any way. After enabling, the application must "feed" the watchdog periodically to prevent it from expiring and resetting the system.

Example usage:

```
from machine import WDT
wdt = WDT(timeout=2000)  # enable it with a timeout of 2s
wdt.feed()
```

Constructors

class machine.**WDT**(*id=0*, *timeout=5000*)

Create a WDT object and start it. The timeout must be given in seconds and the minimum value that is accepted is 1 second. Once it is running the timeout cannot be changed and the WDT cannot be stopped either.

Methods

wdt.**feed**()

Feed the WDT to prevent it from resetting the system. The application should place this call in a sensible place ensuring that the WDT is only fed after verifying that everything is functioning correctly.

4.2.2 micropython – access and control MicroPython internals

Functions

micropython.**mem_info**([*verbose*])

Print information about currently used memory. If the verbose argument is given then extra information is printed.

The information that is printed is implementation dependent, but currently includes the amount of stack and heap used. In verbose mode it prints out the entire heap indicating which blocks are used and which are free.

micropython.**qstr_info**([*verbose*])

Print information about currently interned strings. If the verbose argument is given then extra information is printed.

The information that is printed is implementation dependent, but currently includes the number of interned strings and the amount of RAM they use. In verbose mode it prints out the names of all RAM-interned strings.

micropython.**alloc_emergency_exception_buf**(*size*)

Allocate size bytes of RAM for the emergency exception buffer (a good size is around 100 bytes). The buffer is used to create exceptions in cases when normal RAM allocation would fail (eg within an interrupt handler) and therefore give useful traceback information in these situations.

A good way to use this function is to put it at the start of your main script (eg boot.py or main.py) and then the emergency exception buffer will be active for all the code following it.

4.2.3 network — network configuration

This module provides network drivers and routing configuration. Network drivers for specific hardware are available within this module and are used to configure a hardware network interface. Configured interfaces are then available for use via the socket module. To use this module the network build of firmware must be installed.

For example:

```
# configure a specific network interface
# see below for examples of specific drivers
import network
nic = network.Driver(...)
print(nic.ifconfig())

# now use socket as usual
import socket
addr = socket.getaddrinfo('micropython.org', 80)[0][-1]
s = socket.socket()
s.connect(addr)
s.send(b'GET / HTTP/1.1\r\nHost: micropython.org\r\n\r\n')
data = s.recv(1000)
s.close()
```

class CC3K

This class provides a driver for CC3000 wifi modules. Example usage:

```
import network
nic = network.CC3K(pyb.SPI(2), pyb.Pin.board.Y5, pyb.Pin.board.Y4, pyb.Pin.board.Y3)
nic.connect('your-ssid', 'your-password')
while not nic.isconnected():
    pyb.delay(50)
print(nic.ifconfig())

# now use socket as usual
...
```

For this example to work the CC3000 module must have the following connections:

- MOSI connected to Y8
- MISO connected to Y7
- CLK connected to Y6
- CS connected to Y5
- VBEN connected to Y4
- IRQ connected to Y3

It is possible to use other SPI busses and other pins for CS, VBEN and IRQ.

Constructors

class `network.CC3K`(*spi*, *pin_cs*, *pin_en*, *pin_irq*)

Create a CC3K driver object, initialise the CC3000 module using the given SPI bus and pins, and return the CC3K object.

Arguments are:

- `spi` is an *SPI object* which is the SPI bus that the CC3000 is connected to (the MOSI, MISO and CLK pins).
- `pin_cs` is a *Pin object* which is connected to the CC3000 CS pin.

- `pin_en` is a *Pin object* which is connected to the CC3000 VBEN pin.
- `pin_irq` is a *Pin object* which is connected to the CC3000 IRQ pin.

All of these objects will be initialised by the driver, so there is no need to initialise them yourself. For example, you can use:

```
nic = network.CC3K(pyb.SPI(2), pyb.Pin.board.Y5, pyb.Pin.board.Y4, pyb.Pin.board.Y3)
```

Methods

`cc3k.`**`connect`**(*ssid*, *key=None*, ***, *security=WPA2*, *bssid=None*)
Connect to a wifi access point using the given SSID, and other security parameters.

`cc3k.`**`disconnect`**()
Disconnect from the wifi access point.

`cc3k.`**`isconnected`**()
Returns True if connected to a wifi access point and has a valid IP address, False otherwise.

`cc3k.`**`ifconfig`**()
Returns a 7-tuple with (ip, subnet mask, gateway, DNS server, DHCP server, MAC address, SSID).

`cc3k.`**`patch_version`**()
Return the version of the patch program (firmware) on the CC3000.

`cc3k.`**`patch_program`**(*'pgm'*)
Upload the current firmware to the CC3000. You must pass 'pgm' as the first argument in order for the upload to proceed.

Constants

`CC3K.`**`WEP`**

`CC3K.`**`WPA`**

`CC3K.`**`WPA2`**
security type to use

class WIZNET5K

This class allows you to control WIZnet5x00 Ethernet adaptors based on the W5200 and W5500 chipsets (only W5200 tested).

Example usage:

```
import network
nic = network.WIZNET5K(pyb.SPI(1), pyb.Pin.board.X5, pyb.Pin.board.X4)
print(nic.ifconfig())

# now use socket as usual
...
```

For this example to work the WIZnet5x00 module must have the following connections:

- MOSI connected to X8
- MISO connected to X7

- SCLK connected to X6
- nSS connected to X5
- nRESET connected to X4

It is possible to use other SPI busses and other pins for nSS and nRESET.

Constructors

class network.**WIZNET5K**(*spi*, *pin_cs*, *pin_rst*)

Create a WIZNET5K driver object, initialise the WIZnet5x00 module using the given SPI bus and pins, and return the WIZNET5K object.

Arguments are:

- `spi` is an *SPI object* which is the SPI bus that the WIZnet5x00 is connected to (the MOSI, MISO and SCLK pins).
- `pin_cs` is a *Pin object* which is connected to the WIZnet5x00 nSS pin.
- `pin_rst` is a *Pin object* which is connected to the WIZnet5x00 nRESET pin.

All of these objects will be initialised by the driver, so there is no need to initialise them yourself. For example, you can use:

```
nic = network.WIZNET5K(pyb.SPI(1), pyb.Pin.board.X5, pyb.Pin.board.X4)
```

Methods

wiznet5k.**ifconfig**([*(ip*, *subnet*, *gateway*, *dns)*])

Get/set IP address, subnet mask, gateway and DNS.

When called with no arguments, this method returns a 4-tuple with the above information.

To set the above values, pass a 4-tuple with the required information. For example:

```
nic.ifconfig(('192.168.0.4', '255.255.255.0', '192.168.0.1', '8.8.8.8'))
```

wiznet5k.**regs**()

Dump the WIZnet5x00 registers. Useful for debugging.

4.2.4 uctypes – access C structures

This module implements "foreign data interface" for MicroPython. The idea behind it is similar to CPython's `ctypes` modules, but actual API is different, streamlined and optimized for small size.

Defining structure layout

Structure layout is defined by a "descriptor" - a Python dictionary which encodes field names as keys and other properties required to access them as an associated values. Currently, uctypes requires explicit specification of offsets for each field. Offset are given in bytes from structure start.

Following are encoding examples for various field types:

Scalar types:

```
"field_name": uctypes.UINT32 | 0
```

in other words, value is scalar type identifier ORed with field offset (in bytes) from the start of the structure.

Recursive structures:

```
"sub": (2, {
    "b0": uctypes.UINT8 | 0,
    "b1": uctypes.UINT8 | 1,
})
```

i.e. value is a 2-tuple, first element of which is offset, and second is a structure descriptor dictionary (note: offsets in recursive descriptors are relative to a structure it defines).

Arrays of primitive types:

```
"arr": (uctypes.ARRAY | 0, uctypes.UINT8 | 2),
```

i.e. value is a 2-tuple, first element of which is ARRAY flag ORed with offset, and second is scalar element type ORed number of elements in array.

Arrays of aggregate types:

```
"arr2": (uctypes.ARRAY | 0, 2, {"b": uctypes.UINT8 | 0}),
```

i.e. value is a 3-tuple, first element of which is ARRAY flag ORed with offset, second is a number of elements in array, and third is descriptor of element type.

Pointer to a primitive type:

```
"ptr": (uctypes.PTR | 0, uctypes.UINT8),
```

i.e. value is a 2-tuple, first element of which is PTR flag ORed with offset, and second is scalar element type.

Pointer to aggregate type:

```
"ptr2": (uctypes.PTR | 0, {"b": uctypes.UINT8 | 0}),
```

i.e. value is a 2-tuple, first element of which is PTR flag ORed with offset, second is descriptor of type pointed to.

Bitfields:

```
"bitf0": uctypes.BFUINT16 | 0 | 0 << uctypes.BF_POS | 8 << uctypes.BF_LEN,
```

i.e. value is type of scalar value containing given bitfield (typenames are similar to scalar types, but prefixes with "BF"), ORed with offset for scalar value containing the bitfield, and further ORed with values for bit offset and bit length of the bitfield within scalar value, shifted by BF_POS and BF_LEN positions, respectively. Bitfield position is counted from the least significant bit, and is the number of right-most bit of a field (in other words, it's a number of bits a scalar needs to be shifted right to extra the bitfield).

In the example above, first UINT16 value will be extracted at offset 0 (this detail may be important when accessing hardware registers, where particular access size and alignment are required), and then bitfield whose rightmost bit is least-significant bit of this UINT16, and length is 8 bits, will be extracted - effectively, this will access least-significant byte of UINT16.

Note that bitfield operations are independent of target byte endianness, in particular, example above will access least-significant byte of UINT16 in both little- and big-endian structures. But it depends on the

least significant bit being numbered 0. Some targets may use different numbering in their native ABI, but `uctypes` always uses normalized numbering described above.

Module contents

class `uctypes.`**`struct`**(*addr*, *descriptor*, *layout_type=NATIVE*)
Instantiate a "foreign data structure" object based on structure address in memory, descriptor (encoded as a dictionary), and layout type (see below).

`uctypes.`**`LITTLE_ENDIAN`**
Little-endian packed structure. (Packed means that every field occupies exactly as many bytes as defined in the descriptor, i.e. alignment is 1).

`uctypes.`**`BIG_ENDIAN`**
Big-endian packed structure.

`uctypes.`**`NATIVE`**
Native structure - with data endianness and alignment conforming to the ABI of the system on which MicroPython runs.

`uctypes.`**`sizeof`**(*struct*)
Return size of data structure in bytes. Argument can be either structure class or specific instantiated structure object (or its aggregate field).

`uctypes.`**`addressof`**(*obj*)
Return address of an object. Argument should be bytes, bytearray or other object supporting buffer protocol (and address of this buffer is what actually returned).

`uctypes.`**`bytes_at`**(*addr*, *size*)
Capture memory at the given address and size as bytes object. As bytes object is immutable, memory is actually duplicated and copied into bytes object, so if memory contents change later, created object retains original value.

`uctypes.`**`bytearray_at`**(*addr*, *size*)
Capture memory at the given address and size as bytearray object. Unlike bytes_at() function above, memory is captured by reference, so it can be both written too, and you will access current value at the given memory address.

Structure descriptors and instantiating structure objects

Given a structure descriptor dictionary and its layout type, you can instantiate a specific structure instance at a given memory address using uctypes.struct() constructor. Memory address usually comes from following sources:

- Predefined address, when accessing hardware registers on a baremetal system. Lookup these addresses in datasheet for a particular MCU/SoC.
- As return value from a call to some FFI (Foreign Function Interface) function.
- From uctypes.addressof(), when you want to pass arguments to FFI function, or alternatively, to access some data for I/O (for example, data read from file or network socket).

Structure objects

Structure objects allow accessing individual fields using standard dot notation: `my_struct.field1`. If a field is of scalar type, getting it will produce primitive value (Python integer or float) corresponding to value contained in a field. Scalar field can also be assigned to.

If a field is an array, its individual elements can be accessed with standard subscript operator - both read and assigned to.

If a field is a pointer, it can be dereferenced using `[0]` syntax (corresponding to C `*` operator, though `[0]` works in C too). Subscripting pointer with other integer values but 0 are supported too, with the same semantics as in C.

Summing up, accessing structure fields generally follows C syntax, except for pointer derefence, you need to use `[0]` operator instead of `*`.

4.3 Libraries specific to the pyboard

The following libraries are specific to the pyboard.

4.3.1 pyb — functions related to the board

The `pyb` module contains specific functions related to the board.

Time related functions

`pyb.`**`delay`**(*ms*)
Delay for the given number of milliseconds.

`pyb.`**`udelay`**(*us*)
Delay for the given number of microseconds.

`pyb.`**`millis`**()
Returns the number of milliseconds since the board was last reset.

The result is always a micropython smallint (31-bit signed number), so after 2^30 milliseconds (about 12.4 days) this will start to return negative numbers.

Note that if *pyb.stop()* is issued the hardware counter supporting this function will pause for the duration of the "sleeping" state. This will affect the outcome of *pyb.elapsed_millis()*.

`pyb.`**`micros`**()
Returns the number of microseconds since the board was last reset.

The result is always a micropython smallint (31-bit signed number), so after 2^30 microseconds (about 17.8 minutes) this will start to return negative numbers.

Note that if *pyb.stop()* is issued the hardware counter supporting this function will pause for the duration of the "sleeping" state. This will affect the outcome of *pyb.elapsed_micros()*.

`pyb.`**`elapsed_millis`**(*start*)
Returns the number of milliseconds which have elapsed since `start`.

This function takes care of counter wrap, and always returns a positive number. This means it can be used to measure periods upto about 12.4 days.

Example:

```
start = pyb.millis()
while pyb.elapsed_millis(start) < 1000:
    # Perform some operation
```

pyb.**elapsed_micros**(*start*)
Returns the number of microseconds which have elapsed since `start`.

This function takes care of counter wrap, and always returns a positive number. This means it can be used to measure periods upto about 17.8 minutes.

Example:

```
start = pyb.micros()
while pyb.elapsed_micros(start) < 1000:
    # Perform some operation
    pass
```

Reset related functions

pyb.**hard_reset**()
Resets the pyboard in a manner similar to pushing the external RESET button.

pyb.**bootloader**()
Activate the bootloader without BOOT* pins.

Interrupt related functions

pyb.**disable_irq**()
Disable interrupt requests. Returns the previous IRQ state: `False`/`True` for disabled/enabled IRQs respectively. This return value can be passed to enable_irq to restore the IRQ to its original state.

pyb.**enable_irq**(*state=True*)
Enable interrupt requests. If `state` is `True` (the default value) then IRQs are enabled. If `state` is `False` then IRQs are disabled. The most common use of this function is to pass it the value returned by `disable_irq` to exit a critical section.

Power related functions

pyb.**freq**([*sysclk*[, *hclk*[, *pclk1*[, *pclk2*]]]])
If given no arguments, returns a tuple of clock frequencies: (sysclk, hclk, pclk1, pclk2). These correspond to:

- sysclk: frequency of the CPU
- hclk: frequency of the AHB bus, core memory and DMA
- pclk1: frequency of the APB1 bus
- pclk2: frequency of the APB2 bus

If given any arguments then the function sets the frequency of the CPU, and the busses if additional arguments are given. Frequencies are given in Hz. Eg freq(120000000) sets sysclk (the CPU frequency) to 120MHz. Note that not all values are supported and the largest supported frequency not greater than the given value will be selected.

Supported sysclk frequencies are (in MHz): 8, 16, 24, 30, 32, 36, 40, 42, 48, 54, 56, 60, 64, 72, 84, 96, 108, 120, 144, 168.

The maximum frequency of hclk is 168MHz, of pclk1 is 42MHz, and of pclk2 is 84MHz. Be sure not to set frequencies above these values.

The hclk, pclk1 and pclk2 frequencies are derived from the sysclk frequency using a prescaler (divider). Supported prescalers for hclk are: 1, 2, 4, 8, 16, 64, 128, 256, 512. Supported prescalers for pclk1 and pclk2 are: 1, 2, 4, 8. A prescaler will be chosen to best match the requested frequency.

A sysclk frequency of 8MHz uses the HSE (external crystal) directly and 16MHz uses the HSI (internal oscillator) directly. The higher frequencies use the HSE to drive the PLL (phase locked loop), and then use the output of the PLL.

Note that if you change the frequency while the USB is enabled then the USB may become unreliable. It is best to change the frequency in boot.py, before the USB peripheral is started. Also note that sysclk frequencies below 36MHz do not allow the USB to function correctly.

pyb.**wfi**()
Wait for an internal or external interrupt.

This executes a `wfi` instruction which reduces power consumption of the MCU until any interrupt occurs (be it internal or external), at which point execution continues. Note that the system-tick interrupt occurs once every millisecond (1000Hz) so this function will block for at most 1ms.

pyb.**stop**()
Put the pyboard in a "sleeping" state.

This reduces power consumption to less than 500 uA. To wake from this sleep state requires an external interrupt or a real-time-clock event. Upon waking execution continues where it left off.

See *rtc.wakeup()* to configure a real-time-clock wakeup event.

pyb.**standby**()
Put the pyboard into a "deep sleep" state.

This reduces power consumption to less than 50 uA. To wake from this sleep state requires a real-time-clock event, or an external interrupt on X1 (PA0=WKUP) or X18 (PC13=TAMP1). Upon waking the system undergoes a hard reset.

See *rtc.wakeup()* to configure a real-time-clock wakeup event.

