

# IoT Engineering

## 2: Microcontrollers, Sensors & Actuators

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Slides: [tmb.gr/iot-2](https://tmb.gr/iot-2)

# Overview

These slides introduce *microcontrollers*.

We learn how to run a program on one.

And how to use *sensors* and *actuators*.

# Prerequisites

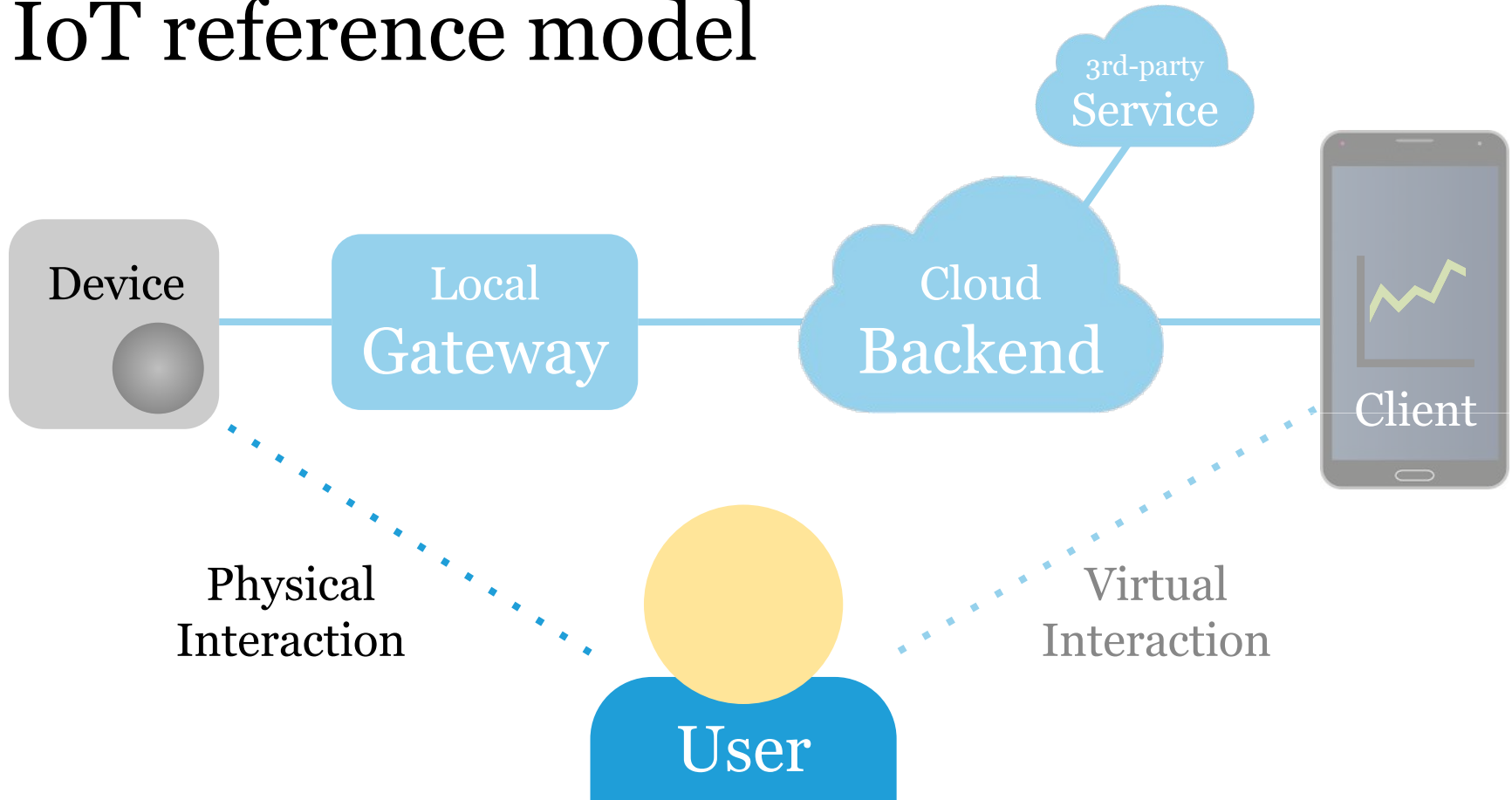
Install the Arduino IDE and set up microcontrollers:

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  $\rightarrow$  Device, e.g. logging temperature.

