IoT Engineering
2: Microcontrollers, Sensors & Actuators

Slides: tmb.gr/iot-2

Source on GDocs

Overview

These slides introduce *microcontrollers*.

How to program them with Arduino.

How to use *sensors* and *actuators*.

Prerequisites

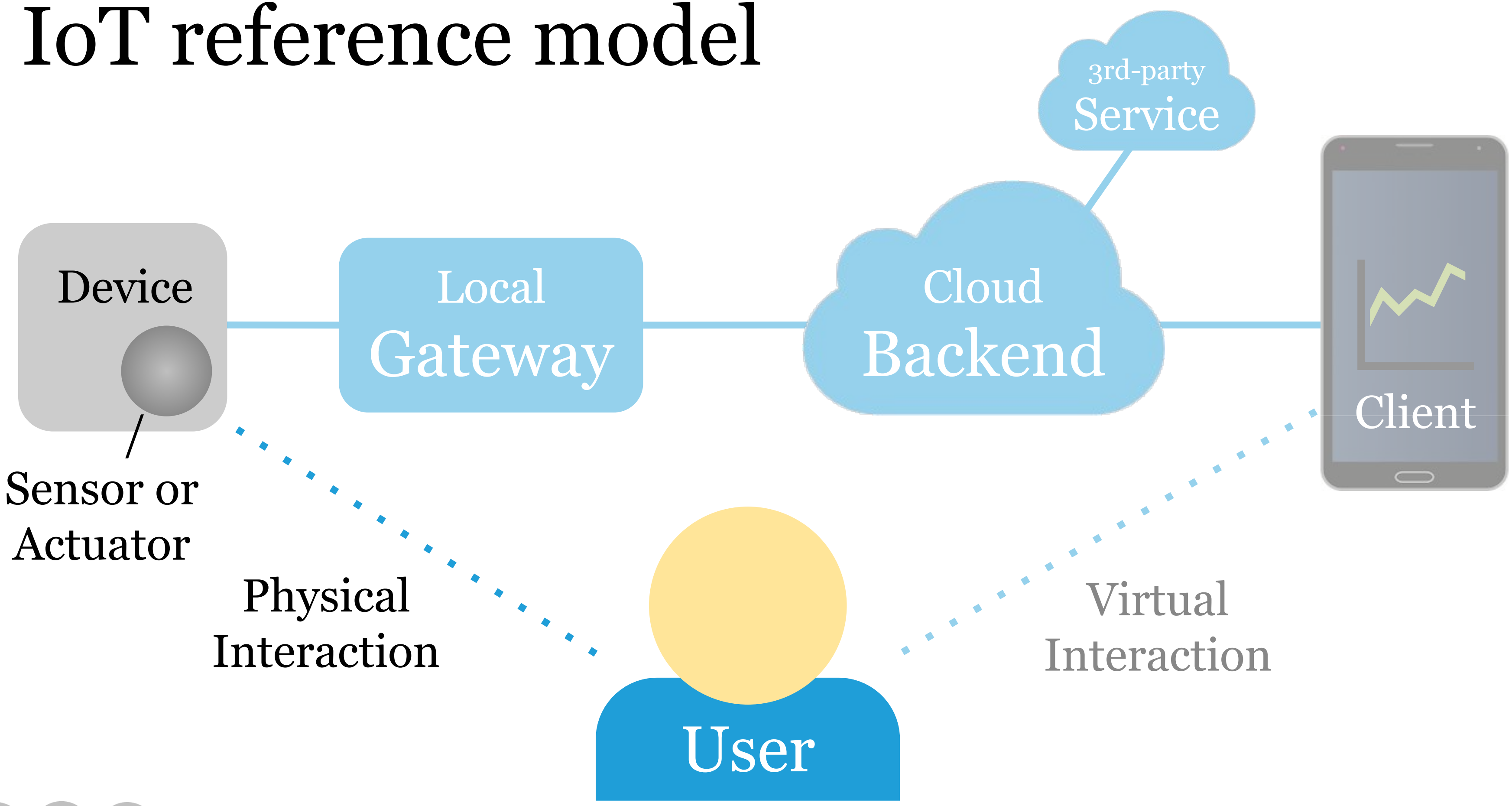
Install the Arduino IDE and set up microcontrollers:

Check the Wiki entry on Installing the Arduino IDE.

Set up the Feather nRF52840 Express for Arduino.

Set up the Feather Huzzah ESP8266 for Arduino.

IoT reference model



Let's look at physical computing

On device sensing/control, no connectivity.

Sensor → Device, e.g. logging temperature.

Device → Actuator, e.g. time-triggered buzzer.

Sensor → Device → Actuator, e.g. RFID door lock.

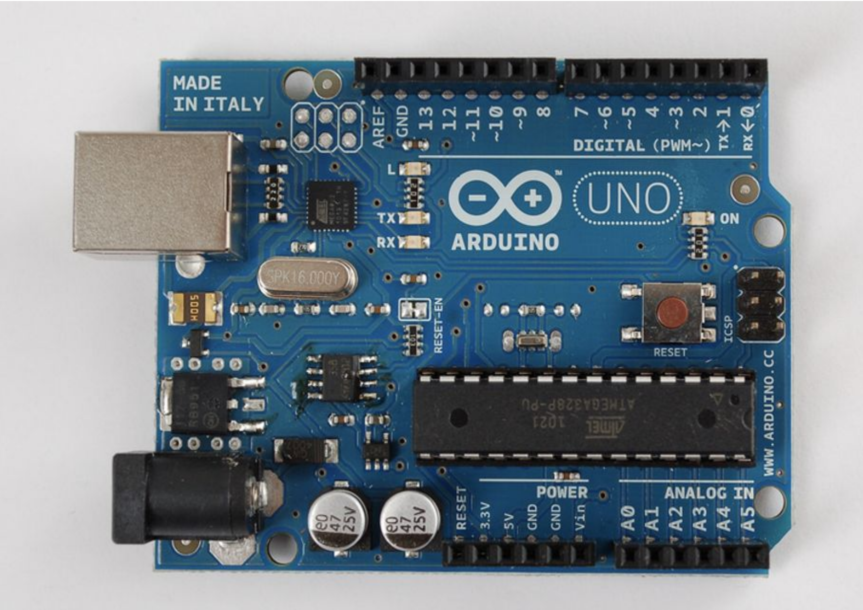
A → B: measurement or control data flow.