Miscellaneous functions

pyb.**have_cdc**()
Return True if USB is connected as a serial device, False otherwise.

Note: This function is deprecated. Use pyb.USB_VCP().isconnected() instead.

---

pyb.**hid**((*buttons*, *x*, *y*, *z)*)
Takes a 4-tuple (or list) and sends it to the USB host (the PC) to signal a HID mouse-motion event.

Note: This function is deprecated. Use pyb.USB_HID().send(...) instead.

---

pyb.**info**([*dump_alloc_table*])
Print out lots of information about the board.

pyb.**main**(*filename*)
Set the filename of the main script to run after boot.py is finished. If this function is not called then the default file main.py will be executed.

It only makes sense to call this function from within boot.py.

pyb.**mount**(*device*, *mountpoint*, *, *readonly=False*, *mkfs=False*)
Mount a block device and make it available as part of the filesystem. `device` must be an object that provides the block protocol:

- `readblocks(self, blocknum, buf)`
- `writeblocks(self, blocknum, buf)` (optional)
- `count(self)`
- `sync(self)` (optional)

`readblocks` and `writeblocks` should copy data between `buf` and the block device, starting from block number `blocknum` on the device. `buf` will be a bytearray with length a multiple of 512. If `writeblocks` is not defined then the device is mounted read-only. The return value of these two functions is ignored.

`count` should return the number of blocks available on the device. `sync`, if implemented, should sync the data on the device.

The parameter `mountpoint` is the location in the root of the filesystem to mount the device. It must begin with a forward-slash.

If `readonly` is `True`, then the device is mounted read-only, otherwise it is mounted read-write.

If `mkfs` is `True`, then a new filesystem is created if one does not already exist.

To unmount a device, pass `None` as the device and the mount location as `mountpoint`.

pyb.**repl_uart**(*uart*)
Get or set the UART object where the REPL is repeated on.

pyb.**rng**()
Return a 30-bit hardware generated random number.

pyb.**sync**()
Sync all file systems.

pyb.**unique_id**()
Returns a string of 12 bytes (96 bits), which is the unique ID of the MCU.

Classes

class Accel – accelerometer control

Accel is an object that controls the accelerometer. Example usage:

```
accel = pyb.Accel()
for i in range(10):
    print(accel.x(), accel.y(), accel.z())
```

Raw values are between -32 and 31.

Constructors

class pyb.**Accel**
Create and return an accelerometer object.

Methods

accel.**filtered_xyz**()
Get a 3-tuple of filtered x, y and z values.

Implementation note: this method is currently implemented as taking the sum of 4 samples, sampled from the 3 previous calls to this function along with the sample from the current call. Returned values are therefore 4 times the size of what they would be from the raw x(), y() and z() calls.

accel.**tilt**()
Get the tilt register.

accel.**x**()
Get the x-axis value.

accel.**y**()
Get the y-axis value.

accel.**z**()
Get the z-axis value.

class ADC – analog to digital conversion

Usage:

```
import pyb

adc = pyb.ADC(pin)              # create an analog object from a pin
val = adc.read()                # read an analog value

adc = pyb.ADCAll(resolution)    # creale an ADCAll object
val = adc.read_channel(channel) # read the given channel
val = adc.read_core_temp()      # read MCU temperature
val = adc.read_core_vbat()      # read MCU VBAT
val = adc.read_core_vref()      # read MCU VREF
```

Constructors

class pyb.**ADC**(*pin*)
Create an ADC object associated with the given pin. This allows you to then read analog values on that pin.

Methods

adc.**read**()
Read the value on the analog pin and return it. The returned value will be between 0 and 4095.

adc.**read_timed**(*buf*, *timer*)
Read analog values into buf at a rate set by the timer object.

buf can be bytearray or array.array for example. The ADC values have 12-bit resolution and are stored directly into buf if its element size is 16 bits or greater. If buf has only 8-bit elements (eg a bytearray) then the sample resolution will be reduced to 8 bits.

timer should be a Timer object, and a sample is read each time the timer triggers. The timer must already be initialised and running at the desired sampling frequency.

To support previous behaviour of this function, timer can also be an integer which specifies the frequency (in Hz) to sample at. In this case Timer(6) will be automatically configured to run at the given frequency.

Example using a Timer object (preferred way):

```
adc = pyb.ADC(pyb.Pin.board.X19)     # create an ADC on pin X19
tim = pyb.Timer(6, freq=10)          # create a timer running at 10Hz
buf = bytearray(100)                 # creat a buffer to store the samples
adc.read_timed(buf, tim)             # sample 100 values, taking 10s
```

Example using an integer for the frequency:

```
adc = pyb.ADC(pyb.Pin.board.X19)     # create an ADC on pin X19
buf = bytearray(100)                 # create a buffer of 100 bytes
adc.read_timed(buf, 10)              # read analog values into buf at 10Hz
                                     #   this will take 10 seconds to finish
for val in buf:                      # loop over all values
    print(val)                       # print the value out
```

This function does not allocate any memory.

The ADCAll Object Instantiating this changes all ADC pins to analog inputs. The raw MCU temperature, VREF and VBAT data can be accessed on ADC channels 16, 17 and 18 respectively. Appropriate scaling will need to be applied. The temperature sensor on the chip has poor absolute accuracy and is suitable only for detecting temperature changes.

The `ADCAll` `read_core_vbat()` and `read_core_vref()` methods read the backup battery voltage and the (1.21V nominal) reference voltage using the 3.3V supply as a reference. Assuming the `ADCAll` object has been Instantiated with `adc = pyb.ADCAll(12)` the 3.3V supply voltage may be calculated:

```
v33 = 3.3 * 1.21 / adc.read_core_vref()
```

If the 3.3V supply is correct the value of `adc.read_core_vbat()` will be valid. If the supply voltage can drop below 3.3V, for example in in battery powered systems with a discharging battery, the regulator will fail to preserve the 3.3V supply resulting in an incorrect reading. To produce a value which will remain valid under these circumstances use the following:

```
vback = adc.read_core_vbat() * 1.21 / adc.read_core_vref()
```

It is possible to access these values without incurring the side effects of `ADCAll`:

```
def adcread(chan):                              # 16 temp 17 vbat 18 vref
    assert chan >= 16 and chan <= 18, 'Invalid ADC channel'
    start = pyb.millis()
    timeout = 100
    stm.mem32[stm.RCC + stm.RCC_APB2ENR] |= 0x100 # enable ADC1 clock.0x4100
    stm.mem32[stm.ADC1 + stm.ADC_CR2] = 1       # Turn on ADC
    stm.mem32[stm.ADC1 + stm.ADC_CR1] = 0       # 12 bit
    if chan == 17:
        stm.mem32[stm.ADC1 + stm.ADC_SMPR1] = 0x200000 # 15 cycles
        stm.mem32[stm.ADC + 4] = 1 << 23
    elif chan == 18:
        stm.mem32[stm.ADC1 + stm.ADC_SMPR1] = 0x1000000
        stm.mem32[stm.ADC + 4] = 0xc00000
    else:
        stm.mem32[stm.ADC1 + stm.ADC_SMPR1] = 0x40000
        stm.mem32[stm.ADC + 4] = 1 << 23
    stm.mem32[stm.ADC1 + stm.ADC_SQR3] = chan
    stm.mem32[stm.ADC1 + stm.ADC_CR2] = 1 | (1 << 30) | (1 << 10) # start conversion
    while not stm.mem32[stm.ADC1 + stm.ADC_SR] & 2: # wait for EOC
        if pyb.elapsed_millis(start) > timeout:
            raise OSError('ADC timout')
    data = stm.mem32[stm.ADC1 + stm.ADC_DR]     # clear down EOC
    stm.mem32[stm.ADC1 + stm.ADC_CR2] = 0       # Turn off ADC
```

```
    return data

def v33():
    return 4096 * 1.21 / adcread(17)

def vbat():
    return  1.21 * 2 * adcread(18) / adcread(17)  # 2:1 divider on Vbat channel

def vref():
    return 3.3 * adcread(17) / 4096

def temperature():
    return 25 + 400 * (3.3 * adcread(16) / 4096 - 0.76)
```

class CAN – controller area network communication bus

CAN implements the standard CAN communications protocol. At the physical level it consists of 2 lines: RX and TX. Note that to connect the pyboard to a CAN bus you must use a CAN transceiver to convert the CAN logic signals from the pyboard to the correct voltage levels on the bus.

Example usage (works without anything connected):

```
from pyb import CAN
can = CAN(1, CAN.LOOPBACK)
can.setfilter(0, CAN.LIST16, 0, (123, 124, 125, 126))  # set a filter to receive messages with id=12
can.send('message!', 123)   # send a message with id 123
can.recv(0)                 # receive message on FIFO 0
```

Constructors

class pyb.**CAN**(*bus*, ...)

Construct a CAN object on the given bus. `bus` can be 1-2, or 'YA' or 'YB'. With no additional parameters, the CAN object is created but not initialised (it has the settings from the last initialisation of the bus, if any). If extra arguments are given, the bus is initialised. See `init` for parameters of initialisation.

The physical pins of the CAN busses are:

- `CAN(1)` is on `YA`: `(RX, TX) = (Y3, Y4) = (PB8, PB9)`
- `CAN(2)` is on `YB`: `(RX, TX) = (Y5, Y6) = (PB12, PB13)`

Class Methods

CAN.**initfilterbanks**(*nr*)

Reset and disable all filter banks and assign how many banks should be available for CAN(1).

STM32F405 has 28 filter banks that are shared between the two available CAN bus controllers. This function configures how many filter banks should be assigned to each. `nr` is the number of banks that will be assigned to CAN(1), the rest of the 28 are assigned to CAN(2). At boot, 14 banks are assigned to each controller.

Methods

can.**init**(*mode*, *extframe=False*, *prescaler=100*, ***, *sjw=1*, *bs1=6*, *bs2=8*)

Initialise the CAN bus with the given parameters:

- `mode` is one of: NORMAL, LOOPBACK, SILENT, SILENT_LOOPBACK

- if `extframe` is True then the bus uses extended identifiers in the frames (29 bits); otherwise it uses standard 11 bit identifiers
- `prescaler` is used to set the duration of 1 time quanta; the time quanta will be the input clock (PCLK1, see *pyb.freq()*) divided by the prescaler
- `sjw` is the resynchronisation jump width in units of the time quanta; it can be 1, 2, 3, 4
- `bs1` defines the location of the sample point in units of the time quanta; it can be between 1 and 1024 inclusive
- `bs2` defines the location of the transmit point in units of the time quanta; it can be between 1 and 16 inclusive

The time quanta tq is the basic unit of time for the CAN bus. tq is the CAN prescaler value divided by PCLK1 (the frequency of internal peripheral bus 1); see *pyb.freq()* to determine PCLK1.

A single bit is made up of the synchronisation segment, which is always 1 tq. Then follows bit segment 1, then bit segment 2. The sample point is after bit segment 1 finishes. The transmit point is after bit segment 2 finishes. The baud rate will be 1/bittime, where the bittime is 1 + BS1 + BS2 multiplied by the time quanta tq.

For example, with PCLK1=42MHz, prescaler=100, sjw=1, bs1=6, bs2=8, the value of tq is 2.38 microseconds. The bittime is 35.7 microseconds, and the baudrate is 28kHz.

See page 680 of the STM32F405 datasheet for more details.

`can.`**`deinit`**`()`

Turn off the CAN bus.

`can.`**`setfilter`**`(`*bank*, *mode*, *fifo*, *params*, *, *rtr*`)`

Configure a filter bank:

- `bank` is the filter bank that is to be configured.
- `mode` is the mode the filter should operate in.
- `fifo` is which fifo (0 or 1) a message should be stored in, if it is accepted by this filter.
- `params` is an array of values the defines the filter. The contents of the array depends on the `mode` argument.

`mode`	contents of parameter array
CAN.LIST16	Four 16 bit ids that will be accepted
CAN.LIST32	Two 32 bit ids that will be accepted
CAN.MASK16	**Two 16 bit id/mask pairs. E.g. (1, 3, 4, 4)** The first pair, 1 and 3 will accept all ids that have bit 0 = 1 and bit 1 = 0. The second pair, 4 and 4, will accept all ids that have bit 2 = 1.
CAN.MASK32	As with CAN.MASK16 but with only one 32 bit id/mask pair.

- `rtr` is an array of booleans that states if a filter should accept a remote transmission request message. If this argument is not given then it defaults to False for all entries. The length of the array depends on the `mode` argument.

mode	length of rtr array
CAN.LIST16	4
CAN.LIST32	2
CAN.MASK16	2
CAN.MASK32	1

can.**clearfilter**(*bank*)
Clear and disables a filter bank:

- `bank` is the filter bank that is to be cleared.

can.**any**(*fifo*)
Return `True` if any message waiting on the FIFO, else `False`.

can.**recv**(*fifo*, *, *timeout=5000*)
Receive data on the bus:

- `fifo` is an integer, which is the FIFO to receive on
- `timeout` is the timeout in milliseconds to wait for the receive.

Return value: A tuple containing four values.

- The id of the message.
- A boolean that indicates if the message is an RTR message.
- The FMI (Filter Match Index) value.
- An array containing the data.

can.**send**(*data*, *id*, *, *timeout=0*, *rtr=False*)
Send a message on the bus:

- `data` is the data to send (an integer to send, or a buffer object).
- `id` is the id of the message to be sent.
- `timeout` is the timeout in milliseconds to wait for the send.
- `rtr` is a boolean that specifies if the message shall be sent as a remote transmission request. If `rtr` is True then only the length of `data` is used to fill in the DLC slot of the frame; the actual bytes in `data` are unused.

If timeout is 0 the message is placed in a buffer in one of three hardware buffers and the method returns immediately. If all three buffers are in use an exception is thrown. If timeout is not 0, the method waits until the message is transmitted. If the message can't be transmitted within the specified time an exception is thrown.

Return value: `None`.

can.**rxcallback**(*fifo*, *fun*)
Register a function to be called when a message is accepted into a empty fifo:

- `fifo` is the receiving fifo.
- `fun` is the function to be called when the fifo becomes non empty.

The callback function takes two arguments the first is the can object it self the second is a integer that indicates the reason for the callback.

Reason	
0	A message has been accepted into a empty FIFO.
1	The FIFO is full
2	A message has been lost due to a full FIFO

Example use of rxcallback:

```
    def cb0(bus, reason):
      print('cb0')
      if reason == 0:
          print('pending')
      if reason == 1:
          print('full')
      if reason == 2:
          print('overflow')

    can = CAN(1, CAN.LOOPBACK)
    can.rxcallback(0, cb0)
```

Constants

CAN.**NORMAL**
CAN.**LOOPBACK**

CAN.**SILENT**

CAN.**SILENT_LOOPBACK**
the mode of the CAN bus

CAN.**LIST16**

CAN.**MASK16**

CAN.**LIST32**

CAN.**MASK32**
the operation mode of a filter

class DAC – digital to analog conversion

The DAC is used to output analog values (a specific voltage) on pin X5 or pin X6. The voltage will be between 0 and 3.3V.

This module will undergo changes to the API.

Example usage:

```
from pyb import DAC

dac = DAC(1)             # create DAC 1 on pin X5
dac.write(128)           # write a value to the DAC (makes X5 1.65V)

dac = DAC(1, bits=12)    # use 12 bit resolution
dac.write(4095)          # output maximum value, 3.3V
```

To output a continuous sine-wave:

```
import math
from pyb import DAC

# create a buffer containing a sine-wave
buf = bytearray(100)
for i in range(len(buf)):
    buf[i] = 128 + int(127 * math.sin(2 * math.pi * i / len(buf)))
```

```
# output the sine-wave at 400Hz
dac = DAC(1)
dac.write_timed(buf, 400 * len(buf), mode=DAC.CIRCULAR)
```

To output a continuous sine-wave at 12-bit resolution:

```
import math
from array import array
from pyb import DAC

# create a buffer containing a sine-wave, using half-word samples
buf = array('H', 2048 + int(2047 * math.sin(2 * math.pi * i / 128)) for i in range(128))

# output the sine-wave at 400Hz
dac = DAC(1, bits=12)
dac.write_timed(buf, 400 * len(buf), mode=DAC.CIRCULAR)
```

Constructors

class pyb.**DAC**(*port*, *bits=8*)

Construct a new DAC object.

`port` can be a pin object, or an integer (1 or 2). DAC(1) is on pin X5 and DAC(2) is on pin X6.

`bits` is an integer specifying the resolution, and can be 8 or 12. The maximum value for the write and write_timed methods will be 2**‘‘bits‘‘-1.

Methods

dac.**init**(*bits=8*)

Reinitialise the DAC. `bits` can be 8 or 12.

dac.**noise**(*freq*)

Generate a pseudo-random noise signal. A new random sample is written to the DAC output at the given frequency.

dac.**triangle**(*freq*)

Generate a triangle wave. The value on the DAC output changes at the given frequency, and the frequence of the repeating triangle wave itself is 2048 times smaller.

dac.**write**(*value*)

Direct access to the DAC output. The minimum value is 0. The maximum value is 2**‘‘bits‘‘-1, where `bits` is set when creating the DAC object or by using the `init` method.

dac.**write_timed**(*data*, *freq*, *, *mode=DAC.NORMAL*)

Initiates a burst of RAM to DAC using a DMA transfer. The input data is treated as an array of bytes in 8-bit mode, and an array of unsigned half-words (array typecode ‘H’) in 12-bit mode.