Device  $\rightarrow$  Actuator, e.g. time-triggered buzzer.

Sensor  $\rightarrow$  Device  $\rightarrow$  Actuator, e.g. RFID door lock.

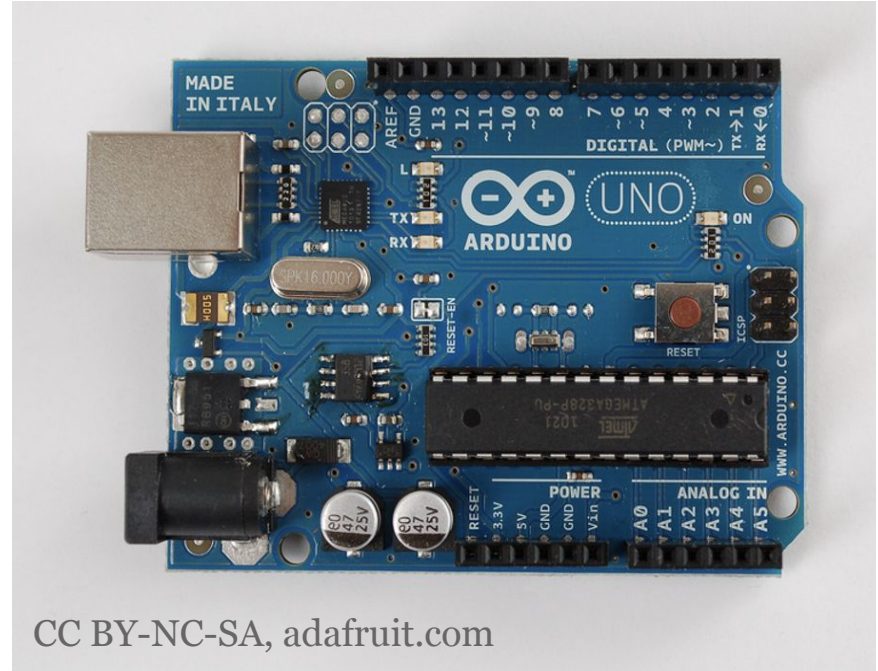
A  $\rightarrow$  B: measurement or control data flow.

# 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.



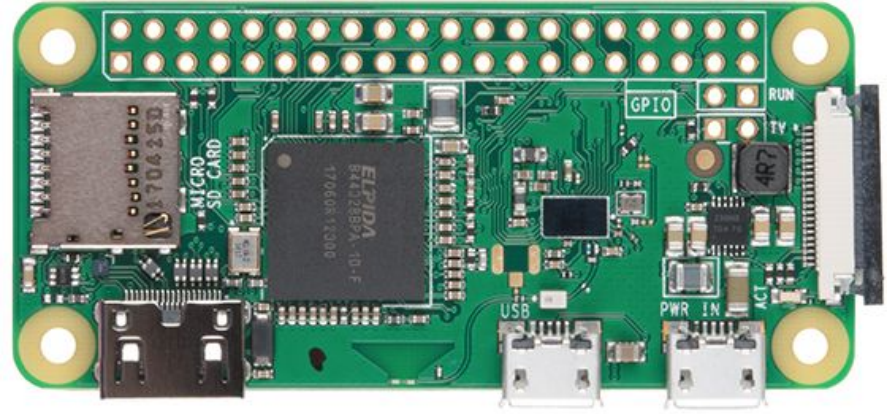
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# Raspberry Pi, a single-board computer

*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.