Arduino, a typical microcontroller

Microcontrollers (MCU) are small computers that run a single program.

Arduino is an MCU for electronics prototyping.

Here's a [video](#) about it with Massimo Banzi.



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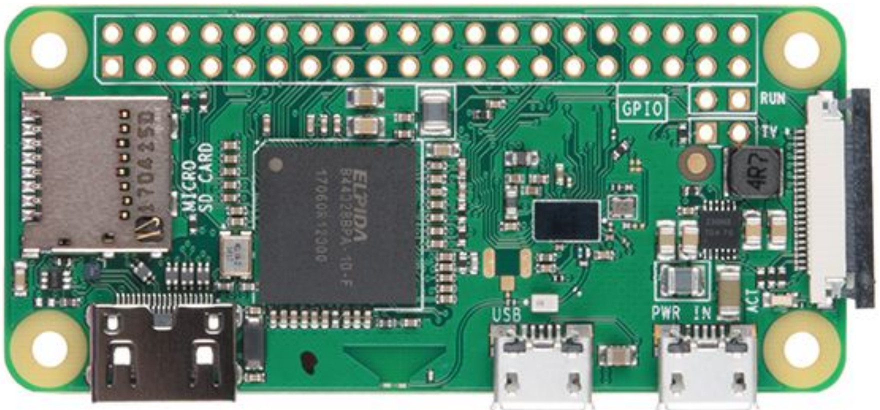
Raspberry Pi, a single-board computer

Single-board computers like the *Raspberry Pi* are *not* microcontrollers.



They run a full Linux OS, have a lot of memory and use way more power.

Here's a video on the Pi.

MCU vs. single-board computer

An MCU has limited memory and a slow processor.

But there's no operating system, i.e. less overhead.

This means an MCU can react faster, in real-time.

Use microcontrollers for simple, low latency tasks.

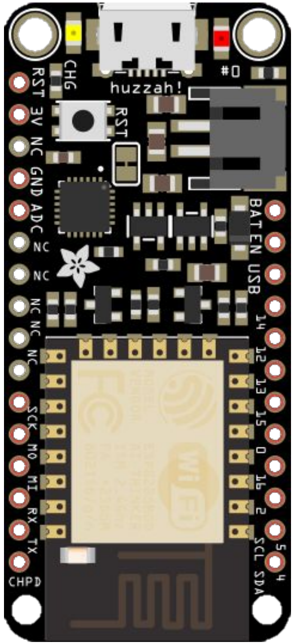
Feather Huzzah ESP8266

Microcontroller with Wi-Fi, used by hobbyists.

Espressif ESP8266 System on Chip (SoC).

32-bit Tensilica CPU, without a FPU.

4 MB flash memory, 80 kB RAM.



For details, check this Wiki page.

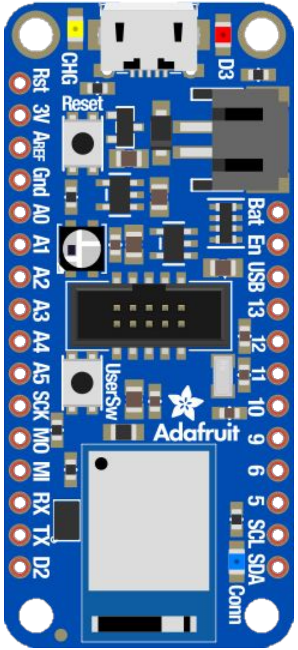
Feather nRF52840 Express

Microcontroller with Bluetooth 5 (i.e. BLE).

Nordic nRF52840 System on Chip (SoC).

32-bit ARM Cortex-M4 CPU with FPU.

1 MB flash memory, 265 kB RAM.



For details, check this Wiki page.

Programming a microcontroller

Microcontrollers are programmed via USB.

Code is (cross-) *compiled* on your computer.

The *binary* is *uploaded* to the microcontroller.

The uploaded program then runs "stand-alone".

Arduino IDE settings

Connect your board via USB and make sure that

Tools > *Board* is set to your microcontroller,

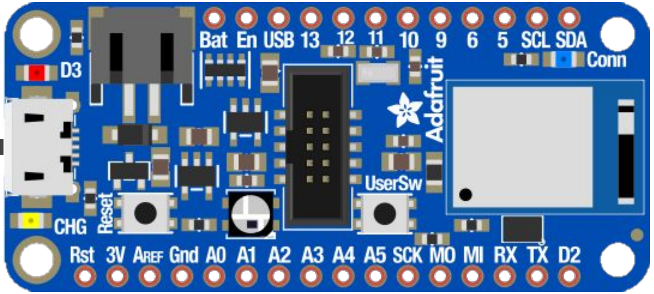
Tools > *Port* matches the current USB port.

Some boards require additional settings.