`freq` can be an integer specifying the frequency to write the DAC samples at, using Timer(6). Or it can be an already-initialised Timer object which is used to trigger the DAC sample. Valid timers are 2, 4, 5, 6, 7 and 8.

`mode` can be `DAC.NORMAL` or `DAC.CIRCULAR`.

Example using both DACs at the same time:

```
dac1 = DAC(1)
dac2 = DAC(2)
dac1.write_timed(buf1, pyb.Timer(6, freq=100), mode=DAC.CIRCULAR)
dac2.write_timed(buf2, pyb.Timer(7, freq=200), mode=DAC.CIRCULAR)
```

class ExtInt – configure I/O pins to interrupt on external events

There are a total of 22 interrupt lines. 16 of these can come from GPIO pins and the remaining 6 are from internal sources.

For lines 0 thru 15, a given line can map to the corresponding line from an arbitrary port. So line 0 can map to Px0 where x is A, B, C, ... and line 1 can map to Px1 where x is A, B, C, ...

```
def callback(line):
    print("line =", line)
```

Note: ExtInt will automatically configure the gpio line as an input.

```
extint = pyb.ExtInt(pin, pyb.ExtInt.IRQ_FALLING, pyb.Pin.PULL_UP, callback)
```

Now every time a falling edge is seen on the X1 pin, the callback will be called. Caution: mechanical pushbuttons have "bounce" and pushing or releasing a switch will often generate multiple edges. See: http://www.eng.utah.edu/~cs5780/debouncing.pdf for a detailed explanation, along with various techniques for debouncing.

Trying to register 2 callbacks onto the same pin will throw an exception.

If pin is passed as an integer, then it is assumed to map to one of the internal interrupt sources, and must be in the range 16 thru 22.

All other pin objects go through the pin mapper to come up with one of the gpio pins.

```
extint = pyb.ExtInt(pin, mode, pull, callback)
```

Valid modes are pyb.ExtInt.IRQ_RISING, pyb.ExtInt.IRQ_FALLING, pyb.ExtInt.IRQ_RISING_FALLING, pyb.ExtInt.EVT_RISING, pyb.ExtInt.EVT_FALLING, and pyb.ExtInt.EVT_RISING_FALLING.

Only the IRQ_xxx modes have been tested. The EVT_xxx modes have something to do with sleep mode and the WFE instruction.

Valid pull values are pyb.Pin.PULL_UP, pyb.Pin.PULL_DOWN, pyb.Pin.PULL_NONE.

There is also a C API, so that drivers which require EXTI interrupt lines can also use this code. See extint.h for the available functions and usrsw.h for an example of using this.

Constructors

class `pyb.`**`ExtInt`**(*pin*, *mode*, *pull*, *callback*)

Create an ExtInt object:

- `pin` is the pin on which to enable the interrupt (can be a pin object or any valid pin name).
- `mode` can be one of: - `ExtInt.IRQ_RISING` - trigger on a rising edge; - `ExtInt.IRQ_FALLING` - trigger on a falling edge; - `ExtInt.IRQ_RISING_FALLING` - trigger on a rising or falling edge.
- `pull` can be one of: - `pyb.Pin.PULL_NONE` - no pull up or down resistors; - `pyb.Pin.PULL_UP` - enable the pull-up resistor; - `pyb.Pin.PULL_DOWN` - enable the pull-down resistor.
- `callback` is the function to call when the interrupt triggers. The callback function must accept exactly 1 argument, which is the line that triggered the interrupt.

Class methods

`ExtInt.`**`regs`**`()`

Dump the values of the EXTI registers.

Methods

`extint.`**`disable`**`()`
Disable the interrupt associated with the ExtInt object. This could be useful for debouncing.

`extint.`**`enable`**`()`
Enable a disabled interrupt.

`extint.`**`line`**`()`
Return the line number that the pin is mapped to.

`extint.`**`swint`**`()`
Trigger the callback from software.

Constants

`ExtInt.`**`IRQ_FALLING`**
interrupt on a falling edge

`ExtInt.`**`IRQ_RISING`**
interrupt on a rising edge

`ExtInt.`**`IRQ_RISING_FALLING`**
interrupt on a rising or falling edge

class I2C – a two-wire serial protocol

I2C is a two-wire protocol for communicating between devices. At the physical level it consists of 2 wires: SCL and SDA, the clock and data lines respectively.

I2C objects are created attached to a specific bus. They can be initialised when created, or initialised later on.

Example:

```
from pyb import I2C

i2c = I2C(1)                           # create on bus 1
i2c = I2C(1, I2C.MASTER)               # create and init as a master
i2c.init(I2C.MASTER, baudrate=20000) # init as a master
i2c.init(I2C.SLAVE, addr=0x42)         # init as a slave with given address
i2c.deinit()                           # turn off the peripheral
```

Printing the i2c object gives you information about its configuration.

The basic methods are send and recv:

```
i2c.send('abc')      # send 3 bytes
i2c.send(0x42)       # send a single byte, given by the number
data = i2c.recv(3)   # receive 3 bytes
```

To receive inplace, first create a bytearray:

```
data = bytearray(3)  # create a buffer
i2c.recv(data)       # receive 3 bytes, writing them into data
```

You can specify a timeout (in ms):

```
i2c.send(b'123', timeout=2000)   # timout after 2 seconds
```

A master must specify the recipient's address:

```
i2c.init(I2C.MASTER)
i2c.send('123', 0x42)        # send 3 bytes to slave with address 0x42
i2c.send(b'456', addr=0x42)  # keyword for address
```

Master also has other methods:

```
i2c.is_ready(0x42)           # check if slave 0x42 is ready
i2c.scan()                   # scan for slaves on the bus, returning
                             #   a list of valid addresses
i2c.mem_read(3, 0x42, 2)     # read 3 bytes from memory of slave 0x42,
                             #   starting at address 2 in the slave
i2c.mem_write('abc', 0x42, 2, timeout=1000) # write 'abc' (3 bytes) to memory of slave 0x42
                                            # starting at address 2 in the slave, timeout after 1 se
```

Constructors

class pyb.**I2C**(*bus*, ...)

Construct an I2C object on the given bus. `bus` can be 1 or 2, 'X' or 'Y'. With no additional parameters, the I2C object is created but not initialised (it has the settings from the last initialisation of the bus, if any). If extra arguments are given, the bus is initialised. See `init` for parameters of initialisation.

The physical pins of the I2C busses on Pyboards V1.0 and V1.1 are:

- `I2C(1)` is on the X position: `(SCL, SDA) = (X9, X10) = (PB6, PB7)`
- `I2C(2)` is on the Y position: `(SCL, SDA) = (Y9, Y10) = (PB10, PB11)`

On the Pyboard Lite:

- `I2C(1)` is on the X position: `(SCL, SDA) = (X9, X10) = (PB6, PB7)`
- `I2C(3)` is on the Y position: `(SCL, SDA) = (Y9, Y10) = (PA8, PB8)`

Calling the constructor with 'X' or 'Y' enables portability between Pyboard types.

Methods

i2c.**deinit**()

Turn off the I2C bus.

i2c.**init**(*mode*, *, *addr=0x12*, *baudrate=400000*, *gencall=False*)

Initialise the I2C bus with the given parameters:

- `mode` must be either `I2C.MASTER` or `I2C.SLAVE`
- `addr` is the 7-bit address (only sensible for a slave)
- `baudrate` is the SCL clock rate (only sensible for a master)
- `gencall` is whether to support general call mode

i2c.**is_ready**(*addr*)

Check if an I2C device responds to the given address. Only valid when in master mode.

i2c.**mem_read**(*data*, *addr*, *memaddr*, *, *timeout=5000*, *addr_size=8*)

Read from the memory of an I2C device:

- `data` can be an integer (number of bytes to read) or a buffer to read into
- `addr` is the I2C device address
- `memaddr` is the memory location within the I2C device
- `timeout` is the timeout in milliseconds to wait for the read

- addr_size selects width of memaddr: 8 or 16 bits

Returns the read data. This is only valid in master mode.

i2c.**mem_write**(*data*, *addr*, *memaddr*, *, *timeout=5000*, *addr_size=8*)
Write to the memory of an I2C device:

- data can be an integer or a buffer to write from
- addr is the I2C device address
- memaddr is the memory location within the I2C device
- timeout is the timeout in milliseconds to wait for the write
- addr_size selects width of memaddr: 8 or 16 bits

Returns None. This is only valid in master mode.

i2c.**recv**(*recv*, *addr=0x00*, *, *timeout=5000*)
Receive data on the bus:

- recv can be an integer, which is the number of bytes to receive, or a mutable buffer, which will be filled with received bytes
- addr is the address to receive from (only required in master mode)
- timeout is the timeout in milliseconds to wait for the receive

Return value: if recv is an integer then a new buffer of the bytes received, otherwise the same buffer that was passed in to recv.

i2c.**send**(*send*, *addr=0x00*, *, *timeout=5000*)
Send data on the bus:

- send is the data to send (an integer to send, or a buffer object)
- addr is the address to send to (only required in master mode)
- timeout is the timeout in milliseconds to wait for the send

Return value: None.

i2c.**scan**()
Scan all I2C addresses from 0x01 to 0x7f and return a list of those that respond. Only valid when in master mode.

Constants

I2C.**MASTER**
for initialising the bus to master mode

I2C.**SLAVE**
for initialising the bus to slave mode

class LCD – LCD control for the LCD touch-sensor pyskin

The LCD class is used to control the LCD on the LCD touch-sensor pyskin, LCD32MKv1.0. The LCD is a 128x32 pixel monochrome screen, part NHD-C12832A1Z.

The pyskin must be connected in either the X or Y positions, and then an LCD object is made using:

```
lcd = pyb.LCD('X')      # if pyskin is in the X position
lcd = pyb.LCD('Y')      # if pyskin is in the Y position
```

Then you can use:

```
lcd.light(True)                 # turn the backlight on
lcd.write('Hello world!\n')     # print text to the screen
```

This driver implements a double buffer for setting/getting pixels. For example, to make a bouncing dot, try:

```
x = y = 0
dx = dy = 1
while True:
    # update the dot's position
    x += dx
    y += dy

    # make the dot bounce of the edges of the screen
    if x <= 0 or x >= 127: dx = -dx
    if y <= 0 or y >= 31: dy = -dy

    lcd.fill(0)                 # clear the buffer
    lcd.pixel(x, y, 1)          # draw the dot
    lcd.show()                  # show the buffer
    pyb.delay(50)               # pause for 50ms
```

Constructors

class `pyb.`**`LCD`**(*skin_position*)

Construct an LCD object in the given skin position. `skin_position` can be 'X' or 'Y', and should match the position where the LCD pyskin is plugged in.

Methods

`lcd.`**`command`**(*instr_data*, *buf*)

Send an arbitrary command to the LCD. Pass 0 for `instr_data` to send an instruction, otherwise pass 1 to send data. `buf` is a buffer with the instructions/data to send.

`lcd.`**`contrast`**(*value*)

Set the contrast of the LCD. Valid values are between 0 and 47.

`lcd.`**`fill`**(*colour*)

Fill the screen with the given colour (0 or 1 for white or black).

This method writes to the hidden buffer. Use `show()` to show the buffer.

`lcd.`**`get`**(*x*, *y*)

Get the pixel at the position `(x, y)`. Returns 0 or 1.

This method reads from the visible buffer.

`lcd.`**`light`**(*value*)

Turn the backlight on/off. True or 1 turns it on, False or 0 turns it off.

`lcd.`**`pixel`**(*x*, *y*, *colour*)

Set the pixel at `(x, y)` to the given colour (0 or 1).

This method writes to the hidden buffer. Use `show()` to show the buffer.

`lcd.`**`show`**()

Show the hidden buffer on the screen.

`lcd.`**`text`**(*str*, *x*, *y*, *colour*)

Draw the given text to the position `(x, y)` using the given colour (0 or 1).

This method writes to the hidden buffer. Use `show()` to show the buffer.

`lcd.`**`write`**`(`*`str`*`)`
Write the string `str` to the screen. It will appear immediately.

class LED – LED object

The LED object controls an individual LED (Light Emitting Diode).

Constructors

class `pyb.`**`LED`**`(`*`id`*`)`
Create an LED object associated with the given LED:

- `id` is the LED number, 1-4.

Methods

`led.`**`intensity`**`(`[*value*]`)`
Get or set the LED intensity. Intensity ranges between 0 (off) and 255 (full on). If no argument is given, return the LED intensity. If an argument is given, set the LED intensity and return `None`.

Note: Only LED(3) and LED(4) can have a smoothly varying intensity, and they use timer PWM to implement it. LED(3) uses Timer(2) and LED(4) uses Timer(3). These timers are only configured for PWM if the intensity of the relevant LED is set to a value between 1 and 254. Otherwise the timers are free for general purpose use.

`led.`**`off`**`()`
Turn the LED off.

`led.`**`on`**`()`
Turn the LED on, to maximum intensity.

`led.`**`toggle`**`()`
Toggle the LED between on (maximum intensity) and off. If the LED is at non-zero intensity then it is considered "on" and toggle will turn it off.

class Pin – control I/O pins

A pin is the basic object to control I/O pins. It has methods to set the mode of the pin (input, output, etc) and methods to get and set the digital logic level. For analog control of a pin, see the ADC class.

Usage Model:

All Board Pins are predefined as pyb.Pin.board.Name:

```
x1_pin = pyb.Pin.board.X1

g = pyb.Pin(pyb.Pin.board.X1, pyb.Pin.IN)
```

CPU pins which correspond to the board pins are available as `pyb.cpu.Name`. For the CPU pins, the names are the port letter followed by the pin number. On the PYBv1.0, `pyb.Pin.board.X1` and `pyb.Pin.cpu.B6` are the same pin.

You can also use strings:

```
g = pyb.Pin('X1', pyb.Pin.OUT_PP)
```

Users can add their own names:

```
MyMapperDict = { 'LeftMotorDir' : pyb.Pin.cpu.C12 }
pyb.Pin.dict(MyMapperDict)
g = pyb.Pin("LeftMotorDir", pyb.Pin.OUT_OD)
```

and can query mappings:

```
pin = pyb.Pin("LeftMotorDir")
```

Users can also add their own mapping function:

```
def MyMapper(pin_name):
   if pin_name == "LeftMotorDir":
       return pyb.Pin.cpu.A0

pyb.Pin.mapper(MyMapper)
```

So, if you were to call: `pyb.Pin("LeftMotorDir", pyb.Pin.OUT_PP)` then `"LeftMotorDir"` is passed directly to the mapper function.

To summarise, the following order determines how things get mapped into an ordinal pin number:

1. Directly specify a pin object
2. User supplied mapping function
3. User supplied mapping (object must be usable as a dictionary key)
4. Supply a string which matches a board pin
5. Supply a string which matches a CPU port/pin

You can set `pyb.Pin.debug(True)` to get some debug information about how a particular object gets mapped to a pin.

When a pin has the `Pin.PULL_UP` or `Pin.PULL_DOWN` pull-mode enabled, that pin has an effective 40k Ohm resistor pulling it to 3V3 or GND respectively (except pin Y5 which has 11k Ohm resistors).

Now every time a falling edge is seen on the gpio pin, the callback will be executed. Caution: mechanical push buttons have "bounce" and pushing or releasing a switch will often generate multiple edges. See: http://www.eng.utah.edu/~cs5780/debouncing.pdf for a detailed explanation, along with various techniques for debouncing.

All pin objects go through the pin mapper to come up with one of the gpio pins.

Constructors

class `pyb.`**`Pin`**(*id*, ...)

Create a new Pin object associated with the id. If additional arguments are given, they are used to initialise the pin. See *pin.init()*.

Class methods

`Pin.`**`af_list`**()

Returns an array of alternate functions available for this pin.

`Pin.`**`debug`**([*state*])

Get or set the debugging state (`True` or `False` for on or off).

`Pin.`**`dict`**([*dict*])

Get or set the pin mapper dictionary.

`Pin.`**`mapper`**([*fun*])

Get or set the pin mapper function.

Methods

pin.**init**(*mode*, *pull=Pin.PULL_NONE*, *af=-1*)

Initialise the pin:

- `mode` can be one of:
  - `Pin.IN` - configure the pin for input;
  - `Pin.OUT_PP` - configure the pin for output, with push-pull control;
  - `Pin.OUT_OD` - configure the pin for output, with open-drain control;
  - `Pin.AF_PP` - configure the pin for alternate function, pull-pull;
  - `Pin.AF_OD` - configure the pin for alternate function, open-drain;
  - `Pin.ANALOG` - configure the pin for analog.
- `pull` can be one of:
  - `Pin.PULL_NONE` - no pull up or down resistors;
  - `Pin.PULL_UP` - enable the pull-up resistor;
  - `Pin.PULL_DOWN` - enable the pull-down resistor.
- when mode is `Pin.AF_PP` or `Pin.AF_OD`, then af can be the index or name of one of the alternate functions associated with a pin.

Returns: `None`.

pin.**value**([*value*])

Get or set the digital logic level of the pin:

- With no argument, return 0 or 1 depending on the logic level of the pin.
- With `value` given, set the logic level of the pin. `value` can be anything that converts to a boolean. If it converts to `True`, the pin is set high, otherwise it is set low.

pin.**__str__**()

Return a string describing the pin object.

pin.**af**()

Returns the currently configured alternate-function of the pin. The integer returned will match one of the allowed constants for the af argument to the init function.

pin.**gpio**()

Returns the base address of the GPIO block associated with this pin.

pin.**mode**()

Returns the currently configured mode of the pin. The integer returned will match one of the allowed constants for the mode argument to the init function.

pin.**name**()

Get the pin name.

pin.**names**()

Returns the cpu and board names for this pin.

pin.**pin**()

Get the pin number.

pin.**port**()

Get the pin port.

pin.**pull**()
Returns the currently configured pull of the pin. The integer returned will match one of the allowed constants for the pull argument to the init function.