# Prototyping hardware form factors

Some modular prototyping hardware *form factors*:

Arduino ([Uno](#) and [MKR](#)) with "shield" extensions.

Adafruit [Feather](#) with [FeatherWing](#) extensions.

[Wemos](#), stackable modules based on ESP8266.

[M5Stack](#), a modular system based on ESP32.

We use Feather compatible microcontrollers.



# Feather Huzzah ESP8266

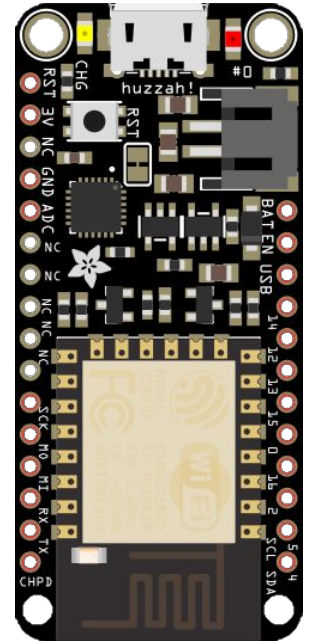
Microcontroller with Wi-Fi, used by hobbyists.

Espressif **ESP8266** System on Chip (SoC).

32-bit **Tensilica** CPU, without a FPU.

4 MB **flash** memory, 80 kB RAM.

See also [Wiki page](#).



# Feather nRF52840 Express

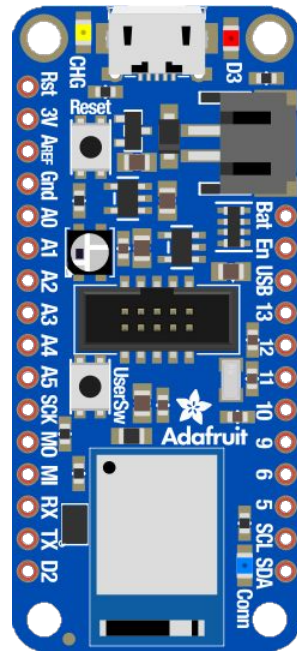
Microcontroller with [Bluetooth 5](#) (and more).

Nordic [nRF52840](#) System on Chip (SoC).

32-bit [ARM Cortex-M4](#) CPU with FPU.

1 MB [flash](#) memory, 265 kB RAM.

For details, check the [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.

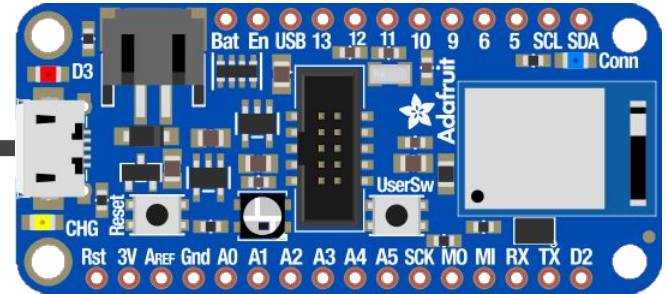
Some boards require additional settings.

# Arduino IDE program upload

The *Upload* button compiles and uploads the code.