Arduino IDE program upload

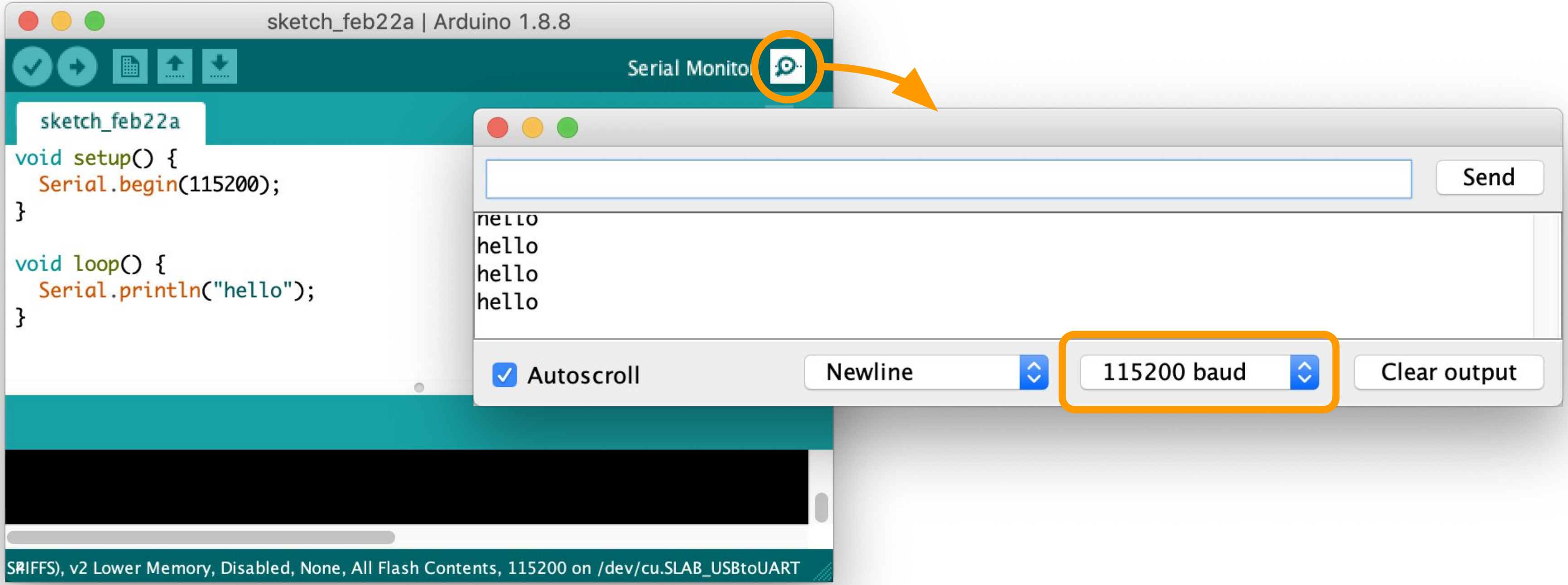
The *Upload* button compiles and uploads the code.

USB



Arduino IDE serial console

Make sure the baud rate matches *Serial.begin()*.



A typical program in Arduino C

```
void setup() { // called once at startup
  Serial.begin(115200); // set baud rate
}

void loop() { // called in a loop
  Serial.println("Hello, World!");
}
```

Arduino language

The Arduino language uses a subset of C/C++.

The user exposed code looks a bit like Java.

There is a string type and a String class.

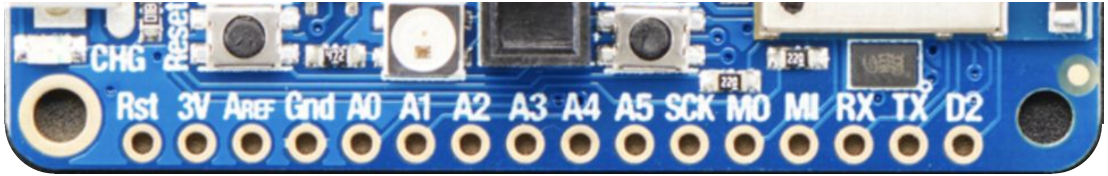
Libraries are programmed in C++.

For details, check the language reference.

General purpose input and output

Microcontrollers can "talk to" the physical world through general purpose input and output (GPIO).

GPIO *pins* allow a MCU to measure/control signals.



E.g. power, ground, analog pins, digital pin.

GPIO pin names

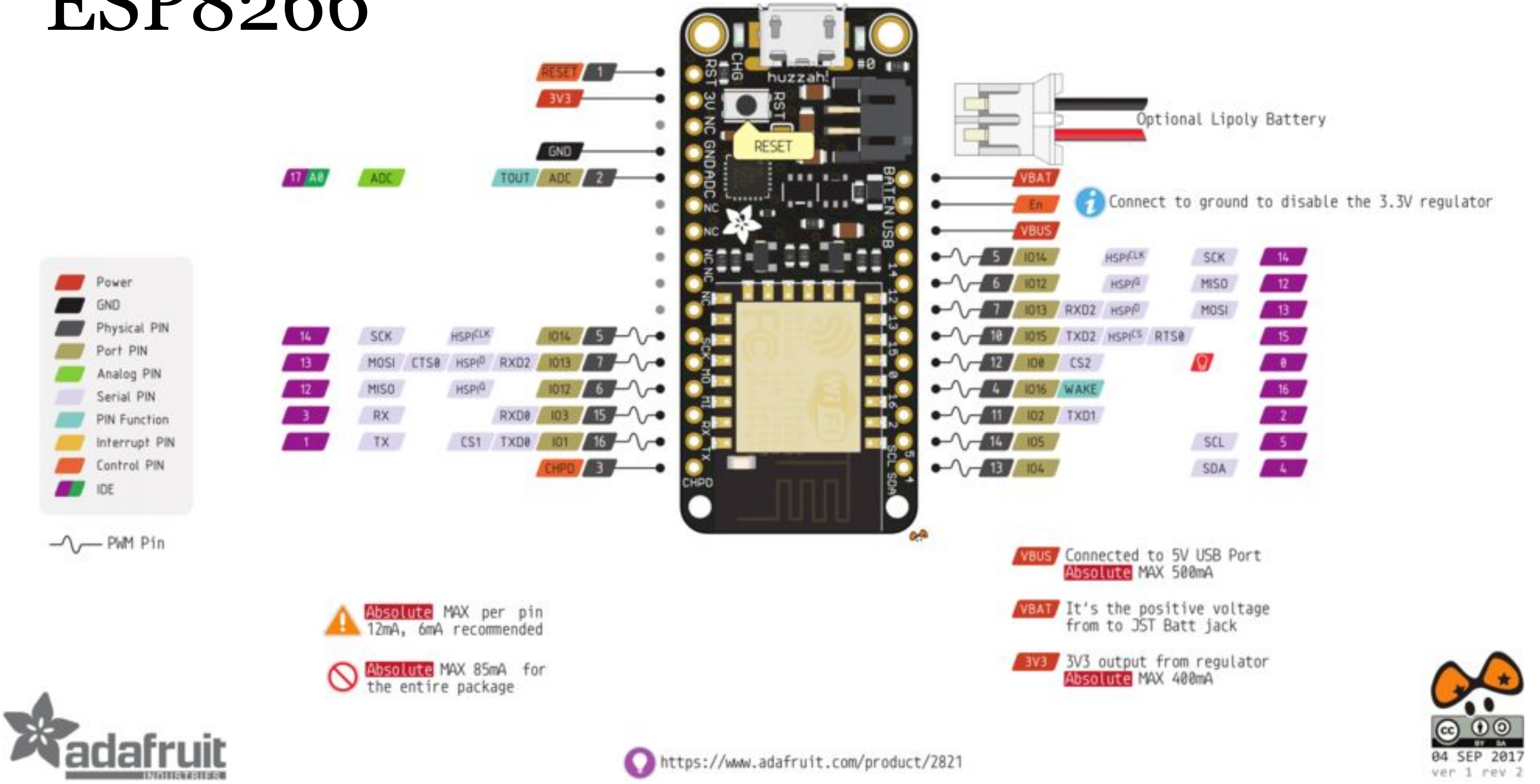
In Arduino, digital *pin names* are just numbers, e.g. pin *2*, while analog pins start with an *A*, like pin *A0*.