Constants

Pin.**AF_OD**
initialise the pin to alternate-function mode with an open-drain drive

Pin.**AF_PP**
initialise the pin to alternate-function mode with a push-pull drive

Pin.**ANALOG**
initialise the pin to analog mode

Pin.**IN**
initialise the pin to input mode

Pin.**OUT_OD**
initialise the pin to output mode with an open-drain drive

Pin.**OUT_PP**
initialise the pin to output mode with a push-pull drive

Pin.**PULL_DOWN**
enable the pull-down resistor on the pin

Pin.**PULL_NONE**
don't enable any pull up or down resistors on the pin

Pin.**PULL_UP**
enable the pull-up resistor on the pin

class PinAF – Pin Alternate Functions

A Pin represents a physical pin on the microcprocessor. Each pin can have a variety of functions (GPIO, I2C SDA, etc). Each PinAF object represents a particular function for a pin.

Usage Model:

```
x3 = pyb.Pin.board.X3
x3_af = x3.af_list()
```

x3_af will now contain an array of PinAF objects which are availble on pin X3.

For the pyboard, x3_af would contain: [Pin.AF1_TIM2, Pin.AF2_TIM5, Pin.AF3_TIM9, Pin.AF7_USART2]

Normally, each peripheral would configure the af automatically, but sometimes the same function is available on multiple pins, and having more control is desired.

To configure X3 to expose TIM2_CH3, you could use:

```
pin = pyb.Pin(pyb.Pin.board.X3, mode=pyb.Pin.AF_PP, af=pyb.Pin.AF1_TIM2)
```

or:

```
pin = pyb.Pin(pyb.Pin.board.X3, mode=pyb.Pin.AF_PP, af=1)
```

Methods

pinaf.**__str__**()
Return a string describing the alternate function.

pinaf.**index**()
Return the alternate function index.

pinaf.**name**()
Return the name of the alternate function.

pinaf.**reg**()
Return the base register associated with the peripheral assigned to this alternate function. For example, if the alternate function were TIM2_CH3 this would return stm.TIM2

class RTC – real time clock

The RTC is and independent clock that keeps track of the date and time.

Example usage:

```
rtc = pyb.RTC()
rtc.datetime((2014, 5, 1, 4, 13, 0, 0, 0))
print(rtc.datetime())
```

Constructors

class pyb.**RTC**
Create an RTC object.

Methods

rtc.**datetime**([*datetimetuple*])
Get or set the date and time of the RTC.

With no arguments, this method returns an 8-tuple with the current date and time. With 1 argument (being an 8-tuple) it sets the date and time.

The 8-tuple has the following format:

(year, month, day, weekday, hours, minutes, seconds, subseconds)

`weekday` is 1-7 for Monday through Sunday.

`subseconds` counts down from 255 to 0

rtc.**wakeup**(*timeout*, *callback=None*)
Set the RTC wakeup timer to trigger repeatedly at every `timeout` milliseconds. This trigger can wake the pyboard from both the sleep states: *pyb.stop()* and *pyb.standby()*.

If `timeout` is `None` then the wakeup timer is disabled.

If `callback` is given then it is executed at every trigger of the wakeup timer. `callback` must take exactly one argument.

rtc.**info**()
Get information about the startup time and reset source.

- The lower 0xffff are the number of milliseconds the RTC took to start up.
- Bit 0x10000 is set if a power-on reset occurred.
- Bit 0x20000 is set if an external reset occurred

rtc.**calibration**(*cal*)

Get or set RTC calibration.

With no arguments, `calibration()` returns the current calibration value, which is an integer in the range [-511 : 512]. With one argument it sets the RTC calibration.

The RTC Smooth Calibration mechanism addjusts the RTC clock rate by adding or subtracting the given number of ticks from the 32768 Hz clock over a 32 second period (corresponding to 2^20 clock ticks.) Each tick added will speed up the clock by 1 part in 2^20, or 0.954 ppm; likewise the RTC clock it slowed by negative values. The usable calibration range is: (-511 * 0.954) ~= -487.5 ppm up to (512 * 0.954) ~= 488.5 ppm

class Servo – 3-wire hobby servo driver

Servo objects control standard hobby servo motors with 3-wires (ground, power, signal). There are 4 positions on the pyboard where these motors can be plugged in: pins X1 through X4 are the signal pins, and next to them are 4 sets of power and ground pins.

Example usage:

```
import pyb

s1 = pyb.Servo(1)    # create a servo object on position X1
s2 = pyb.Servo(2)    # create a servo object on position X2

s1.angle(45)         # move servo 1 to 45 degrees
s2.angle(0)          # move servo 2 to 0 degrees

# move servo1 and servo2 synchronously, taking 1500ms
s1.angle(-60, 1500)
s2.angle(30, 1500)
```

Note: The Servo objects use Timer(5) to produce the PWM output. You can use Timer(5) for Servo control, or your own purposes, but not both at the same time.

Constructors

class pyb.**Servo**(*id*)

Create a servo object. `id` is 1-4, and corresponds to pins X1 through X4.

Methods

servo.**angle**([*angle*, *time=0*])

If no arguments are given, this function returns the current angle.

If arguments are given, this function sets the angle of the servo:

- `angle` is the angle to move to in degrees.
- `time` is the number of milliseconds to take to get to the specified angle. If omitted, then the servo moves as quickly as possible to its new position.

servo.**speed**([*speed*, *time=0*])

If no arguments are given, this function returns the current speed.

If arguments are given, this function sets the speed of the servo:

- `speed` is the speed to change to, between -100 and 100.

- `time` is the number of milliseconds to take to get to the specified speed. If omitted, then the servo accelerates as quickly as possible.

`servo.`**`pulse_width`**`(`[*value*]`)`

If no arguments are given, this function returns the current raw pulse-width value.

If an argument is given, this function sets the raw pulse-width value.

`servo.`**`calibration`**`(`[*pulse_min*, *pulse_max*, *pulse_centre*[, *pulse_angle_90*, *pulse_speed_100*]]`)`

If no arguments are given, this function returns the current calibration data, as a 5-tuple.

If arguments are given, this function sets the timing calibration:

- `pulse_min` is the minimum allowed pulse width.
- `pulse_max` is the maximum allowed pulse width.
- `pulse_centre` is the pulse width corresponding to the centre/zero position.
- `pulse_angle_90` is the pulse width corresponding to 90 degrees.
- `pulse_speed_100` is the pulse width corresponding to a speed of 100.

class SPI – a master-driven serial protocol

SPI is a serial protocol that is driven by a master. At the physical level there are 3 lines: SCK, MOSI, MISO.

See usage model of I2C; SPI is very similar. Main difference is parameters to init the SPI bus:

```
from pyb import SPI
spi = SPI(1, SPI.MASTER, baudrate=600000, polarity=1, phase=0, crc=0x7)
```

Only required parameter is mode, SPI.MASTER or SPI.SLAVE. Polarity can be 0 or 1, and is the level the idle clock line sits at. Phase can be 0 or 1 to sample data on the first or second clock edge respectively. Crc can be None for no CRC, or a polynomial specifier.

Additional methods for SPI:

```
data = spi.send_recv(b'1234')         # send 4 bytes and receive 4 bytes
buf = bytearray(4)
spi.send_recv(b'1234', buf)           # send 4 bytes and receive 4 into buf
spi.send_recv(buf, buf)               # send/recv 4 bytes from/to buf
```

Constructors

class `pyb.`**`SPI`**`(`*bus*, ...`)`

Construct an SPI object on the given bus. `bus` can be 1 or 2, or 'X' or 'Y'. With no additional parameters, the SPI object is created but not initialised (it has the settings from the last initialisation of the bus, if any). If extra arguments are given, the bus is initialised. See `init` for parameters of initialisation.

The physical pins of the SPI busses are:

- `SPI(1)` is on the X position: `(NSS, SCK, MISO, MOSI) = (X5, X6, X7, X8) = (PA4, PA5, PA6, PA7)`
- `SPI(2)` is on the Y position: `(NSS, SCK, MISO, MOSI) = (Y5, Y6, Y7, Y8) = (PB12, PB13, PB14, PB15)`

At the moment, the NSS pin is not used by the SPI driver and is free for other use.

Methods

spi.**deinit**()
Turn off the SPI bus.

spi.**init**(*mode*, *baudrate=328125*, ***, *prescaler*, *polarity=1*, *phase=0*, *bits=8*, *firstbit=SPI.MSB*, *ti=False*, *crc=None*)
Initialise the SPI bus with the given parameters:

- `mode` must be either `SPI.MASTER` or `SPI.SLAVE`.
- `baudrate` is the SCK clock rate (only sensible for a master).
- `prescaler` is the prescaler to use to derive SCK from the APB bus frequency; use of `prescaler` overrides `baudrate`.
- `polarity` can be 0 or 1, and is the level the idle clock line sits at.
- `phase` can be 0 or 1 to sample data on the first or second clock edge respectively.
- `firstbit` can be `SPI.MSB` or `SPI.LSB`.
- `crc` can be None for no CRC, or a polynomial specifier.

Note that the SPI clock frequency will not always be the requested baudrate. The hardware only supports baudrates that are the APB bus frequency (see *pyb.freq()*) divided by a prescaler, which can be 2, 4, 8, 16, 32, 64, 128 or 256. SPI(1) is on AHB2, and SPI(2) is on AHB1. For precise control over the SPI clock frequency, specify `prescaler` instead of `baudrate`.

Printing the SPI object will show you the computed baudrate and the chosen prescaler.

spi.**recv**(*recv*, ***, *timeout=5000*)
Receive data on the bus:

- `recv` can be an integer, which is the number of bytes to receive, or a mutable buffer, which will be filled with received bytes.
- `timeout` is the timeout in milliseconds to wait for the receive.

Return value: if `recv` is an integer then a new buffer of the bytes received, otherwise the same buffer that was passed in to `recv`.

spi.**send**(*send*, ***, *timeout=5000*)
Send data on the bus:

- `send` is the data to send (an integer to send, or a buffer object).
- `timeout` is the timeout in milliseconds to wait for the send.

Return value: `None`.

spi.**send_recv**(*send*, *recv=None*, ***, *timeout=5000*)
Send and receive data on the bus at the same time:

- `send` is the data to send (an integer to send, or a buffer object).
- `recv` is a mutable buffer which will be filled with received bytes. It can be the same as `send`, or omitted. If omitted, a new buffer will be created.
- `timeout` is the timeout in milliseconds to wait for the receive.

Return value: the buffer with the received bytes.

Constants

SPI.**MASTER**

SPI.**SLAVE**
for initialising the SPI bus to master or slave mode

SPI.**LSB**

SPI.**MSB**
set the first bit to be the least or most significant bit

class Switch – switch object

A Switch object is used to control a push-button switch.

Usage:

```
sw = pyb.Switch()        # create a switch object
sw()                     # get state (True if pressed, False otherwise)
sw.callback(f)           # register a callback to be called when the
                         #   switch is pressed down
sw.callback(None)        # remove the callback
```

Example:

```
pyb.Switch().callback(lambda: pyb.LED(1).toggle())
```

Constructors

class pyb.**Switch**
Create and return a switch object.

Methods

switch()
Return the switch state: True if pressed down, False otherwise.

switch.**callback**(*fun*)
Register the given function to be called when the switch is pressed down. If fun is None, then it disables the callback.

class Timer – control internal timers

Timers can be used for a great variety of tasks. At the moment, only the simplest case is implemented: that of calling a function periodically.

Each timer consists of a counter that counts up at a certain rate. The rate at which it counts is the peripheral clock frequency (in Hz) divided by the timer prescaler. When the counter reaches the timer period it triggers an event, and the counter resets back to zero. By using the callback method, the timer event can call a Python function.

Example usage to toggle an LED at a fixed frequency:

```
tim = pyb.Timer(4)               # create a timer object using timer 4
tim.init(freq=2)                 # trigger at 2Hz
tim.callback(lambda t:pyb.LED(1).toggle())
```

Example using named function for the callback:

```
def tick(timer):                 # we will receive the timer object when being called
    print(timer.counter())       # show current timer's counter value
tim = pyb.Timer(4, freq=1)       # create a timer object using timer 4 - trigger at 1Hz
tim.callback(tick)               # set the callback to our tick function
```

Further examples:

```
tim = pyb.Timer(4, freq=100)      # freq in Hz
tim = pyb.Timer(4, prescaler=0, period=99)
tim.counter()                     # get counter (can also set)
tim.prescaler(2)                  # set prescaler (can also get)
tim.period(199)                   # set period (can also get)
tim.callback(lambda t: ...)       # set callback for update interrupt (t=tim instance)
tim.callback(None)                # clear callback
```

Note: Timer(2) and Timer(3) are used for PWM to set the intensity of LED(3) and LED(4) respectively. But these timers are only configured for PWM if the intensity of the relevant LED is set to a value between 1 and 254. If the intensity feature of the LEDs is not used then these timers are free for general purpose use. Similarly, Timer(5) controls the servo driver, and Timer(6) is used for timed ADC/DAC reading/writing. It is recommended to use the other timers in your programs.

Note: Memory can't be allocated during a callback (an interrupt) and so exceptions raised within a callback don't give much information. See *micropython.alloc_emergency_exception_buf()* for how to get around this limitation.

Constructors

class pyb.**Timer**(*id*, ...)

Construct a new timer object of the given id. If additional arguments are given, then the timer is initialised by `init(...)`. `id` can be 1 to 14.

Methods

timer.**init**(*, *freq*, *prescaler*, *period*)

Initialise the timer. Initialisation must be either by frequency (in Hz) or by prescaler and period:

```
tim.init(freq=100)                  # set the timer to trigger at 100Hz
tim.init(prescaler=83, period=999)  # set the prescaler and period directly
```

Keyword arguments:

- `freq` — specifies the periodic frequency of the timer. You migh also view this as the frequency with which the timer goes through one complete cycle.
- `prescaler` [0-0xffff] - specifies the value to be loaded into the timer's Prescaler Register (PSC). The timer clock source is divided by (`prescaler + 1`) to arrive at the timer clock. Timers 2-7 and 12-14 have a clock source of 84 MHz (pyb.freq()[2] * 2), and Timers 1, and 8-11 have a clock source of 168 MHz (pyb.freq()[3] * 2).
- `period` [0-0xffff] for timers 1, 3, 4, and 6-15. [0-0x3fffffff] for timers 2 & 5. Specifies the value to be loaded into the timer's AutoReload Register (ARR). This determines the period of the timer (i.e. when the counter cycles). The timer counter will roll-over after `period + 1` timer clock cycles.
- `mode` can be one of:
  - `Timer.UP` - configures the timer to count from 0 to ARR (default)
  - `Timer.DOWN` - configures the timer to count from ARR down to 0.
  - `Timer.CENTER` - confgures the timer to count from 0 to ARR and then back down to 0.
- `div` can be one of 1, 2, or 4. Divides the timer clock to determine the sampling clock used by the digital filters.
- `callback` - as per Timer.callback()

- `deadtime` - specifies the amount of "dead" or inactive time between transitions on complimentary channels (both channels will be inactive) for this time). `deadtime` may be an integer between 0 and 1008, with the following restrictions: 0-128 in steps of 1. 128-256 in steps of 2, 256-512 in steps of 8, and 512-1008 in steps of 16. `deadime` measures ticks of `source_freq` divided by `div` clock ticks. `deadtime` is only available on timers 1 and 8.

You must either specify freq or both of period and prescaler.

`timer.`**`deinit`**`()`

Deinitialises the timer.

Disables the callback (and the associated irq).

Disables any channel callbacks (and the associated irq). Stops the timer, and disables the timer peripheral.

`timer.`**`callback`**`(`*`fun`*`)`

Set the function to be called when the timer triggers. `fun` is passed 1 argument, the timer object. If `fun` is `None` then the callback will be disabled.

`timer.`**`channel`**`(`*`channel`*`, `*`mode`*`, ...)`

If only a channel number is passed, then a previously initialized channel object is returned (or `None` if there is no previous channel).

Othwerwise, a TimerChannel object is initialized and returned.

Each channel can be configured to perform pwm, output compare, or input capture. All channels share the same underlying timer, which means that they share the same timer clock.

Keyword arguments:

- `mode` can be one of:
  - `Timer.PWM` — configure the timer in PWM mode (active high).
  - `Timer.PWM_INVERTED` — configure the timer in PWM mode (active low).
  - `Timer.OC_TIMING` — indicates that no pin is driven.
  - `Timer.OC_ACTIVE` — the pin will be made active when a compare match occurs (active is determined by polarity)
  - `Timer.OC_INACTIVE` — the pin will be made inactive when a compare match occurs.
  - `Timer.OC_TOGGLE` — the pin will be toggled when an compare match occurs.
  - `Timer.OC_FORCED_ACTIVE` — the pin is forced active (compare match is ignored).
  - `Timer.OC_FORCED_INACTIVE` — the pin is forced inactive (compare match is ignored).
  - `Timer.IC` — configure the timer in Input Capture mode.
  - `Timer.ENC_A` — configure the timer in Encoder mode. The counter only changes when CH1 changes.
  - `Timer.ENC_B` — configure the timer in Encoder mode. The counter only changes when CH2 changes.
  - `Timer.ENC_AB` — configure the timer in Encoder mode. The counter changes when CH1 or CH2 changes.
- `callback` - as per TimerChannel.callback()
- `pin` None (the default) or a Pin object. If specified (and not None) this will cause the alternate function of the the indicated pin to be configured for this timer channel. An error will be raised if the pin doesn't support any alternate functions for this timer channel.