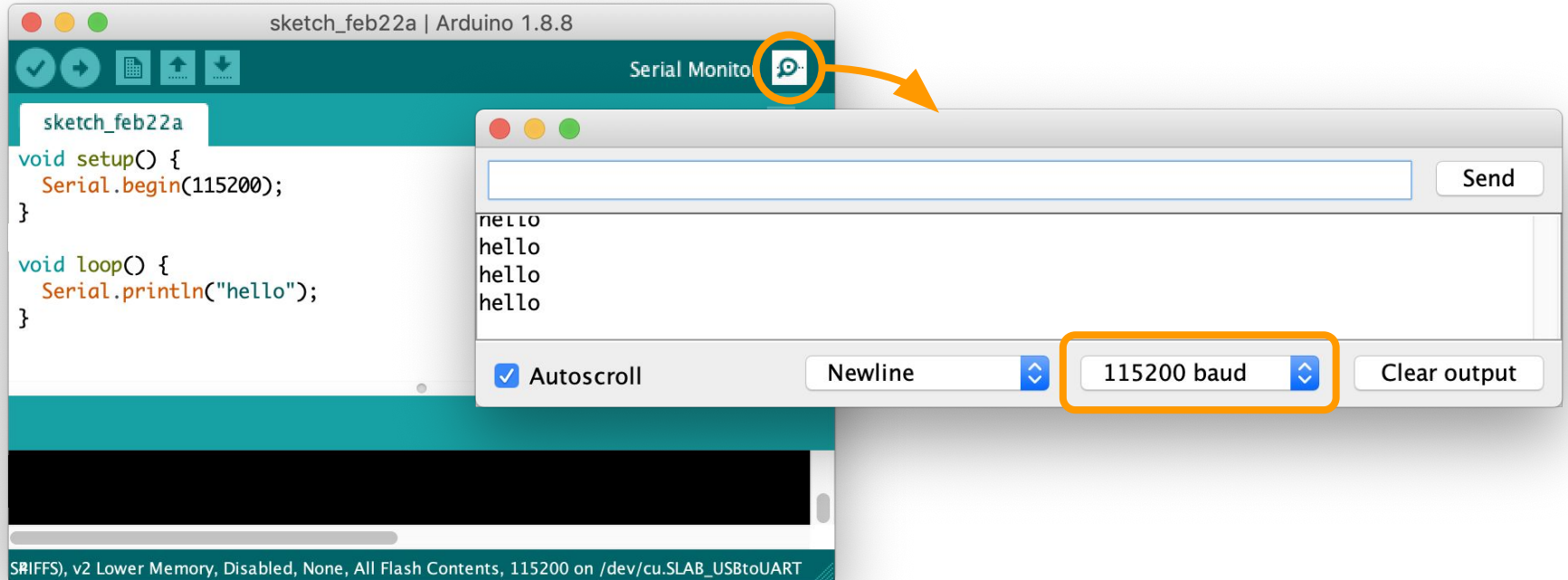
USB



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# 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++.

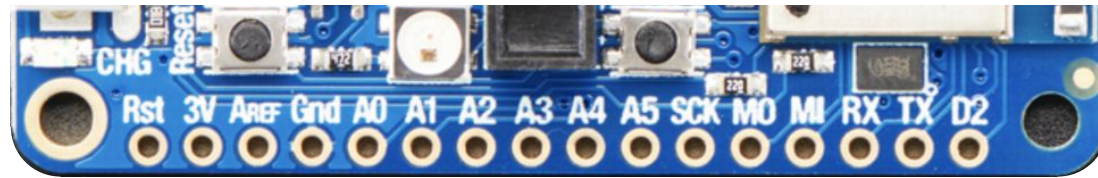
For details, check the [language reference](#).