Which pins are available depends on the device.

The map of available pins is called *pinout*.

A pin can have multiple functions.

ESP8266



RESET 1
3V3
GND
17 A0 ADC TOUT ADC 2
Power
GND
Physical PIN
Port PIN
Analog PIN
Serial PIN
PIN Function
Interrupt PIN
Control PIN
IDE
PWM Pin
14 SCK HSPI CLK IO14 5
13 MOSI CTS0 HSPI RXD2 IO13 7
12 MISO HSPI IO12 6
3 RX RXD0 IO3 15
1 TX CS1 TXD0 IO1 16
CHPD 3
RESET
huzzah!
Optional Lipoly Battery
VBAT
En
Connect to ground to disable the 3.3V regulator
VBUS
5 IO14 HSPI CLK SCK 14
6 IO12 HSPI MISO 12
7 IO13 RXD2 HSPI MOSI 13
10 IO15 TXD2 HSPI CS RTS0 15
12 IO0 CS2 0
4 IO16 WAKE 16
11 IO2 TXD1 2
14 IO5 SCL 5
13 IO4 SDA 4
VBUS Connected to 5V USB Port Absolute MAX 500mA
VBAT It's the positive voltage from to JST Batt jack
3V3 3V3 output from regulator Absolute MAX 400mA
Absolute MAX per pin 12mA, 6mA recommended
Absolute MAX 85mA for the entire package
adafruit
https://www.adafruit.com/product/2821
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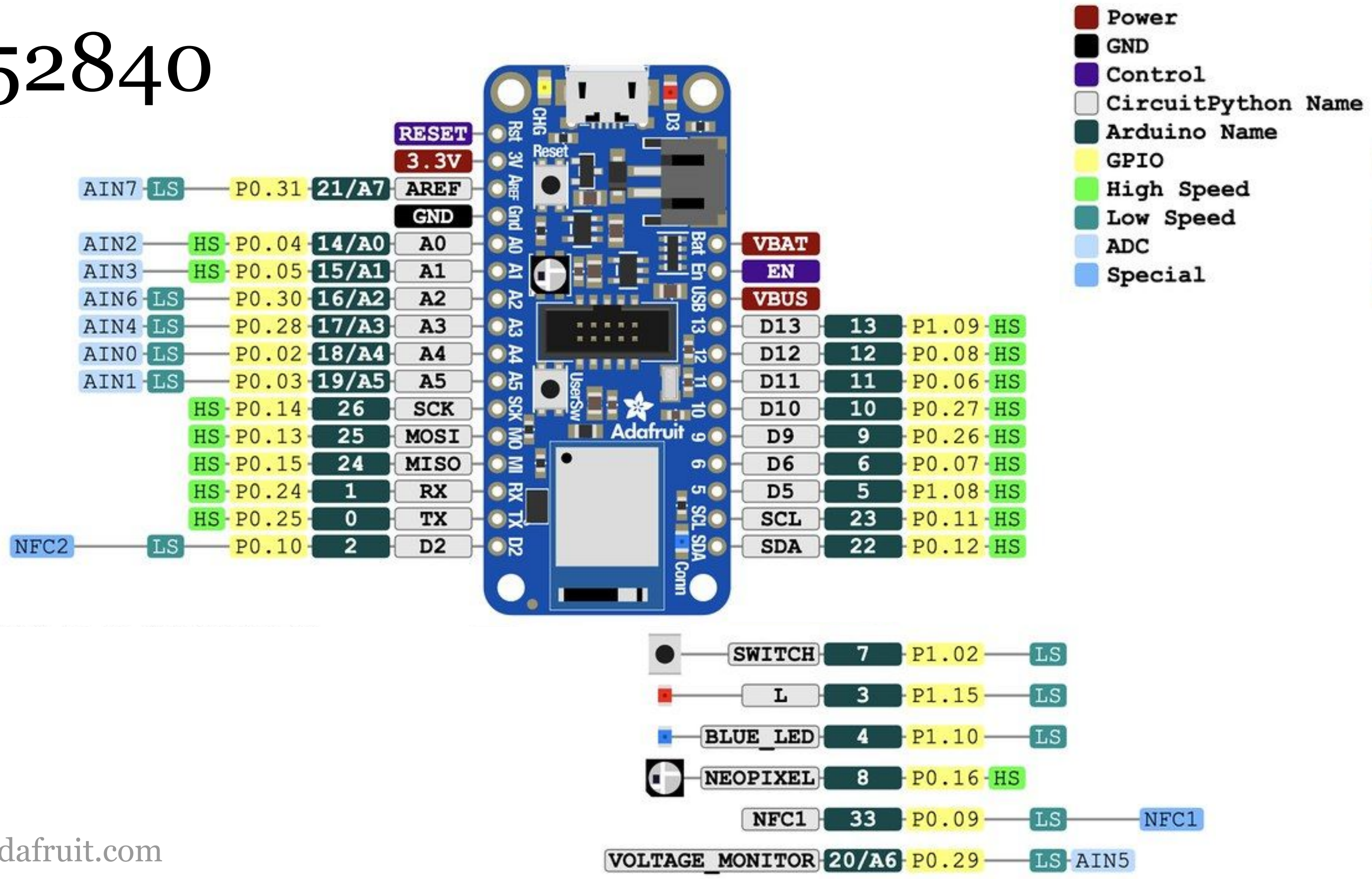
ver 1 rev 2