Keyword arguments for Timer.PWM modes:

- `pulse_width` - determines the initial pulse width value to use.
- `pulse_width_percent` - determines the initial pulse width percentage to use.

Keyword arguments for Timer.OC modes:

- `compare` - determines the initial value of the compare register.
- `polarity` can be one of:
  - `Timer.HIGH` - output is active high
  - `Timer.LOW` - output is acive low

Optional keyword arguments for Timer.IC modes:

- `polarity` can be one of:
  - `Timer.RISING` - captures on rising edge.
  - `Timer.FALLING` - captures on falling edge.
  - `Timer.BOTH` - captures on both edges.

Note that capture only works on the primary channel, and not on the complimentary channels.

Notes for Timer.ENC modes:

- Requires 2 pins, so one or both pins will need to be configured to use the appropriate timer AF using the Pin API.
- Read the encoder value using the timer.counter() method.
- Only works on CH1 and CH2 (and not on CH1N or CH2N)
- The channel number is ignored when setting the encoder mode.

PWM Example:

```
timer = pyb.Timer(2, freq=1000)
ch2 = timer.channel(2, pyb.Timer.PWM, pin=pyb.Pin.board.X2, pulse_width=8000)
ch3 = timer.channel(3, pyb.Timer.PWM, pin=pyb.Pin.board.X3, pulse_width=16000)
```

`timer.`**`counter`**`([`*value*`])`
Get or set the timer counter.

`timer.`**`freq`**`([`*value*`])`
Get or set the frequency for the timer (changes prescaler and period if set).

`timer.`**`period`**`([`*value*`])`
Get or set the period of the timer.

`timer.`**`prescaler`**`([`*value*`])`
Get or set the prescaler for the timer.

`timer.`**`source_freq`**`()`
Get the frequency of the source of the timer.

class TimerChannel — setup a channel for a timer

Timer channels are used to generate/capture a signal using a timer.

TimerChannel objects are created using the Timer.channel() method.

Methods

`timerchannel.`**`callback`**(*fun*)

Set the function to be called when the timer channel triggers. `fun` is passed 1 argument, the timer object. If `fun` is `None` then the callback will be disabled.

`timerchannel.`**`capture`**([*value*])

Get or set the capture value associated with a channel. capture, compare, and pulse_width are all aliases for the same function. capture is the logical name to use when the channel is in input capture mode.

`timerchannel.`**`compare`**([*value*])

Get or set the compare value associated with a channel. capture, compare, and pulse_width are all aliases for the same function. compare is the logical name to use when the channel is in output compare mode.

`timerchannel.`**`pulse_width`**([*value*])

Get or set the pulse width value associated with a channel. capture, compare, and pulse_width are all aliases for the same function. pulse_width is the logical name to use when the channel is in PWM mode.

In edge aligned mode, a pulse_width of `period + 1` corresponds to a duty cycle of 100% In center aligned mode, a pulse width of `period` corresponds to a duty cycle of 100%

`timerchannel.`**`pulse_width_percent`**([*value*])

Get or set the pulse width percentage associated with a channel. The value is a number between 0 and 100 and sets the percentage of the timer period for which the pulse is active. The value can be an integer or floating-point number for more accuracy. For example, a value of 25 gives a duty cycle of 25%.

class UART – duplex serial communication bus

UART implements the standard UART/USART duplex serial communications protocol. At the physical level it consists of 2 lines: RX and TX. The unit of communication is a character (not to be confused with a string character) which can be 8 or 9 bits wide.

UART objects can be created and initialised using:

```
from pyb import UART

uart = UART(1, 9600)                         # init with given baudrate
uart.init(9600, bits=8, parity=None, stop=1) # init with given parameters
```

Bits can be 7, 8 or 9. Parity can be None, 0 (even) or 1 (odd). Stop can be 1 or 2.

Note: with parity=None, only 8 and 9 bits are supported. With parity enabled, only 7 and 8 bits are supported.

A UART object acts like a stream object and reading and writing is done using the standard stream methods:

```
uart.read(10)       # read 10 characters, returns a bytes object
uart.readall()      # read all available characters
uart.readline()     # read a line
uart.readinto(buf)  # read and store into the given buffer
uart.write('abc')   # write the 3 characters
```

Individual characters can be read/written using:

```
uart.readchar()     # read 1 character and returns it as an integer
uart.writechar(42)  # write 1 character
```

To check if there is anything to be read, use:

```
uart.any()          # returns the number of characters waiting
```

Note: The stream functions `read`, `write`, etc. are new in MicroPython v1.3.4. Earlier versions use `uart.send` and `uart.recv`.

Constructors

class pyb.**UART**(*bus*, ...)

Construct a UART object on the given bus. bus can be 1-6, or 'XA', 'XB', 'YA', or 'YB'. With no additional parameters, the UART object is created but not initialised (it has the settings from the last initialisation of the bus, if any). If extra arguments are given, the bus is initialised. See init for parameters of initialisation.

The physical pins of the UART busses are:

- UART(4) is on XA: (TX, RX) = (X1, X2) = (PA0, PA1)
- UART(1) is on XB: (TX, RX) = (X9, X10) = (PB6, PB7)
- UART(6) is on YA: (TX, RX) = (Y1, Y2) = (PC6, PC7)
- UART(3) is on YB: (TX, RX) = (Y9, Y10) = (PB10, PB11)
- UART(2) is on: (TX, RX) = (X3, X4) = (PA2, PA3)

The Pyboard Lite supports UART(1), UART(2) and UART(6) only. Pins are as above except:

- UART(2) is on: (TX, RX) = (X1, X2) = (PA2, PA3)

Methods

uart.**init**(*baudrate*, *bits=8*, *parity=None*, *stop=1*, ***, *timeout=1000*, *flow=0*, *timeout_char=0*, *read_buf_len=64*)

Initialise the UART bus with the given parameters:

- baudrate is the clock rate.
- bits is the number of bits per character, 7, 8 or 9.
- parity is the parity, None, 0 (even) or 1 (odd).
- stop is the number of stop bits, 1 or 2.
- flow sets the flow control type. Can be 0, UART.RTS, UART.CTS or UART.RTS | UART.CTS.
- timeout is the timeout in milliseconds to wait for the first character.
- timeout_char is the timeout in milliseconds to wait between characters.
- read_buf_len is the character length of the read buffer (0 to disable).

This method will raise an exception if the baudrate could not be set within 5% of the desired value. The minimum baudrate is dictated by the frequency of the bus that the UART is on; UART(1) and UART(6) are APB2, the rest are on APB1. The default bus frequencies give a minimum baudrate of 1300 for UART(1) and UART(6) and 650 for the others. Use *pyb.freq* to reduce the bus frequencies to get lower baudrates.

Note: with parity=None, only 8 and 9 bits are supported. With parity enabled, only 7 and 8 bits are supported.

uart.**deinit**()

Turn off the UART bus.

uart.**any**()

Returns the number of bytes waiting (may be 0).

uart.**writechar**(*char*)

Write a single character on the bus. char is an integer to write. Return value: None. See note below if CTS flow control is used.

uart.**read**([*nbytes*])

Read characters. If nbytes is specified then read at most that many bytes. If nbytes are available in the buffer, returns immediately, otherwise returns when sufficient characters arrive or the timeout elapses.

Note: for 9 bit characters each character takes two bytes, `nbytes` must be even, and the number of characters is `nbytes/2`.

Return value: a bytes object containing the bytes read in. Returns `None` on timeout.

`uart.`**`readall`**`()`
Read as much data as possible. Returns after the timeout has elapsed.

Return value: a bytes object or `None` if timeout prevents any data being read.

`uart.`**`readchar`**`()`
Receive a single character on the bus.

Return value: The character read, as an integer. Returns -1 on timeout.

`uart.`**`readinto`**`(`*buf*[, *nbytes*]`)`
Read bytes into the `buf`. If `nbytes` is specified then read at most that many bytes. Otherwise, read at most `len(buf)` bytes.

Return value: number of bytes read and stored into `buf` or `None` on timeout.

`uart.`**`readline`**`()`
Read a line, ending in a newline character. If such a line exists, return is immediate. If the timeout elapses, all available data is returned regardless of whether a newline exists.

Return value: the line read or `None` on timeout if no data is available.

`uart.`**`write`**`(`*buf*`)`
Write the buffer of bytes to the bus. If characters are 7 or 8 bits wide then each byte is one character. If characters are 9 bits wide then two bytes are used for each character (little endian), and `buf` must contain an even number of bytes.

Return value: number of bytes written. If a timeout occurs and no bytes were written returns `None`.

`uart.`**`sendbreak`**`()`
Send a break condition on the bus. This drives the bus low for a duration of 13 bits. Return value: `None`.

Constants

`UART.`**`RTS`**
`UART.`**`CTS`**
to select the flow control type.

Flow Control On Pyboards V1 and V1.1 `UART(2)` and `UART(3)` support RTS/CTS hardware flow control using the following pins:

- `UART(2)` is on: `(TX, RX, nRTS, nCTS) = (X3, X4, X2, X1) = (PA2, PA3, PA1, PA0)`
- `UART(3)` is on `:(TX, RX, nRTS, nCTS) = (Y9, Y10, Y7, Y6) = (PB10, PB11, PB14, PB13)`

On the Pyboard Lite only `UART(2)` supports flow control on these pins:

```
(TX, RX, nRTS, nCTS) = (X1, X2, X4, X3) = (PA2, PA3, PA1, PA0)
```

In the following paragraphs the term "target" refers to the device connected to the UART.

When the UART's `init()` method is called with `flow` set to one or both of `UART.RTS` and `UART.CTS` the relevant flow control pins are configured. `nRTS` is an active low output, `nCTS` is an active low input with pullup enabled. To achieve flow control the Pyboard's `nCTS` signal should be connected to the target's `nRTS` and the Pyboard's `nRTS` to the target's `nCTS`.

CTS: target controls Pyboard transmitter If CTS flow control is enabled the write behaviour is as follows:

If the Pyboard's `uart.write(buf)` method is called, transmission will stall for any periods when `nCTS` is `False`. This will result in a timeout if the entire buffer was not transmitted in the timeout period. The method returns the number of bytes written, enabling the user to write the remainder of the data if required. In the event of a timeout, a character will remain in the UART pending `nCTS`. The number of bytes composing this character will be included in the return value.

If `uart.writechar()` is called when `nCTS` is `False` the method will time out unless the target asserts `nCTS` in time. If it times out `OSError 116` will be raised. The character will be transmitted as soon as the target asserts `nCTS`.

RTS: Pyboard controls target's transmitter If RTS flow control is enabled, behaviour is as follows:

If buffered input is used (`read_buf_len` > 0), incoming characters are buffered. If the buffer becomes full, the next character to arrive will cause `nRTS` to go `False`: the target should cease transmission. `nRTS` will go `True` when characters are read from the buffer.

Note that the `any()` method returns the number of bytes in the buffer. Assume a buffer length of `N` bytes. If the buffer becomes full, and another character arrives, `nRTS` will be set False, and `any()` will return the count `N`. When characters are read the additional character will be placed in the buffer and will be included in the result of a subsequent `any()` call.

If buffered input is not used (`read_buf_len` == 0) the arrival of a character will cause `nRTS` to go `False` until the character is read.

class USB_VCP – USB virtual comm port

The USB_VCP class allows creation of an object representing the USB virtual comm port. It can be used to read and write data over USB to the connected host.

Constructors

class `pyb.`**`USB_VCP`**
Create a new USB_VCP object.

Methods

`usb_vcp.`**`setinterrupt`**`(`*chr*`)`
Set the character which interrupts running Python code. This is set to 3 (CTRL-C) by default, and when a CTRL-C character is received over the USB VCP port, a KeyboardInterrupt exception is raised.

Set to -1 to disable this interrupt feature. This is useful when you want to send raw bytes over the USB VCP port.

`usb_vcp.`**`isconnected`**`()`
Return `True` if USB is connected as a serial device, else `False`.

`usb_vcp.`**`any`**`()`
Return `True` if any characters waiting, else `False`.

`usb_vcp.`**`close`**`()`
This method does nothing. It exists so the USB_VCP object can act as a file.

`usb_vcp.`**`read`**`(`[*nbytes*]`)`
Read at most `nbytes` from the serial device and return them as a bytes object. If `nbytes` is not specified then the method acts as `readall()`. USB_VCP stream implicitly works in non-blocking mode, so if no pending data available, this method will return immediately with `None` value.

usb_vcp.**readall**()
Read all available bytes from the serial device and return them as a bytes object, or `None` if no pending data available.

usb_vcp.**readinto**(*buf*[, *maxlen*])
Read bytes from the serial device and store them into `buf`, which should be a buffer-like object. At most `len(buf)` bytes are read. If `maxlen` is given and then at most `min(maxlen, len(buf))` bytes are read.

Returns the number of bytes read and stored into `buf` or `None` if no pending data available.

usb_vcp.**readline**()
Read a whole line from the serial device.

Returns a bytes object containing the data, including the trailing newline character or `None` if no pending data available.

usb_vcp.**readlines**()
Read as much data as possible from the serial device, breaking it into lines.

Returns a list of bytes objects, each object being one of the lines. Each line will include the newline character.

usb_vcp.**write**(*buf*)
Write the bytes from `buf` to the serial device.

Returns the number of bytes written.

usb_vcp.**recv**(*data*, *, *timeout=5000*)
Receive data on the bus:

- `data` can be an integer, which is the number of bytes to receive, or a mutable buffer, which will be filled with received bytes.
- `timeout` is the timeout in milliseconds to wait for the receive.

Return value: if `data` is an integer then a new buffer of the bytes received, otherwise the number of bytes read into `data` is returned.

usb_vcp.**send**(*data*, *, *timeout=5000*)
Send data over the USB VCP:

- `data` is the data to send (an integer to send, or a buffer object).
- `timeout` is the timeout in milliseconds to wait for the send.

Return value: number of bytes sent.

CHAPTER 5

The pyboard hardware

For the pyboard:

- PYBv1.0 schematics and layout (2.4MiB PDF)
- PYBv1.0 metric dimensions (360KiB PDF)
- PYBv1.0 imperial dimensions (360KiB PDF)

For the official skin modules:

- LCD32MKv1.0 schematics (194KiB PDF)
- AMPv1.0 schematics (209KiB PDF)

CHAPTER 6

Datasheets for the components on the pyboard

- The microcontroller: STM32F405RGT6 (link to manufacturer's site)
- The accelerometer: Freescale MMA7660 (800kiB PDF)
- The LDO voltage regulator: Microchip MCP1802 (400kiB PDF)

CHAPTER 7

Datasheets for other components

- The LCD display on the LCD touch-sensor skin: Newhaven Display NHD-C12832A1Z-FSW-FBW-3V3 (460KiB PDF)
- The touch sensor chip on the LCD touch-sensor skin: Freescale MPR121 (280KiB PDF)
- The digital potentiometer on the audio skin: Microchip MCP4541 (2.7MiB PDF)

CHAPTER 8

MicroPython license information

CHAPTER 9

MicroPython documentation contents

9.1 The MicroPython language

MicroPython aims to implement the Python 3.4 standard, and most of the features of MicroPython are identical to those described by the documentation at docs.python.org.

Differences to standard Python as well as additional features of MicroPython are described in the sections here.

9.1.1 The MicroPython Interactive Interpreter Mode (aka REPL)

This section covers some characteristics of the MicroPython Interactive Interpreter Mode. A commonly used term for this is REPL (read-eval-print-loop) which will be used to refer to this interactive prompt.

Auto-indent

When typing python statements which end in a colon (for example if, for, while) then the prompt will change to three dots (...) and the cursor will be indented by 4 spaces. When you press return, the next line will continue at the same level of indentation for regular statements or an additional level of indentation where appropriate. If you press the backspace key then it will undo one level of indentation.

If your cursor is all the way back at the beginning, pressing RETURN will then execute the code that you've entered. The following shows what you'd see after entering a for statement (the underscore shows where the cursor winds up):

```
>>> for i in range(3):
...     _
```

If you then enter an if statement, an additional level of indentation will be provided:

```
>>> for i in range(30):
...     if i > 3:
...         _
```

Now enter `break` followed by RETURN and press BACKSPACE:

```
>>> for i in range(30):
...     if i > 3:
...         break
...     _
```

Finally type `print(i)`, press RETURN, press BACKSPACE and press RETURN again:

```
>>> for i in range(30):
...     if i > 3:
...         break
...     print(i)
...
0
1
2
3
>>>
```

Auto-indent won't be applied if the previous two lines were all spaces. This means that you can finish entering a compound statment by pressing RETURN twice, and then a third press will finish and execute.