# 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

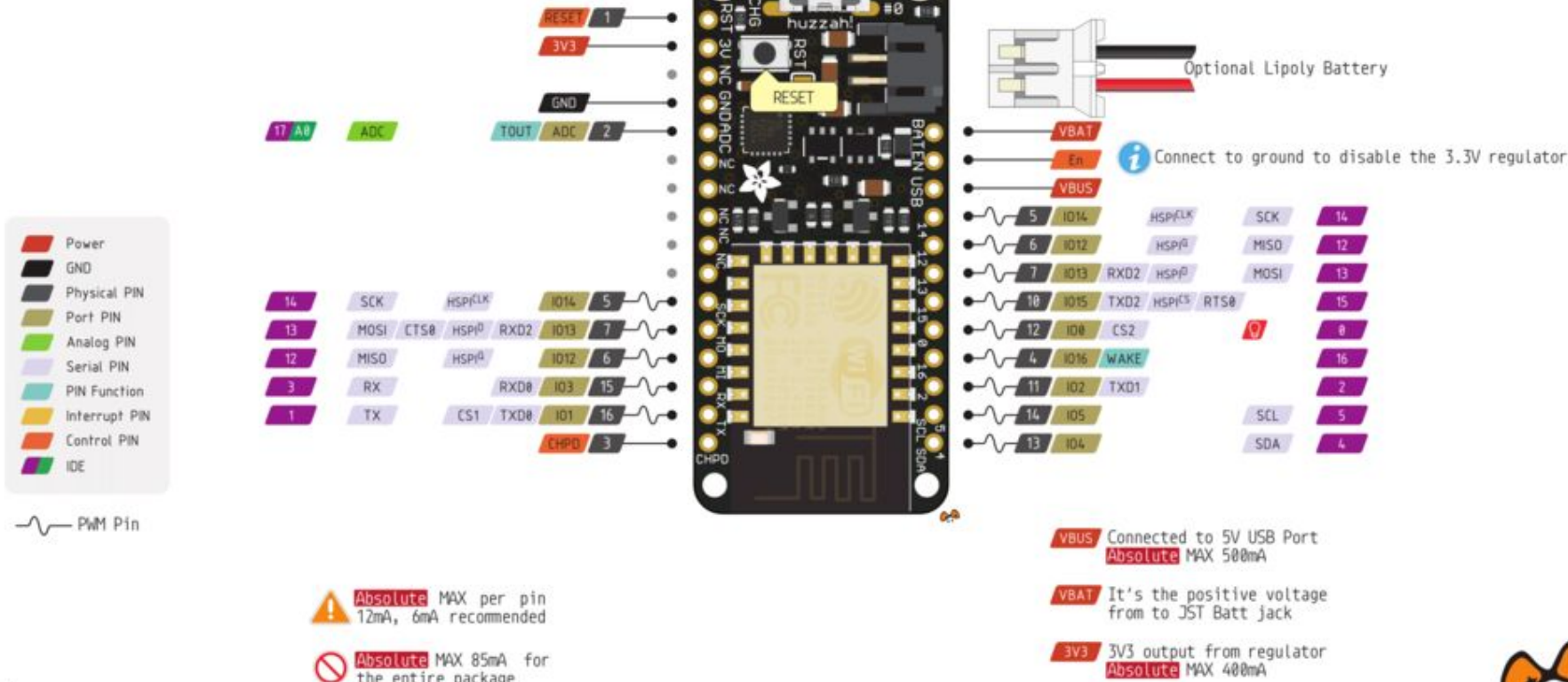
In Arduino, digital *pin names* are just numbers, e.g. pin 2, while analog pins start with an *A*, like pin *A0*.

Which pins are available depends on the device.