nRF52840



Power
GND
Control
CircuitPython Name
Arduino Name
GPIO
High Speed
Low Speed
ADC
Special
RESET
3.3V
AIN7 LS P0.31 21/A7 AREF
GND
AIN2 HS P0.04 14/A0 A0
AIN3 HS P0.05 15/A1 A1
AIN6 LS P0.30 16/A2 A2
AIN4 LS P0.28 17/A3 A3
AIN0 LS P0.02 18/A4 A4
AIN1 LS P0.03 19/A5 A5
HS P0.14 26 SCK
HS P0.13 25 MOSI
HS P0.15 24 MISO
HS P0.24 1 RX
HS P0.25 0 TX
NFC2 LS P0.10 2 D2
VBAT
EN
VBUS
D13 13 P1.09 HS
D12 12 P0.08 HS
D11 11 P0.06 HS
D10 10 P0.27 HS
D9 9 P0.26 HS
D6 6 P0.07 HS
D5 5 P1.08 HS
SCL 23 P0.11 HS
SDA 22 P0.12 HS
SWITCH 7 P1.02 LS
L 3 P1.15 LS
BLUE_LED 4 P1.10 LS
NEOPIXEL 8 P0.16 HS
NFC1 33 P0.09 LS NFC1
VOLTAGE_MONITOR 20/A6 P0.29 LS AIN5
Rst 3V Aref Gnd A0 A1 A2 A3 A4 A5 SCK MO MI RX TX D2
CHG Reset UserSw D3
Bat En USB 13 12 11 10 9 6 5 SCL SDA
Conn
Adafruit

Sensors read the real world

Convert physical properties to electrical *input* signals.

E.g. temperature, humidity, brightness or orientation.

Input can be *digital* (0 or 1) or *analog* (e.g. 0 - 2^10).

Measuring = *reading* sensor values from input pins.

Actuators control the real world

Convert electrical *output* signals to physical properties.

E.g. light, current with a relay or motion with a motor.

Output can be *digital* (0 or 1) or *analog* (with PWM).

Controlling = *writing* actuator values to output pins.

Wiring sensors to the MCU

Sensors and actuators exchange signals with the MCU.

For prototyping, we use wires to achieve this, e.g.

Breadboard and wires, or the *Grove* standard.

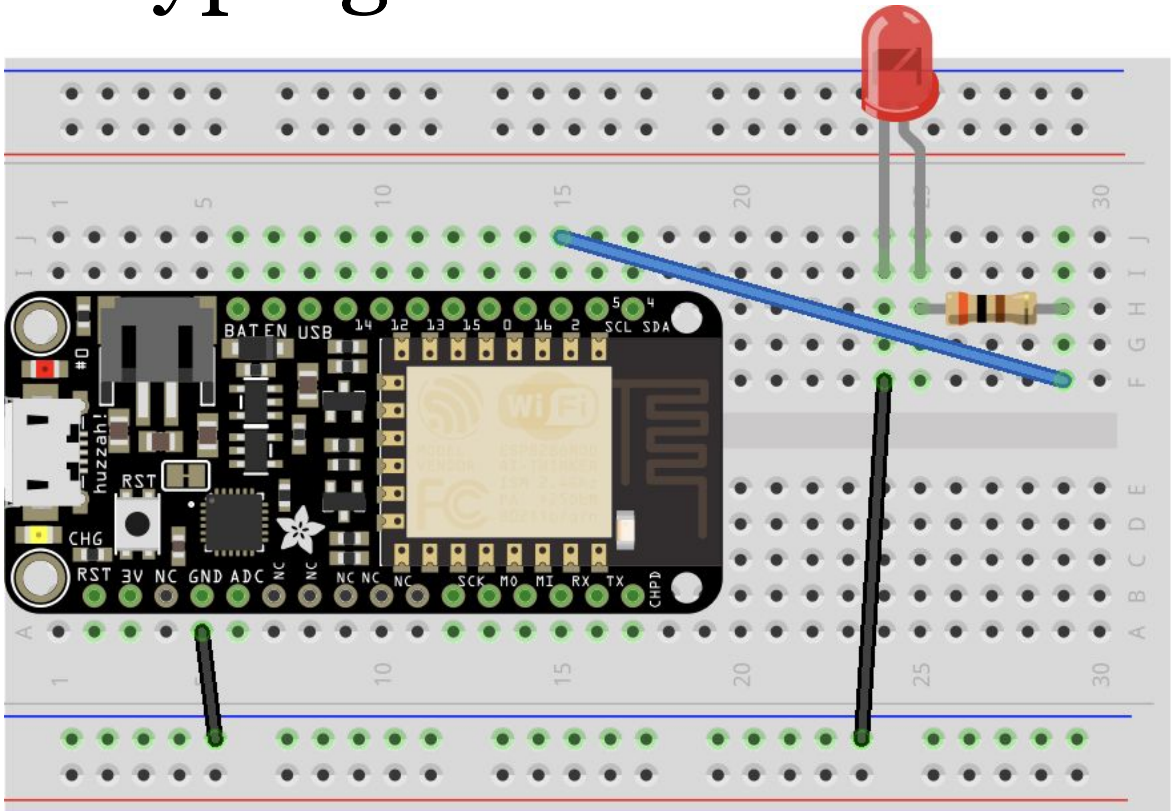
For products, custom PCBs are designed*.