Auto-completion

While typing a command at the REPL, if the line typed so far corresponds to the beginning of the name of something, then pressing TAB will show possible things that could be entered. For example type `m` and press TAB and it should expand to `machine`. Enter a dot `.` and press TAB again. You should see something like:

```
>>> machine.
__name__        info            unique_id       reset
bootloader      freq            rng             idle
sleep           deepsleep       disable_irq     enable_irq
Pin
```

The word will be expanded as much as possible until multiple possibilities exist. For example, type `machine.Pin.AF3` and press TAB and it will expand to `machine.Pin.AF3_TIM`. Pressing TAB a second time will show the possible expansions:

```
>>> machine.Pin.AF3_TIM
AF3_TIM10       AF3_TIM11       AF3_TIM8        AF3_TIM9
>>> machine.Pin.AF3_TIM
```

Interrupting a running program

You can interupt a running program by pressing Ctrl-C. This will raise a KeyboardInterrupt which will bring you back to the REPL, providing your program doesn't intercept the KeyboardInterrupt exception.

For example:

```
>>> for i in range(1000000):
...     print(i)
...
0
1
2
3
...
6466
6467
6468
Traceback (most recent call last):
  File "<stdin>", line 2, in <module>
KeyboardInterrupt:
>>>
```

Paste Mode

If you want to paste some code into your terminal window, the auto-indent feature will mess things up. For example, if you had the following python code:

```
def foo():
    print('This is a test to show paste mode')
    print('Here is a second line')
foo()
```

and you try to paste this into the normal REPL, then you will see something like this:

```
>>> def foo():
...         print('This is a test to show paste mode')
...             print('Here is a second line')
...             foo()
...
  File "<stdin>", line 3
IndentationError: unexpected indent
```

If you press Ctrl-E, then you will enter paste mode, which essentially turns off the auto-indent feature, and changes the prompt from >>> to ===. For example:

```
>>>
paste mode; Ctrl-C to cancel, Ctrl-D to finish
=== def foo():
===     print('This is a test to show paste mode')
===     print('Here is a second line')
=== foo()
===
This is a test to show paste mode
Here is a second line
>>>
```

Paste Mode allows blank lines to be pasted. The pasted text is compiled as if it were a file. Pressing Ctrl-D exits paste mode and initiates the compilation.

Soft Reset

A soft reset will reset the python interpreter, but tries not to reset the method by which you're connected to the MicroPython board (USB-serial, or Wifi).

You can perform a soft reset from the REPL by pressing Ctrl-D, or from your python code by executing:

```
raise SystemExit
```

For example, if you reset your MicroPython board, and you execute a dir() command, you'd see something like this:

```
>>> dir()
['__name__', 'pyb']
```

Now create some variables and repeat the dir() command:

```
>>> i = 1
>>> j = 23
>>> x = 'abc'
>>> dir()
['j', 'x', '__name__', 'pyb', 'i']
>>>
```

Now if you enter Ctrl-D, and repeat the dir() command, you'll see that your variables no longer exist:

```
PYB: sync filesystems
PYB: soft reboot
MicroPython v1.5-51-g6f70283-dirty on 2015-10-30; PYBv1.0 with STM32F405RG
Type "help()" for more information.
>>> dir()
['__name__', 'pyb']
>>>
```

The special variable _ (underscore)

When you use the REPL, you may perfom computations and see the results. MicroPython stores the results of the previous statment in the variable _ (underscore). So you can use the underscore to save the result in a variable. For example:

```
>>> 1 + 2 + 3 + 4 + 5
15
>>> x = _
>>> x
15
>>>
```

Raw Mode

Raw mode is not something that a person would normally use. It is intended for programmatic use. It essentially behaves like paste mode with echo turned off.

Raw mode is entered using Ctrl-A. You then send your python code, followed by a Ctrl-D. The Ctrl-D will be acknowledged by 'OK' and then the python code will be compiled and executed. Any output (or errors) will be sent back. Entering Ctrl-B will leave raw mode and return the the regular (aka friendly) REPL.

The `tools/pyboard.py` program uses the raw REPL to execute python files on the MicroPython board.

9.1.2 Writing interrupt handlers

On suitable hardware MicroPython offers the ability to write interrupt handlers in Python. Interrupt handlers - also known as interrupt service routines (ISR's) - are defined as callback functions. These are executed in response to an event such as a timer trigger or a voltage change on a pin. Such events can occur at any point in the execution of the program code. This carries significant consequences, some specific to the MicroPython language. Others are common to all systems capable of responding to real time events. This document covers the language specific issues first, followed by a brief introduction to real time programming for those new to it.

This introduction uses vague terms like "slow" or "as fast as possible". This is deliberate, as speeds are application dependent. Acceptable durations for an ISR are dependent on the rate at which interrupts occur, the nature of the main program, and the presence of other concurrent events.

Tips and recommended practices

This summarises the points detailed below and lists the principal recommendations for interrupt handler code.

- Keep the code as short and simple as possible.
- Avoid memory allocation: no appending to lists or insertion into dictionaries, no floating point.

- Where an ISR returns multiple bytes use a pre-allocated `bytearray`. If multiple integers are to be shared between an ISR and the main program consider an array (`array.array`).
- Where data is shared between the main program and an ISR, consider disabling interrupts prior to accessing the data in the main program and re-enabling them immediately afterwards (see Critcal Sections).
- Allocate an emergency exception buffer (see below).

MicroPython Issues

The emergency exception buffer

If an error occurs in an ISR, MicroPython is unable to produce an error report unless a special buffer is created for the purpose. Debugging is simplified if the following code is included in any program using interrupts.

```
import micropython
micropython.alloc_emergency_exception_buf(100)
```

Simplicity

For a variety of reasons it is important to keep ISR code as short and simple as possible. It should do only what has to be done immediately after the event which caused it: operations which can be deferred should be delegated to the main program loop. Typically an ISR will deal with the hardware device which caused the interrupt, making it ready for the next interrupt to occur. It will communicate with the main loop by updating shared data to indicate that the interrupt has occurred, and it will return. An ISR should return control to the main loop as quickly as possible. This is not a specific MicroPython issue so is covered in more detail *below*.

Communication between an ISR and the main program

Normally an ISR needs to communicate with the main program. The simplest means of doing this is via one or more shared data objects, either declared as global or shared via a class (see below). There are various restrictions and hazards around doing this, which are covered in more detail below. Integers, `bytes` and `bytearray` objects are commonly used for this purpose along with arrays (from the array module) which can store various data types.

The use of object methods as callbacks

MicroPython supports this powerful technique which enables an ISR to share instance variables with the underlying code. It also enables a class implementing a device driver to support multiple device instances. The following example causes two LED's to flash at different rates.

```
import pyb, micropython
micropython.alloc_emergency_exception_buf(100)
class Foo(object):
    def __init__(self, timer, led):
        self.led = led
        timer.callback(self.cb)
    def cb(self, tim):
        self.led.toggle()

red = Foo(pyb.Timer(4, freq=1), pyb.LED(1))
greeen = Foo(pyb.Timer(2, freq=0.8), pyb.LED(2))
```

In this example the `red` instance associates timer 4 with LED 1: when a timer 4 interrupt occurs `red.cb()` is called causing LED 1 to change state. The `green` instance operates similarly: a timer 2 interrupt results in the execution of `green.cb()` and toggles LED 2. The use of instance methods confers two benefits. Firstly a single class enables code to be shared between multiple hardware instances. Secondly, as a bound method the callback function's first argument is `self`. This enables the callback to access instance data and to save state between successive calls. For example, if the class above had a variable `self.count` set to zero in the constructor, `cb()` could increment the counter. The `red` and `green` instances would then maintain independent counts of the number of times each LED had changed state.

Creation of Python objects

ISR's cannot create instances of Python objects. This is because MicroPython needs to allocate memory for the object from a store of free memory block called the heap. This is not permitted in an interrupt handler because heap allocation is not re-entrant. In other words the interrupt might occur when the main program is part way through performing an allocation - to maintain the integrity of the heap the interpreter disallows memory allocations in ISR code.

A consequence of this is that ISR's can't use floating point arithmetic; this is because floats are Python objects. Similarly an ISR can't append an item to a list. In practice it can be hard to determine exactly which code constructs will attempt to perform memory allocation and provoke an error message: another reason for keeping ISR code short and simple.

One way to avoid this issue is for the ISR to use pre-allocated buffers. For example a class constructor creates a `bytearray` instance and a boolean flag. The ISR method assigns data to locations in the buffer and sets the flag. The memory allocation occurs in the main program code when the object is instantiated rather than in the ISR.

The MicroPython library I/O methods usually provide an option to use a pre-allocated buffer. For example `pyb.i2c.recv()` can accept a mutable buffer as its first argument: this enables its use in an ISR.

Use of Python objects

A further restriction on objects arises because of the way Python works. When an `import` statement is executed the Python code is compiled to bytecode, with one line of code typically mapping to multiple bytecodes. When the code runs the interpreter reads each bytecode and executes it as a series of machine code instructions. Given that an interrupt can occur at any time between machine code instructions, the original line of Python code may be only partially executed. Consequently a Python object such as a set, list or dictionary modified in the main loop may lack internal consistency at the moment the interrupt occurs.

A typical outcome is as follows. On rare occasions the ISR will run at the precise moment in time when the object is partially updated. When the ISR tries to read the object, a crash results. Because such problems typically occur on rare, random occasions they can be hard to diagnose. There are ways to circumvent this issue, described in *Critical Sections* below.

It is important to be clear about what constitutes the modification of an object. An alteration to a built-in type such as a dictionary is problematic. Altering the contents of an array or bytearray is not. This is because bytes or words are written as a single machine code instruction which is not interruptible: in the parlance of real time programming the write is atomic. A user defined object might instantiate an integer, array or bytearray. It is valid for both the main loop and the ISR to alter the contents of these.

MicroPython supports integers of arbitrary precision. Values between 2**30 -1 and -2**30 will be stored in a single machine word. Larger values are stored as Python objects. Consequently changes to long integers cannot be considered atomic. The use of long integers in ISR's is unsafe because memory allocation may be attempted as the variable's value changes.

Overcoming the float limitation

In general it is best to avoid using floats in ISR code: hardware devices normally handle integers and conversion to floats is normally done in the main loop. However there are a few DSP algorithms which require floating point. On platforms with hardware floating point (such as the Pyboard) the inline ARM Thumb assembler can be used to work round this limitation. This is because the processor stores float values in a machine word; values can be shared between the ISR and main program code via an array of floats.

Exceptions

If an ISR raises an exception it will not propagate to the main loop. The interrupt will be disabled unless the exception is handled by the ISR code.

General Issues

This is merely a brief introduction to the subject of real time programming. Beginners should note that design errors in real time programs can lead to faults which are particularly hard to diagnose. This is because they can occur rarely and at intervals which are essentially random. It is crucial to get the initial design right and to anticipate issues before they arise. Both interrupt handlers and the main program need to be designed with an appreciation of the following issues.

Interrupt Handler Design

As mentioned above, ISR's should be designed to be as simple as possible. They should always return in a short, predictable period of time. This is important because when the ISR is running, the main loop is not: inevitably the main loop experiences pauses in its execution at random points in the code. Such pauses can be a source of hard to diagnose bugs particularly if their duration is long or variable. In order to understand the implications of ISR run time, a basic grasp of interrupt priorities is required.

Interrupts are organised according to a priority scheme. ISR code may itself be interrupted by a higher priority interrupt. This has implications if the two interrupts share data (see Critical Sections below). If such an interrupt occurs it interposes a delay into the ISR code. If a lower priority interrupt occurs while the ISR is running, it will be delayed until the ISR is complete: if the delay is too long, the lower priority interrupt may fail. A further issue with slow ISR's is the case where a second interrupt of the same type occurs during its execution. The second interrupt will be handled on termination of the first. However if the rate of incoming interrupts consistently exceeds the capacity of the ISR to service them the outcome will not be a happy one.

Consequently looping constructs should be avoided or minimised. I/O to devices other than to the interrupting device should normally be avoided: I/O such as disk access, `print` statements and UART access is relatively slow, and its duration may vary. A further issue here is that filesystem functions are not reentrant: using filesystem I/O in an ISR and the main program would be hazardous. Crucially ISR code should not wait on an event. I/O is acceptable if the code can be guaranteed to return in a predictable period, for example toggling a pin or LED. Accessing the interrupting device via I2C or SPI may be necessary but the time taken for such accesses should be calculated or measured and its impact on the application assessed.

There is usually a need to share data between the ISR and the main loop. This may be done either through global variables or via class or instance variables. Variables are typically integer or boolean types, or integer or byte arrays (a pre-allocated integer array offers faster access than a list). Where multiple values are modified by the ISR it is necessary to consider the case where the interrupt occurs at a time when the main program has accessed some, but not all, of the values. This can lead to inconsistencies.

Consider the following design. An ISR stores incoming data in a bytearray, then adds the number of bytes received to an integer representing total bytes ready for processing. The main program reads the number of bytes, processes the

bytes, then clears down the number of bytes ready. This will work until an interrupt occurs just after the main program has read the number of bytes. The ISR puts the added data into the buffer and updates the number received, but the main program has already read the number, so processes the data originally received. The newly arrived bytes are lost.

There are various ways of avoiding this hazard, the simplest being to use a circular buffer. If it is not possible to use a structure with inherent thread safety other ways are described below.

Reentrancy

A potential hazard may occur if a function or method is shared between the main program and one or more ISR's or between multiple ISR's. The issue here is that the function may itself be interrupted and a further instance of that function run. If this is to occur, the function must be designed to be reentrant. How this is done is an advanced topic beyond the scope of this tutorial.

Critical Sections

An example of a critical section of code is one which accesses more than one variable which can be affected by an ISR. If the interrupt happens to occur between accesses to the individual variables, their values will be inconsistent. This is an instance of a hazard known as a race condition: the ISR and the main program loop race to alter the variables. To avoid inconsistency a means must be employed to ensure that the ISR does not alter the values for the duration of the critical section. One way to achieve this is to issue `pyb.disable_irq()` before the start of the section, and `pyb.enable_irq()` at the end. Here is an example of this approach:

```
import pyb, micropython, array
micropython.alloc_emergency_exception_buf(100)

class BoundsException(Exception):
    pass

ARRAYSIZE = const(20)
index = 0
data = array.array('i', 0 for x in range(ARRAYSIZE))

def callback1(t):
    global data, index
    for x in range(5):
        data[index] = pyb.rng() # simulate input
        index += 1
        if index >= ARRAYSIZE:
            raise BoundsException('Array bounds exceeded')

tim4 = pyb.Timer(4, freq=100, callback=callback1)

for loop in range(1000):
    if index > 0:
        irq_state = pyb.disable_irq() # Start of critical section
        for x in range(index):
            print(data[x])
        index = 0
        pyb.enable_irq(irq_state) # End of critical section
        print('loop {}'.format(loop))
    pyb.delay(1)

tim4.callback(None)
```

A critical section can comprise a single line of code and a single variable. Consider the following code fragment.

```
count = 0
def cb(): # An interrupt callback
    count +=1
def main():
    # Code to set up the interrupt callback omitted
    while True:
        count += 1
```

This example illustrates a subtle source of bugs. The line `count += 1` in the main loop carries a specific race condition hazard known as a read-modify-write. This is a classic cause of bugs in real time systems. In the main loop MicroPython reads the value of `t.counter`, adds 1 to it, and writes it back. On rare occasions the interrupt occurs after the read and before the write. The interrupt modifies `t.counter` but its change is overwritten by the main loop when the ISR returns. In a real system this could lead to rare, unpredictable failures.

As mentioned above, care should be taken if an instance of a Python built in type is modified in the main code and that instance is accessed in an ISR. The code performing the modification should be regarded as a critical section to ensure that the instance is in a valid state when the ISR runs.

Particular care needs to be taken if a dataset is shared between different ISR's. The hazard here is that the higher priority interrupt may occur when the lower priority one has partially updated the shared data. Dealing with this situation is an advanced topic beyond the scope of this introduction other than to note that mutex objects described below can sometimes be used.

Disabling interrupts for the duration of a critical section is the usual and simplest way to proceed, but it disables all interrupts rather than merely the one with the potential to cause problems. It is generally undesirable to disable an interrupt for long. In the case of timer interrupts it introduces variability to the time when a callback occurs. In the case of device interrupts, it can lead to the device being serviced too late with possible loss of data or overrun errors in the device hardware. Like ISR's, a critical section in the main code should have a short, predictable duration.

An approach to dealing with critical sections which radically reduces the time for which interrupts are disabled is to use an object termed a mutex (name derived from the notion of mutual exclusion). The main program locks the mutex before running the critical section and unlocks it at the end. The ISR tests whether the mutex is locked. If it is, it avoids the critical section and returns. The design challenge is defining what the ISR should do in the event that access to the critical variables is denied. A simple example of a mutex may be found here. Note that the mutex code does disable interrupts, but only for the duration of eight machine instructions: the benefit of this approach is that other interrupts are virtually unaffected.

9.1.3 Maximising Python Speed

This tutorial describes ways of improving the performance of MicroPython code. Optimisations involving other languages are covered elsewhere, namely the use of modules written in C and the MicroPython inline ARM Thumb-2 assembler.

The process of developing high performance code comprises the following stages which should be performed in the order listed.

- Design for speed.
- Code and debug.

Optimisation steps:

- Identify the slowest section of code.
- Improve the efficiency of the Python code.
- Use the native code emitter.
- Use the viper code emitter.

Designing for speed

Performance issues should be considered at the outset. This involves taking a view on the sections of code which are most performance critical and devoting particular attention to their design. The process of optimisation begins when the code has been tested: if the design is correct at the outset optimisation will be straightforward and may actually be unnecessary.