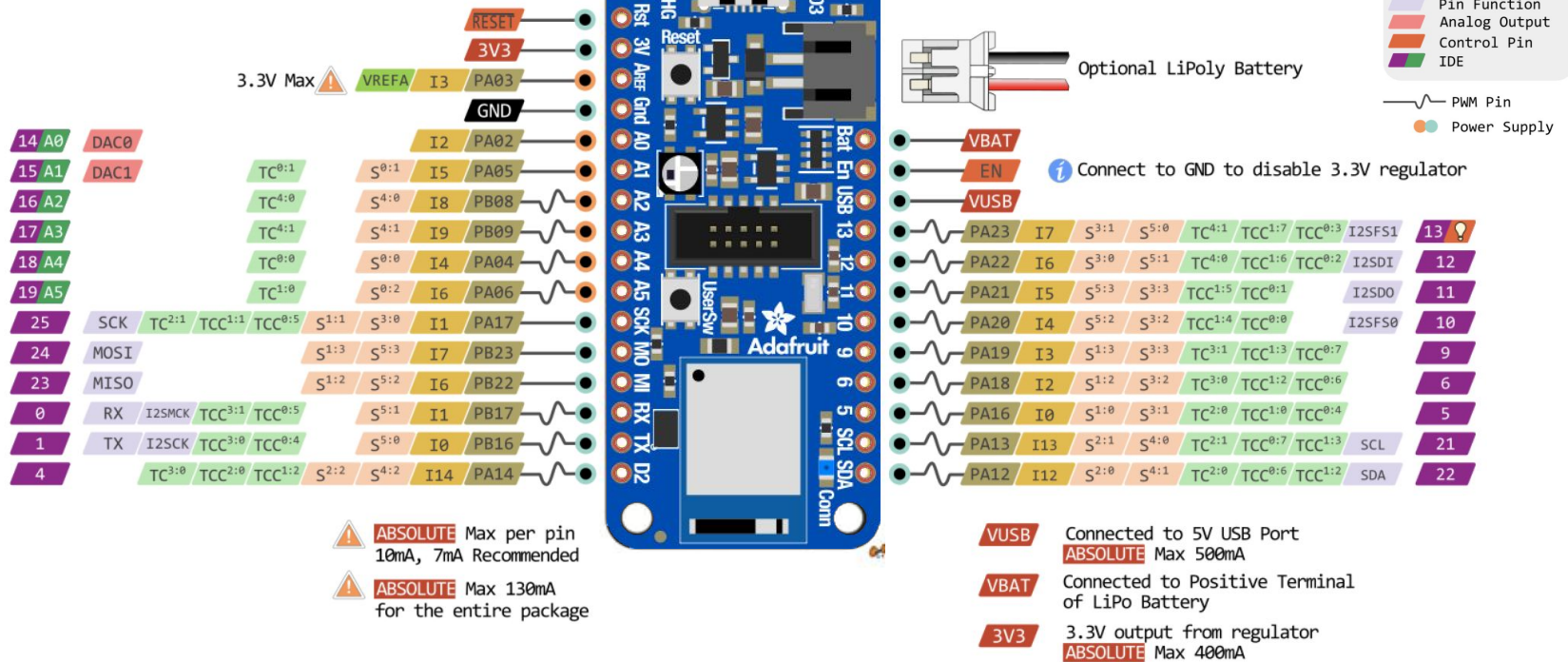
The map of available pins is called *pinout*.

A pin can have multiple functions.