*See slides on Prototype to Product.

Breadboard prototyping

Wire electronic components, no soldering.

Under the hood, the columns are connected, also the power rails.

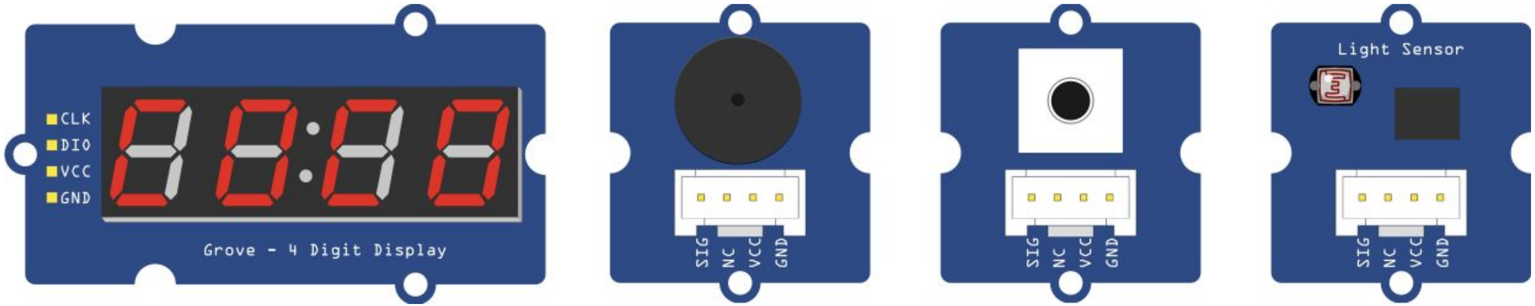


Grove wiring standard

Grove is a simple way to wire sensors and actuators.

It defines wires for power, ground and two signals.

Signals can be digital, analog, UART serial or I2C.



Arduino example code

Each Arduino library comes with example code.

And there are a number of basic examples.

See *Arduino IDE > File > Examples*

GPIO pin numbers may vary.

Use the pin mapping.

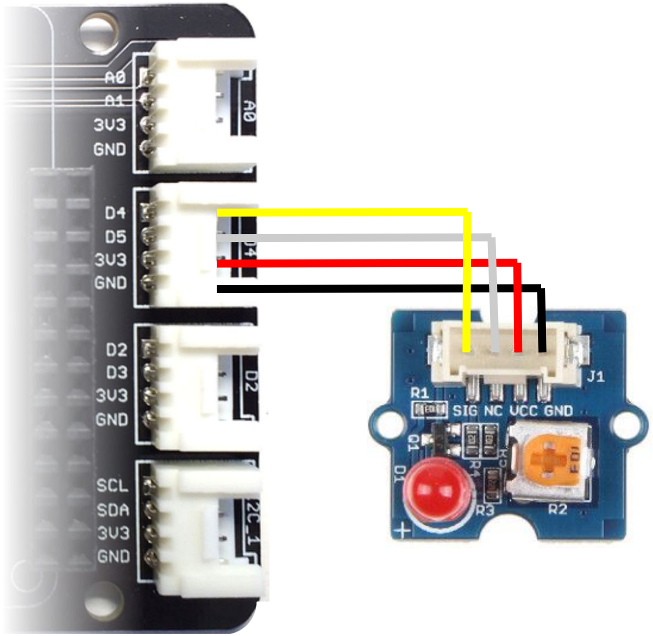
Blinking a LED (digital output)

Use *Examples > Basics > Blink*

Connect to Grove port *D4*.

It maps to ESP8266 pin *0*.

Or nRF52840 pin *9*.



The same code works with the buzzer.

Blinking a LED (digital output)

```
int pin = 0; // for ESP8266, or 9 for nRF52840

void setup() { // called once
  pinMode(pin, OUTPUT); // configure pin
}

void loop() { // called in a loop
  digitalWrite(pin, HIGH); // switch pin on
  delay(500); // ms
  digitalWrite(pin, LOW); // switch pin off
  delay(500); // ms
}
```

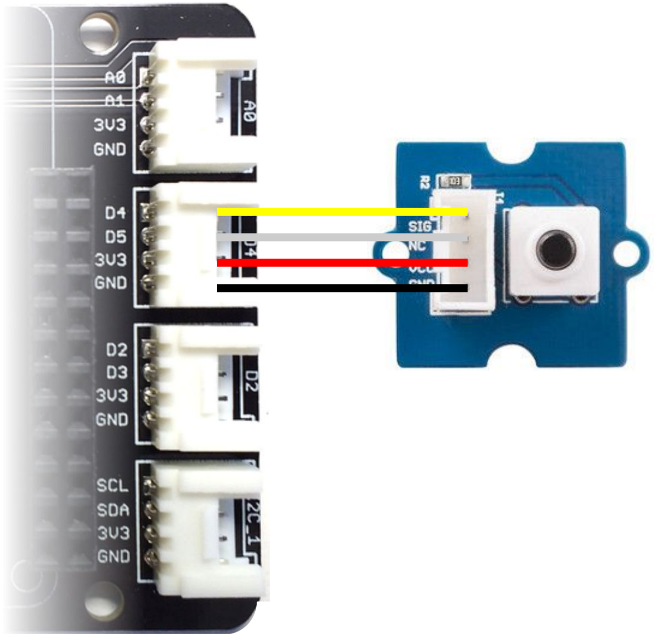
Reading a button (digital input)

Use *Basics > DigitalReadSerial*

Connect to Grove port *D4*.