Algorithms

The most important aspect of designing any routine for performance is ensuring that the best algorithm is employed. This is a topic for textbooks rather than for a MicroPython guide but spectacular performance gains can sometimes be achieved by adopting algorithms known for their efficiency.

RAM Allocation

To design efficient MicroPython code it is necessary to have an understanding of the way the interpreter allocates RAM. When an object is created or grows in size (for example where an item is appended to a list) the necessary RAM is allocated from a block known as the heap. This takes a significant amount of time; further it will on occasion trigger a process known as garbage collection which can take several milliseconds.

Consequently the performance of a function or method can be improved if an object is created once only and not permitted to grow in size. This implies that the object persists for the duration of its use: typically it will be instantiated in a class constructor and used in various methods.

This is covered in further detail *Controlling garbage collection* below.

Buffers

An example of the above is the common case where a buffer is required, such as one used for communication with a device. A typical driver will create the buffer in the constructor and use it in its I/O methods which will be called repeatedly.

The MicroPython libraries typically provide support for pre-allocated buffers. For example, objects which support stream interface (e.g., file or UART) provide `read()` method which allocate new buffer for read data, but also a `readinto()` method to read data into an existing buffer.

Floating Point

Some MicroPython ports allocate floating point numbers on heap. Some other ports may lack dedicated floating-point coprocessor, and perform arithmetic operations on them in "software" at considerably lower speed than on integers. Where performance is important, use integer operations and restrict the use of floating point to sections of the code where performance is not paramount. For example, capture ADC readings as integers values to an array in one quick go, and only then convert them to floating-point numbers for signal processing.

Arrays

Consider the use of the various types of array classes as an alternative to lists. The `array` module supports various element types with 8-bit elements supported by Python's built in `bytes` and `bytearray` classes. These data structures all store elements in contiguous memory locations. Once again to avoid memory allocation in critical code these should be pre-allocated and passed as arguments or as bound objects.

When passing slices of objects such as `bytearray` instances, Python creates a copy which involves allocation of the size proportional to the size of slice. This can be alleviated using a `memoryview` object. `memoryview` itself is allocated on heap, but is a small, fixed-size object, regardless of the size of slice it points too.

```
ba = bytearray(10000)   # big array
func(ba[30:2000])       # a copy is passed, ~2K new allocation
mv = memoryview(ba)     # small object is allocated
func(mv[30:2000])       # a pointer to memory is passed
```

A `memoryview` can only be applied to objects supporting the buffer protocol - this includes arrays but not lists. Small caveat is that while memoryview object is live, it also keeps alive the original buffer object. So, a memoryview isn't a universal panacea. For instance, in the example above, if you are done with 10K buffer and just need those bytes 30:2000 from it, it may be better to make a slice, and let the 10K buffer go (be ready for garbage collection), instead of making a long-living memoryview and keeping 10K blocked for GC.

Nonetheless, `memoryview` is indispensable for advanced preallocated buffer management. `.readinto()` method discussed above puts data at the beginning of buffer and fills in entire buffer. What if you need to put data in the middle of existing buffer? Just create a memoryview into the needed section of buffer and pass it to `.readinto()`.

Identifying the slowest section of code

This is a process known as profiling and is covered in textbooks and (for standard Python) supported by various software tools. For the type of smaller embedded application likely to be running on MicroPython platforms the slowest function or method can usually be established by judicious use of the timing `ticks` group of functions documented here. Code execution time can be measured in ms, us, or CPU cycles.

The following enables any function or method to be timed by adding an `@timed_function` decorator:

```
def timed_function(f, *args, **kwargs):
    myname = str(f).split(' ')[1]
    def new_func(*args, **kwargs):
        t = time.ticks_us()
        result = f(*args, **kwargs)
        delta = time.ticks_diff(t, time.ticks_us())
        print('Function {} Time = {:6.3f}ms'.format(myname, delta/1000))
        return result
    return new_func
```

MicroPython code improvements

The const() declaration

MicroPython provides a `const()` declaration. This works in a similar way to `#define` in C in that when the code is compiled to bytecode the compiler substitutes the numeric value for the identifier. This avoids a dictionary lookup at runtime. The argument to `const()` may be anything which, at compile time, evaluates to an integer e.g. `0x100` or `1 << 8`.

Caching object references

Where a function or method repeatedly accesses objects performance is improved by caching the object in a local variable:

```
class foo(object):
    def __init__(self):
        ba = bytearray(100)
    def bar(self, obj_display):
        ba_ref = self.ba
        fb = obj_display.framebuffer
        # iterative code using these two objects
```

This avoids the need repeatedly to look up `self.ba` and `obj_display.framebuffer` in the body of the method `bar()`.

Controlling garbage collection

When memory allocation is required, MicroPython attempts to locate an adequately sized block on the heap. This may fail, usually because the heap is cluttered with objects which are no longer referenced by code. If a failure occurs, the process known as garbage collection reclaims the memory used by these redundant objects and the allocation is then tried again - a process which can take several milliseconds.

There are benefits in pre-empting this by periodically issuing `gc.collect()`. Firstly doing a collection before it is actually required is quicker - typically on the order of 1ms if done frequently. Secondly you can determine the point in code where this time is used rather than have a longer delay occur at random points, possibly in a speed critical section. Finally performing collections regularly can reduce fragmentation in the heap. Severe fragmentation can lead to non-recoverable allocation failures.

Accessing hardware directly

This comes into the category of more advanced programming and involves some knowledge of the target MCU. Consider the example of toggling an output pin on the Pyboard. The standard approach would be to write

```
mypin.value(mypin.value() ^ 1) # mypin was instantiated as an output pin
```

This involves the overhead of two calls to the `Pin` instance's `value()` method. This overhead can be eliminated by performing a read/write to the relevant bit of the chip's GPIO port output data register (odr). To facilitate this the `stm` module provides a set of constants providing the addresses of the relevant registers. A fast toggle of pin `P4` (CPU pin `A14`) - corresponding to the green LED - can be performed as follows:

```
BIT14 = const(1 << 14)
stm.mem16[stm.GPIOA + stm.GPIO_ODR] ^= BIT14
```

The Native code emitter

This causes the MicroPython compiler to emit ARM native opcodes rather than bytecode. It covers the bulk of the Python language so most functions will require no adaptation (but see below). It is invoked by means of a function decorator:

```
@micropython.native
def foo(self, arg):
    buf = self.linebuf # Cached object
    # code
```

There are certain limitations in the current implementation of the native code emitter.

- Context managers are not supported (the `with` statement).
- Generators are not supported.

- If `raise` is used an argument must be supplied.

The trade-off for the improved performance (roughly twices as fast as bytecode) is an increase in compiled code size.

The Viper code emitter

The optimisations discussed above involve standards-compliant Python code. The Viper code emitter is not fully compliant. It supports special Viper native data types in pursuit of performance. Integer processing is non-compliant because it uses machine words: arithmetic on 32 bit hardware is performed modulo 2**32.

Like the Native emitter Viper produces machine instructions but further optimisations are performed, substantially increasing performance especially for integer arithmetic and bit manipulations. It is invoked using a decorator:

```
@micropython.viper
def foo(self, arg: int) -> int:
    # code
```

As the above fragment illustrates it is beneficial to use Python type hints to assist the Viper optimiser. Type hints provide information on the data types of arguments and of the return value; these are a standard Python language feature formally defined here PEP0484. Viper supports its own set of types namely `int`, `uint` (unsigned integer), `ptr`, `ptr8`, `ptr16` and `ptr32`. The `ptrX` types are discussed below. Currently the `uint` type serves a single purpose: as a type hint for a function return value. If such a function returns `0xffffffff` Python will interpret the result as 2**32 -1 rather than as -1.

In addition to the restrictions imposed by the native emitter the following constraints apply:

- Functions may have up to four arguments.
- Default argument values are not permitted.
- Floating point may be used but is not optimised.

Viper provides pointer types to assist the optimiser. These comprise

- `ptr` Pointer to an object.
- `ptr8` Points to a byte.
- `ptr16` Points to a 16 bit half-word.
- `ptr32` Points to a 32 bit machine word.

The concept of a pointer may be unfamiliar to Python programmers. It has similarities to a Python `memoryview` object in that it provides direct access to data stored in memory. Items are accessed using subscript notation, but slices are not supported: a pointer can return a single item only. Its purpose is to provide fast random access to data stored in contiguous memory locations - such as data stored in objects which support the buffer protocol, and memory-mapped peripheral registers in a microcontroller. It should be noted that programming using pointers is hazardous: bounds checking is not performed and the compiler does nothing to prevent buffer overrun errors.

Typical usage is to cache variables:

```
@micropython.viper
def foo(self, arg: int) -> int:
    buf = ptr8(self.linebuf) # self.linebuf is a bytearray or bytes object
    for x in range(20, 30):
        bar = buf[x] # Access a data item through the pointer
        # code omitted
```

In this instance the compiler "knows" that `buf` is the address of an array of bytes; it can emit code to rapidly compute the address of `buf[x]` at runtime. Where casts are used to convert objects to Viper native types these should be performed at the start of the function rather than in critical timing loops as the cast operation can take several microseconds. The rules for casting are as follows:

- Casting operators are currently: `int`, `bool`, `uint`, `ptr`, `ptr8`, `ptr16` and `ptr32`.
- The result of a cast will be a native Viper variable.
- Arguments to a cast can be a Python object or a native Viper variable.
- If argument is a native Viper variable, then cast is a no-op (i.e. costs nothing at runtime) that just changes the type (e.g. from `uint` to `ptr8`) so that you can then store/load using this pointer.
- If the argument is a Python object and the cast is `int` or `uint`, then the Python object must be of integral type and the value of that integral object is returned.
- The argument to a bool cast must be integral type (boolean or integer); when used as a return type the viper function will return True or False objects.
- If the argument is a Python object and the cast is `ptr`, `ptr`, `ptr16` or `ptr32`, then the Python object must either have the buffer protocol with read-write capabilities (in which case a pointer to the start of the buffer is returned) or it must be of integral type (in which case the value of that integral object is returned).

The following example illustrates the use of a `ptr16` cast to toggle pin X1 `n` times:

```
BIT0 = const(1)
@micropython.viper
def toggle_n(n: int):
    odr = ptr16(stm.GPIOA + stm.GPIO_ODR)
    for _ in range(n):
        odr[0] ^= BIT0
```

A detailed technical description of the three code emitters may be found on Kickstarter here Note 1 and here Note 2

9.1.4 Inline Assembler for Thumb2 architectures

This document assumes some familiarity with assembly language programming and should be read after studying the *tutorial*. For a detailed description of the instruction set consult the Architecture Reference Manual detailed below. The inline assembler supports a subset of the ARM Thumb-2 instruction set described here. The syntax tries to be as close as possible to that defined in the above ARM manual, converted to Python function calls.

Instructions operate on 32 bit signed integer data except where stated otherwise. Most supported instructions operate on registers `R0-R7` only: where `R8-R15` are supported this is stated. Registers `R8-R12` must be restored to their initial value before return from a function. Registers `R13-R15` constitute the Link Register, Stack Pointer and Program Counter respectively.

Document conventions

Where possible the behaviour of each instruction is described in Python, for example

- add(Rd, Rn, Rm) `Rd = Rn + Rm`

This enables the effect of instructions to be demonstrated in Python. In certain case this is impossible because Python doesn't support concepts such as indirection. The pseudocode employed in such cases is described on the relevant page.

Instruction Categories

The following sections details the subset of the ARM Thumb-2 instruction set supported by MicroPython.

Register move instructions

Document conventions Notation: `Rd, Rn` denote ARM registers R0-R15. `immN` denotes an immediate value having a width of N bits. These instructions affect the condition flags.

Register moves Where immediate values are used, these are zero-extended to 32 bits. Thus `mov(R0, 0xff)` will set R0 to 255.

- mov(Rd, imm8) `Rd = imm8`
- mov(Rd, Rn) `Rd = Rn`
- movw(Rd, imm16) `Rd = imm16`
- movt(Rd, imm16) `Rd = (Rd & 0xffff) | (imm16 << 16)`

movt writes an immediate value to the top halfword of the destination register. It does not affect the contents of the bottom halfword.

- movwt(Rd, imm32) `Rd = imm32`

movwt is a pseudo-instruction: the MicroPython assembler emits a `movw` followed by a `movt` to move a 32-bit value into Rd.

Load register from memory

Document conventions Notation: `Rt, Rn` denote ARM registers R0-R7 except where stated. `immN` represents an immediate value having a width of N bits hence `imm5` is constrained to the range 0-31. `[Rn + immN]` is the contents of the memory address obtained by adding Rn and the offset `immN`. Offsets are measured in bytes. These instructions affect the condition flags.

Register Load

- ldr(Rt, [Rn, imm7]) `Rt = [Rn + imm7]` Load a 32 bit word
- ldrb(Rt, [Rn, imm5]) `Rt = [Rn + imm5]` Load a byte
- ldrh(Rt, [Rn, imm6]) `Rt = [Rn + imm6]` Load a 16 bit half word

Where a byte or half word is loaded, it is zero-extended to 32 bits.

The specified immediate offsets are measured in bytes. Hence in the case of `ldr` the 7 bit value enables 32 bit word aligned values to be accessed with a maximum offset of 31 words. In the case of `ldrh` the 6 bit value enables 16 bit half-word aligned values to be accessed with a maximum offset of 31 half-words.

Store register to memory

Document conventions Notation: `Rt, Rn` denote ARM registers R0-R7 except where stated. `immN` represents an immediate value having a width of N bits hence `imm5` is constrained to the range 0-31. `[Rn + imm5]` is the contents of the memory address obtained by adding Rn and the offset `imm5`. Offsets are measured in bytes. These instructions do not affect the condition flags.

Register Store

- str(Rt, [Rn, imm7]) `[Rn + imm7] = Rt` Store a 32 bit word
- strb(Rt, [Rn, imm5]) `[Rn + imm5] = Rt` Store a byte (b0-b7)
- strh(Rt, [Rn, imm6]) `[Rn + imm6] = Rt` Store a 16 bit half word (b0-b15)

The specified immediate offsets are measured in bytes. Hence in the case of `str` the 7 bit value enables 32 bit word aligned values to be accessed with a maximum offset of 31 words. In the case of `strh` the 6 bit value enables 16 bit half-word aligned values to be accessed with a maximum offset of 31 half-words.

Logical & Bitwise instructions

Document conventions Notation: `Rd, Rn` denote ARM registers R0-R7 except in the case of the special instructions where R0-R15 may be used. `Rn<a-b>` denotes an ARM register whose contents must lie in range `a <= contents <= b`. In the case of instructions with two register arguments, it is permissible for them to be identical. For example the following will zero R0 (Python `R0 ^= R0`) regardless of its initial contents.

- eor(r0, r0)

These instructions affect the condition flags except where stated.

Logical instructions

- and_(Rd, Rn) `Rd &= Rn`
- orr(Rd, Rn) `Rd |= Rn`
- eor(Rd, Rn) `Rd ^= Rn`
- mvn(Rd, Rn) `Rd = Rn ^ 0xffffffff` i.e. Rd = 1's complement of Rn
- bic(Rd, Rn) `Rd &= ~Rn` bit clear Rd using mask in Rn

Note the use of "and_" instead of "and", because "and" is a reserved keyword in Python.

Shift and rotation instructions

- lsl(Rd, Rn<0-31>) `Rd <<= Rn`
- lsr(Rd, Rn<1-32>) `Rd = (Rd & 0xffffffff) >> Rn` Logical shift right
- asr(Rd, Rn<1-32>) `Rd >>= Rn` arithmetic shift right
- ror(Rd, Rn<1-31>) `Rd = rotate_right(Rd, Rn)` Rd is rotated right Rn bits.

A rotation by (for example) three bits works as follows. If Rd initially contains bits `b31 b30..b0` after rotation it will contain `b2 b1 b0 b31 b30..b3`

Special instructions Condition codes are unaffected by these instructions.

- clz(Rd, Rn) `Rd = count_leading_zeros(Rn)`

count_leading_zeros(Rn) returns the number of binary zero bits before the first binary one bit in Rn.

- rbit(Rd, Rn) `Rd = bit_reverse(Rn)`

bit_reverse(Rn) returns the bit-reversed contents of Rn. If Rn contains bits `b31 b30..b0` Rd will be set to `b0 b1 b2..b31`

Trailing zeros may be counted by performing a bit reverse prior to executing clz.

Arithmetic instructions

Document conventions Notation: `Rd, Rm, Rn` denote ARM registers R0-R7. `immN` denotes an immediate value having a width of N bits e.g. `imm8`, `imm3`. `carry` denotes the carry condition flag, `not(carry)` denotes its complement. In the case of instructions with more than one register argument, it is permissible for some to be identical. For example the following will add the contents of R0 to itself, placing the result in R0:

- add(r0, r0, r0)

Arithmetic instructions affect the condition flags except where stated.

Addition

- add(Rdn, imm8) `Rdn = Rdn + imm8`
- add(Rd, Rn, imm3) `Rd = Rn + imm3`
- add(Rd, Rn, Rm) `Rd = Rn +Rm`
- adc(Rd, Rn) `Rd = Rd + Rn + carry`

Subtraction

- sub(Rdn, imm8) `Rdn = Rdn - imm8`
- sub(Rd, Rn, imm3) `Rd = Rn - imm3`
- sub(Rd, Rn, Rm) `Rd = Rn - Rm`
- sbc(Rd, Rn) `Rd = Rd - Rn - not(carry)`

Negation

- neg(Rd, Rn) `Rd = -Rn`

Multiplication and division

- mul(Rd, Rn) `Rd = Rd * Rn`

This produces a 32 bit result with overflow lost. The result may be treated as signed or unsigned according to the definition of the operands.