# ESP8266



# nRF52840



# 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](#).



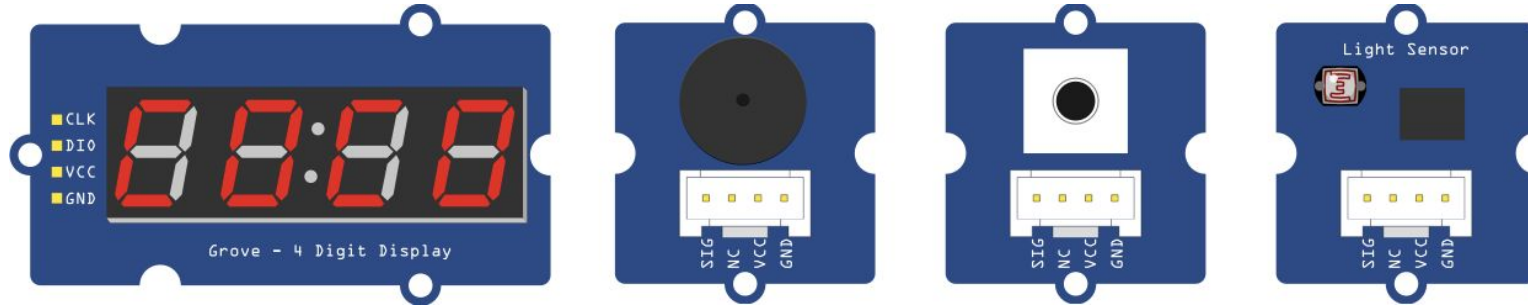


# Grove wiring standard

**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](#).

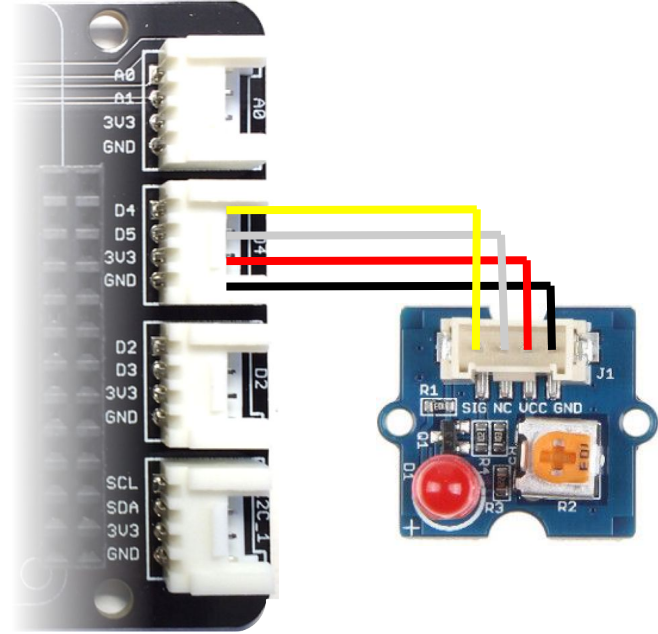
# Blinking a LED (digital output)

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)

```
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
}
```

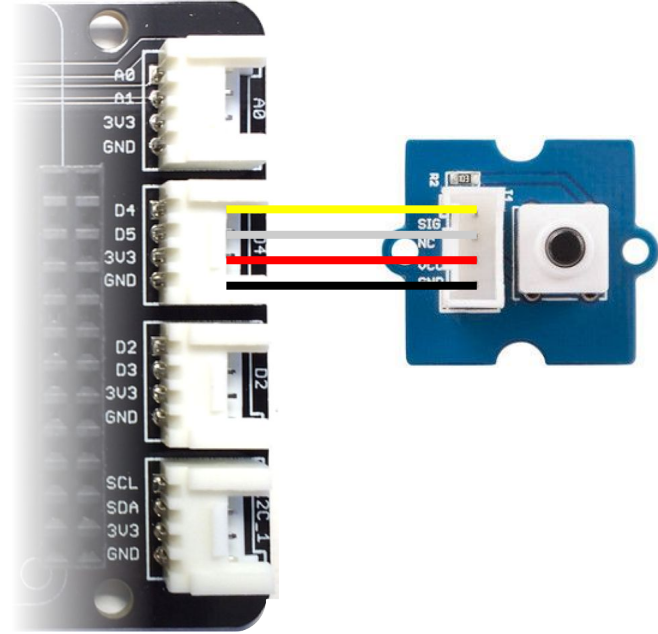
# Reading a button (digital input)