It maps to ESP8266 pin *0*.

Or nRF52840 pin *9*.



Use the serial console to see output.

Reading a button (digital input)

```
int pin = 0; // for ESP8266, or 9 for nRF52840

void setup() { // called once
  pinMode(pin, INPUT); // configure pin
  Serial.begin(115200);
}

void loop() { // called in a loop
  int value = digitalRead(pin);
  Serial.println(value);
  delay(500); // ms
}
```

Hands-on, 15': Button-triggered LED

Connect the LED to port *D2**, and the button to *D4*.

Combine the previous examples to switch the LED.

Use the pin mapping to adapt the pin numbers.

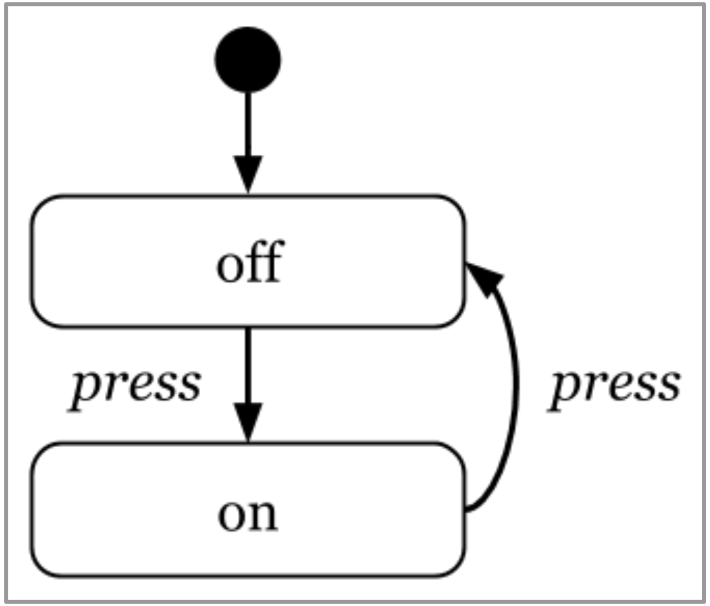
*On the ESP8266, remove LED for programming.

State machine

A (finite-) state machine helps you write robust code.

System is in one *state* at a time, *events* trigger state *transitions*.

E.g. 1st button *press* => light *on*, 2nd button *press* => light *off*, 3rd => *on*, 4th => *off*, etc.

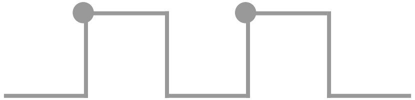


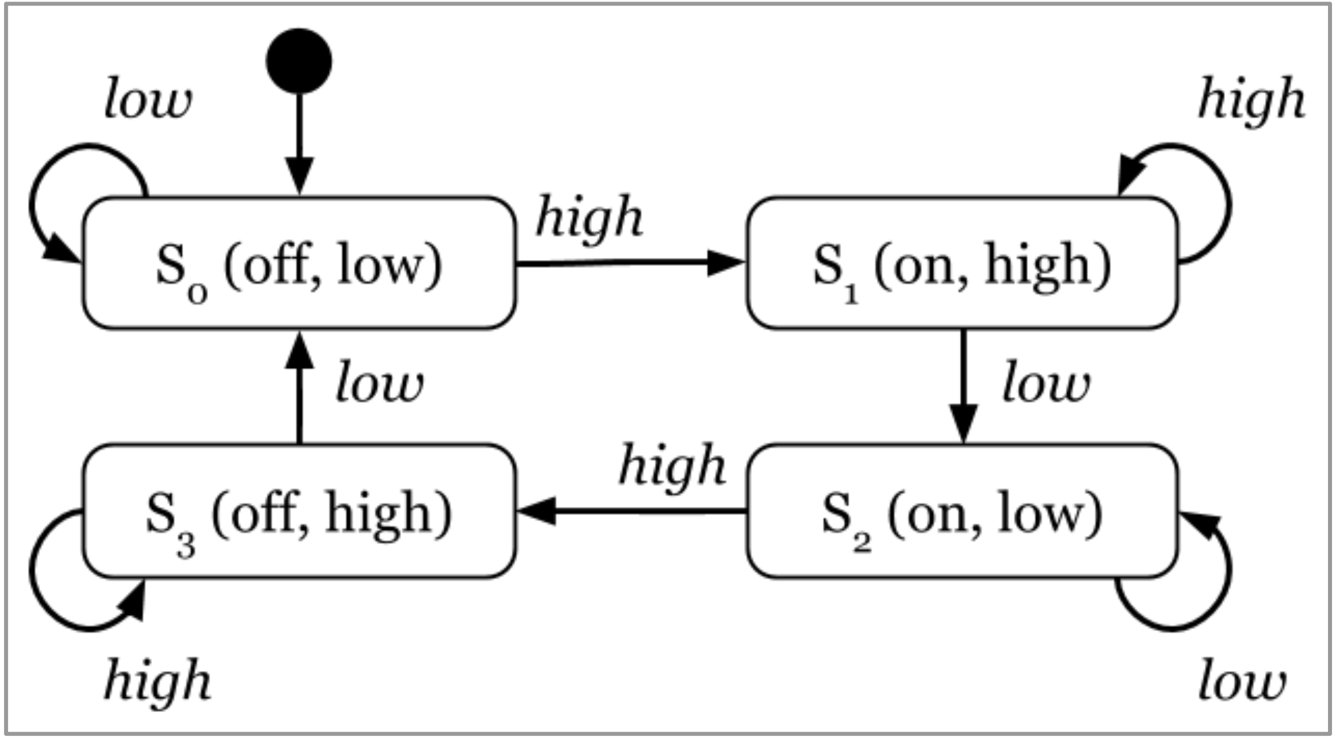
State machine (refined)

Button is *high* or *low*.