- sdiv(Rd, Rn, Rm) `Rd = Rn / Rm`
- udiv(Rd, Rn, Rm) `Rd = Rn / Rm`

These functions perform signed and unsigned division respectively. Condition flags are not affected.

Comparison instructions

These perform an arithmetic or logical instruction on two arguments, discarding the result but setting the condition flags. Typically these are used to test data values without changing them prior to executing a conditional branch.

Document conventions Notation: `Rd, Rm, Rn` denote ARM registers R0-R7. `imm8` denotes an immediate value having a width of 8 bits.

The Application Program Status Register (APSR) This contains four bits which are tested by the conditional branch instructions. Typically a conditional branch will test multiple bits, for example `bge(LABEL)`. The meaning of condition codes can depend on whether the operands of an arithmetic instruction are viewed as signed or unsigned integers. Thus `bhi(LABEL)` assumes unsigned numbers were processed while `bgt(LABEL)` assumes signed operands.

APSR Bits

- Z (zero)

This is set if the result of an operation is zero or the operands of a comparison are equal.

- N (negative)

Set if the result is negative.

- C (carry)

An addition sets the carry flag when the result overflows out of the MSB, for example adding 0x80000000 and 0x80000000. By the nature of two's complement arithmetic this behaviour is reversed on subtraction, with a borrow indicated by the carry bit being clear. Thus 0x10 - 0x01 is executed as 0x10 + 0xffffffff which will set the carry bit.

- V (overflow)

The overflow flag is set if the result, viewed as a two's compliment number, has the "wrong" sign in relation to the operands. For example adding 1 to 0x7fffffff will set the overflow bit because the result (0x8000000), viewed as a two's complement integer, is negative. Note that in this instance the carry bit is not set.

Comparison instructions These set the APSR (Application Program Status Register) N (negative), Z (zero), C (carry) and V (overflow) flags.

- cmp(Rn, imm8) `Rn - imm8`
- cmp(Rn, Rm) `Rn - Rm`
- cmn(Rn, Rm) `Rn + Rm`
- tst(Rn, Rm) `Rn & Rm`

Conditional execution The `it` and `ite` instructions provide a means of conditionally executing from one to four subsequent instructions without the need for a label.

- it(<condition>) If then

Execute the next instruction if <condition> is true:

```
cmp(r0, r1)
it(eq)
mov(r0, 100) # runs if r0 == r1
# execution continues here
```

- ite(<condition>) If then else

If <condtion> is true, execute the next instruction, otherwise execute the subsequent one. Thus:

```
cmp(r0, r1)
ite(eq)
mov(r0, 100) # runs if r0 == r1
mov(r0, 200) # runs if r0 != r1
# execution continues here
```

This may be extended to control the execution of upto four subsequent instructions: it[x[y[z]]] where x,y,z=t/e; e.g. itt, itee, itete, ittte, itttt, iteee, etc.

Branch instructions

These cause execution to jump to a target location usually specified by a label (see the `label` assembler directive). Conditional branches and the `it` and `ite` instructions test the Application Program Status Register (APSR) N (negative), Z (zero), C (carry) and V (overflow) flags to determine whether the branch should be executed.

Most of the exposed assembler instructions (including move operations) set the flags but there are explicit comparison instructions to enable values to be tested.

Further detail on the meaning of the condition flags is provided in the section describing comparison functions.

Document conventions Notation: `Rm` denotes ARM registers R0-R15. `LABEL` denotes a label defined with the `label()` assembler directive. `<condition>` indicates one of the following condition specifiers:

- eq Equal to (result was zero)
- ne Not equal
- cs Carry set
- cc Carry clear
- mi Minus (negaive)
- pl Plus (positive)
- vs Overflow set
- vc Overflow clear
- hi > (unsigned comparison)
- ls <= (unsigned comparison)
- ge >= (signed comparison)
- lt < (signed comparison)
- gt > (signed comparison)
- le <= (signed comparison)

Branch to label

- b(LABEL) Unconditional branch
- beq(LABEL) branch if equal
- bne(LABEL) branch if not equal
- bge(LABEL) branch if greater than or equal
- bgt(LABEL) branch if greater than
- blt(LABEL) branch if less than (<) (signed)
- ble(LABEL) branch if less than or equal to (<=) (signed)
- bcs(LABEL) branch if carry flag is set
- bcc(LABEL) branch if carry flag is clear

- bmi(LABEL) branch if negative
- bpl(LABEL) branch if positive
- bvs(LABEL) branch if overflow flag set
- bvc(LABEL) branch if overflow flag is clear
- bhi(LABEL) branch if higher (unsigned)
- bls(LABEL) branch if lower or equal (unsigned)

Long branches The code produced by the branch instructions listed above uses a fixed bit width to specify the branch destination, which is PC relative. Consequently in long programs where the branch instruction is remote from its destination the assembler will produce a "branch not in range" error. This can be overcome with the "wide" variants such as

- beq_w(LABEL) long branch if equal

Wide branches use 4 bytes to encode the instruction (compared with 2 bytes for standard branch instructions).

Subroutines (functions) When entering a subroutine the processor stores the return address in register r14, also known as the link register (lr). Return to the instruction after the subroutine call is performed by updating the program counter (r15 or pc) from the link register, This process is handled by the following instructions.

- bl(LABEL)

Transfer execution to the instruction after `LABEL` storing the return address in the link register (r14).

- bx(Rm) Branch to address specified by Rm.

Typically `bx(lr)` is issued to return from a subroutine. For nested subroutines the link register of outer scopes must be saved (usually on the stack) before performing inner subroutine calls.

Stack push and pop

Document conventions The `push()` and `pop()` instructions accept as their argument a register set containing a subset, or possibly all, of the general-purpose registers R0-R12 and the link register (lr or R14). As with any Python set the order in which the registers are specified is immaterial. Thus the in the following example the pop() instruction would restore R1, R7 and R8 to their contents prior to the push():

- push({r1, r8, r7}) Save three registers on the stack.
- pop({r7, r1, r8}) Restore them

Stack operations

- push({regset}) Push a set of registers onto the stack
- pop({regset}) Restore a set of registers from the stack

Miscellaneous instructions

- nop() `pass` no operation.
- wfi() Suspend execution in a low power state until an interrupt occurs.
- cpsid(flags) set the Priority Mask Register - disable interrupts.

- cpsie(flags) clear the Priority Mask Register - enable interrupts.
- mrs(Rd, special_reg) `Rd = special_reg` copy a special register to a general register. The special register may be IPSR (Interrupt Status Register) or BASEPRI (Base Priority Register). The IPSR provides a means of determining the exception number of an interrupt being processed. It contains zero if no interrupt is being processed.

Currently the `cpsie()` and `cpsid()` functions are partially implemented. They require but ignore the flags argument and serve as a means of enabling and disabling interrupts.

Floating Point instructions

These instructions support the use of the ARM floating point coprocessor (on platforms such as the Pyboard which are equipped with one). The FPU has 32 registers known as `s0-s31` each of which can hold a single precision float. Data can be passed between the FPU registers and the ARM core registers with the `vmov` instruction.

Note that MicroPython doesn't support passing floats to assembler functions, nor can you put a float into `r0` and expect a reasonable result. There are two ways to overcome this. The first is to use arrays, and the second is to pass and/or return integers and convert to and from floats in code.

Document conventions Notation: `Sd, Sm, Sn` denote FPU registers, `Rd, Rm, Rn` denote ARM core registers. The latter can be any ARM core register although registers `R13-R15` are unlikely to be appropriate in this context.

Arithmetic

- vadd(Sd, Sn, Sm) `Sd = Sn + Sm`
- vsub(Sd, Sn, Sm) `Sd = Sn - Sm`
- vneg(Sd, Sm) `Sd = -Sm`
- vmul(Sd, Sn, Sm) `Sd = Sn * Sm`
- vdiv(Sd, Sn, Sm) `Sd = Sn / Sm`
- vsqrt(Sd, Sm) `Sd = sqrt(Sm)`

Registers may be identical: `vmul(S0, S0, S0)` will execute `S0 = S0*S0`

Move between ARM core and FPU registers

- vmov(Sd, Rm) `Sd = Rm`
- vmov(Rd, Sm) `Rd = Sm`

The FPU has a register known as FPSCR, similar to the ARM core's APSR, which stores condition codes plus other data. The following instructions provide access to this.

- vmrs(APSR_nzcv, FPSCR)

Move the floating-point N, Z, C, and V flags to the APSR N, Z, C, and V flags.

This is done after an instruction such as an FPU comparison to enable the condition codes to be tested by the assembler code. The following is a more general form of the instruction.

- vmrs(Rd, FPSCR) `Rd = FPSCR`

Move between FPU register and memory

- vldr(Sd, [Rn, offset]) `Sd = [Rn + offset]`
- vstr(Sd, [Rn, offset]) `[Rn + offset] = Sd`

Where `[Rn + offset]` denotes the memory address obtained by adding Rn to the offset. This is specified in bytes. Since each float value occupies a 32 bit word, when accessing arrays of floats the offset must always be a multiple of four bytes.

Data Comparison

- vcmp(Sd, Sm)

Compare the values in Sd and Sm and set the FPU N, Z, C, and V flags. This would normally be followed by `vmrs(APSR_nzcv, FPSCR)` to enable the results to be tested.

Convert between integer and float

- vcvt_f32_s32(Sd, Sm) `Sd = float(Sm)`
- vcvt_s32_f32(Sd, Sm) `Sd = int(Sm)`

Assembler Directives

Labels

- label(INNER1)

This defines a label for use in a branch instruction. Thus elsewhere in the code a `b(INNER1)` will cause execution to continue with the instruction after the label directive.

Defining inline data The following assembler directives facilitate embedding data in an assembler code block.

- data(size, d0, d1 .. dn)

The data directive creates n array of data values in memory. The first argument specifies the size in bytes of the subsequent arguments. Hence the first statement below will cause the assembler to put three bytes (with values 2, 3 and 4) into consecutive memory locations while the second will cause it to emit two four byte words.

```
data(1, 2, 3, 4)
data(4, 2, 100000)
```

Data values longer than a single byte are stored in memory in little-endian format.

- align(nBytes)

Align the following instruction to an nBytes value. ARM Thumb-2 instructions must be two byte aligned, hence it's advisable to issue `align(2)` after `data` directives and prior to any subsequent code. This ensures that the code will run irrespective of the size of the data array.

Usage examples

These sections provide further code examples and hints on the use of the assembler.

Hints and tips

The following are some examples of the use of the inline assembler and some information on how to work around its limitations. In this document the term "assembler function" refers to a function declared in Python with the `@micropython.asm_thumb` decorator, whereas "subroutine" refers to assembler code called from within an assembler function.

Code branches and subroutines It is important to appreciate that labels are local to an assembler function. There is currently no way for a subroutine defined in one function to be called from another.

To call a subroutine the instruction `bl(LABEL)` is issued. This transfers control to the instruction following the `label(LABEL)` directive and stores the return address in the link register (`lr` or `r14`). To return the instruction `bx(lr)` is issued which causes execution to continue with the instruction following the subroutine call. This mechanism implies that, if a subroutine is to call another, it must save the link register prior to the call and restore it before terminating.

The following rather contrived example illustrates a function call. Note that it's necessary at the start to branch around all subroutine calls: subroutines end execution with `bx(lr)` while the outer function simply "drops off the end" in the style of Python functions.

```
@micropython.asm_thumb
def quad(r0):
    b(START)
    label(DOUBLE)
    add(r0, r0, r0)
    bx(lr)
    label(START)
    bl(DOUBLE)
    bl(DOUBLE)

print(quad(10))
```

The following code example demonstrates a nested (recursive) call: the classic Fibonacci sequence. Here, prior to a recursive call, the link register is saved along with other registers which the program logic requires to be preserved.

```
@micropython.asm_thumb
def fib(r0):
    b(START)
    label(DOFIB)
    push({r1, r2, lr})
    cmp(r0, 1)
    ble(FIBDONE)
    sub(r0, 1)
    mov(r2, r0) # r2 = n -1
    bl(DOFIB)
    mov(r1, r0) # r1 = fib(n -1)
    sub(r0, r2, 1)
    bl(DOFIB)   # r0 = fib(n -2)
    add(r0, r0, r1)
    label(FIBDONE)
    pop({r1, r2, lr})
    bx(lr)
    label(START)
    bl(DOFIB)

for n in range(10):
    print(fib(n))
```

Argument passing and return The tutorial details the fact that assembler functions can support from zero to three arguments, which must (if used) be named `r0`, `r1` and `r2`. When the code executes the registers will be initialised to those values.

The data types which can be passed in this way are integers and memory addresses. With current firmware all possible 32 bit values may be passed and returned. If the return value may have the most significant bit set a Python type hint should be employed to enable MicroPython to determine whether the value should be interpreted as a signed or unsigned integer: types are `int` or `uint`.

```
@micropython.asm_thumb
def uadd(r0, r1) -> uint:
    add(r0, r0, r1)
```

`hex(uadd(0x40000000,0x40000000))` will return 0x80000000, demonstrating the passing and return of integers where bits 30 and 31 differ.

The limitations on the number of arguments and return values can be overcome by means of the `array` module which enables any number of values of any type to be accessed.

Multiple arguments If a Python array of integers is passed as an argument to an assembler function, the function will receive the address of a contiguous set of integers. Thus multiple arguments can be passed as elements of a single array. Similarly a function can return multiple values by assigning them to array elements. Assembler functions have no means of determining the length of an array: this will need to be passed to the function.

This use of arrays can be extended to enable more than three arrays to be used. This is done using indirection: the `uctypes` module supports `addressof()` which will return the address of an array passed as its argument. Thus you can populate an integer array with the addresses of other arrays:

```
from uctypes import addressof
@micropython.asm_thumb
def getindirect(r0):
    ldr(r0, [r0, 0]) # Address of array loaded from passed array
    ldr(r0, [r0, 4]) # Return element 1 of indirect array (24)

def testindirect():
    a = array.array('i',[23, 24])
    b = array.array('i',[0,0])
    b[0] = addressof(a)
    print(getindirect(b))
```

Non-integer data types These may be handled by means of arrays of the appropriate data type. For example, single precison floating point data may be processed as follows. This code example takes an array of floats and replaces its contents with their squares.

```
from array import array

@micropython.asm_thumb
def square(r0, r1):
    label(LOOP)
    vldr(s0, [r0, 0])
    vmul(s0, s0, s0)
    vstr(s0, [r0, 0])
    add(r0, 4)
    sub(r1, 1)
    bgt(LOOP)

a = array('f', (x for x in range(10)))
```

```
square(a, len(a))
print(a)
```

The uctypes module supports the use of data structures beyond simple arrays. It enables a Python data structure to be mapped onto a bytearray instance which may then be passed to the assembler function.

Named constants Assembler code may be made more readable and maintainable by using named constants rather than littering code with numbers. This may be achieved thus:

```
MYDATA = const(33)

@micropython.asm_thumb
def foo():
    mov(r0, MYDATA)
```

The const() construct causes MicroPython to replace the variable name with its value at compile time. If constants are declared in an outer Python scope they can be shared between mutiple assembler functions and with Python code.

Assembler code as class methods MicroPython passes the address of the object instance as the first argument to class methods. This is normally of little use to an assembler function. It can be avoided by declaring the function as a static method thus:

```
class foo:
  @staticmethod
  @micropython.asm_thumb
  def bar(r0):
    add(r0, r0, r0)
```

Use of unsupported instructions These can be coded using the data statement as shown below. While `push()` and `pop()` are supported the example below illustrates the principle. The necessary machine code may be found in the ARM v7-M Architecture Reference Manual. Note that the first argument of data calls such as

```
data(2, 0xe92d, 0x0f00) # push r8,r9,r10,r11
```

indicates that each subsequent argument is a two byte quantity.

Overcoming MicroPython's integer restriction The Pyboard chip includes a CRC generator. Its use presents a problem in MicroPython because the returned values cover the full gamut of 32 bit quantities whereas small integers in MicroPython cannot have differing values in bits 30 and 31. This limitation is overcome with the following code, which uses assembler to put the result into an array and Python code to coerce the result into an arbitrary precision unsigned integer.

```
from array import array
import stm

def enable_crc():
    stm.mem32[stm.RCC + stm.RCC_AHB1ENR] |= 0x1000

def reset_crc():
    stm.mem32[stm.CRC+stm.CRC_CR] = 1

@micropython.asm_thumb
def getval(r0, r1):
    movwt(r3, stm.CRC + stm.CRC_DR)
```

```
    str(r1, [r3, 0])
    ldr(r2, [r3, 0])
    str(r2, [r0, 0])

def getcrc(value):
    a = array('i', [0])
    getval(a, value)
    return a[0] & 0xffffffff # coerce to arbitrary precision

enable_crc()
reset_crc()
for x in range(20):
    print(hex(getcrc(0)))
```

References

- *Assembler Tutorial*
- Wiki hints and tips
- uPy Inline Assembler source-code, emitinlinethumb.c
- ARM Thumb2 Instruction Set Quick Reference Card
- RM0090 Reference Manual
- ARM v7-M Architecture Reference Manual (Available on the ARM site after a simple registration procedure. Also available on academic sites but beware of out of date versions.)

CHAPTER 10

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