Light is *on* or *off*.

Pressed = *low* → *high*.





State machine (code snippet)

```
int b = digitalRead(buttonPin);
if (s == 0 && b == HIGH) { // s is state
  s = 1; digitalWrite(ledPin, HIGH); // on
} else if (s == 1 && b == LOW) {
  s = 2;
} else if (s == 2 && b == HIGH) {
  s = 3; digitalWrite(ledPin, LOW); // off
} else if (s == 3 && b == LOW) {
  s = 0;
}
```

Hands-on, 15': State machine

Copy and complete the code of the state machine.

Make sure it works, with a button and LED setup.

Change it to switch off only, if the 2nd press is *long*.

Let's define long as > 1s, measure time with millis().

Commit the resulting code to the hands-on repo.

Reading a light sensor (analog input)

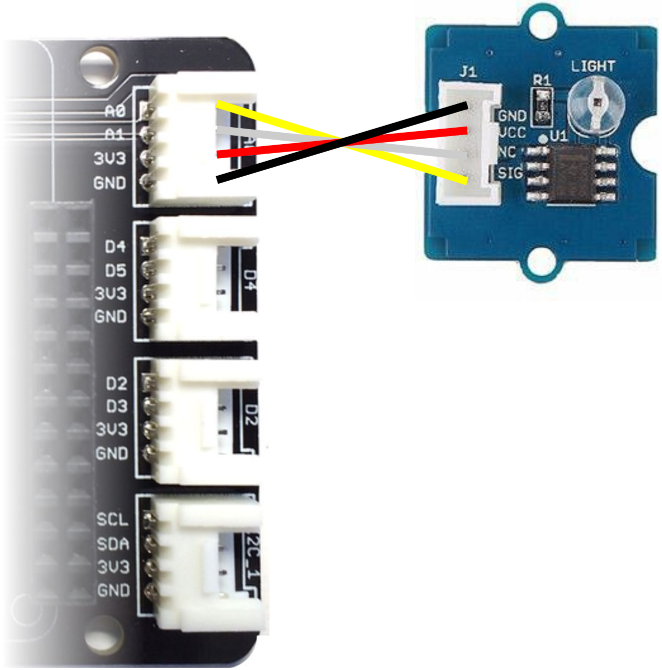
Use *Basics* > *AnalogReadSerial*

Connect to Grove port / pin *A0*.

The analog value is, e.g. 0-1024*

```
int value = analogRead(pin);
```

Use serial plotter to see output.



*Range depends on ADC resolution.

Mapping input to value range

Sometimes mapping sensor value ranges helps, e.g.

0 - 1024 analog input => 0 - 9 brightness levels.

Arduino has a simple map() function for this:

```
int map(value, // measured input value
  fromLow, fromHigh, // from range
  toLow, toHigh); // to range

e.g. result = map(value, 0, 1024, 0, 9);
```

Measuring temperature (DHT11)

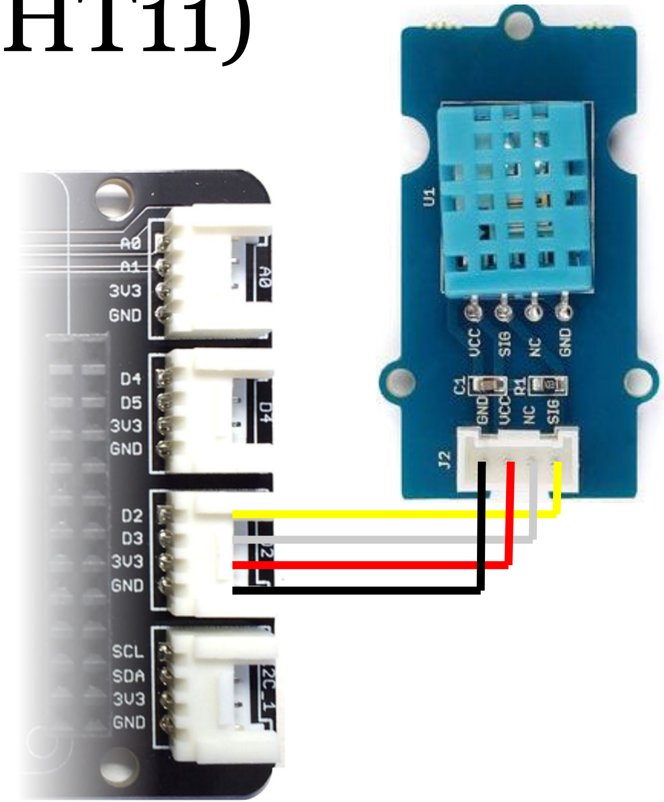
DHT11 sensors require a library.

Setup and examples in the Wiki.

Connect to adapter port *D2*.

It maps to ESP8266 pin *2*.

Or nRF52840 pin *5*.



New to libraries? See Arduino library guide.

Hands-on, 15': Kitchen timer

Design a kitchen timer to the following specification:

Displays a countdown to 0, in minutes and seconds.

Let's the user reset to 00:00, enter a new timespan.

Allows the user to start the countdown at *mm:ss*.

Starts buzzing if the countdown reaches *00:00*.

Use a state machine, get the time with millis().

Summary

We programmed a microcontroller in (Arduino) C.

We used digital and analog sensors and actuators.

We learned to design and code a state machine.

These are the basics of physical computing.

Next: Sending Sensor Data to IoT Platforms.

Challenge

Build and implement the kitchen timer you designed.

Document the timer state machine (ASCII or image).

Commit the code and docs to the hands-on repo.

Bring the (working) timer to the next lesson.

Consider cooking something to test it.

Feedback or questions?

Write me on Teams or email

thomas.amberg@fhnw.ch

Thanks for your time.