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)

```
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.

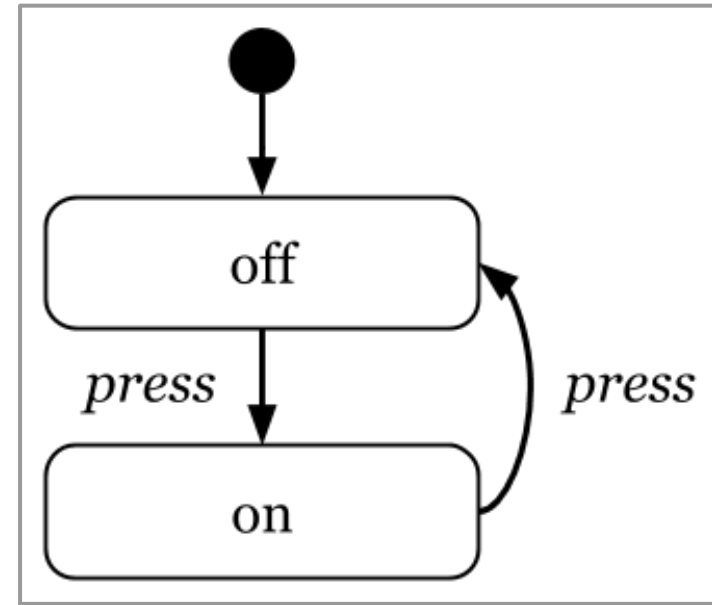
\*On the ESP8266, remove LED for programming.

# State machine

A (finite-) **state machine** is a simple way to manage state in embedded programs.

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

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



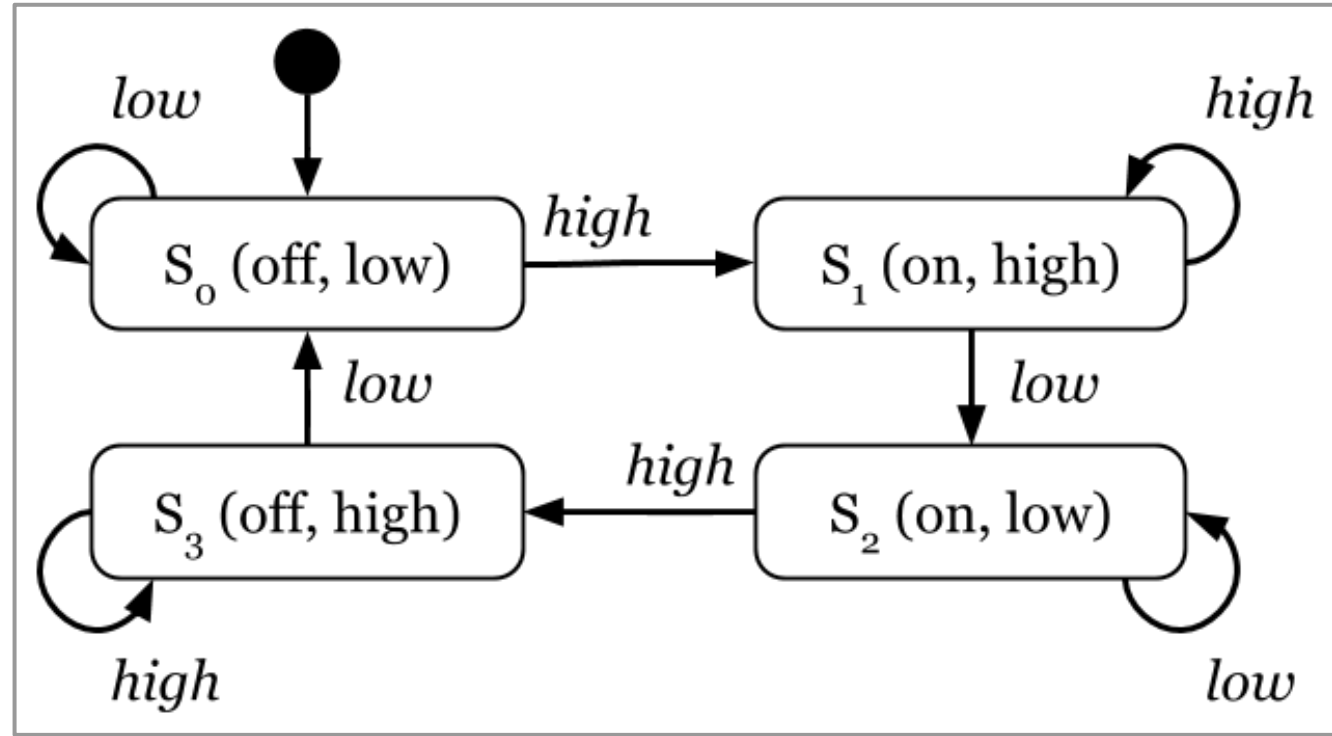


# State machine (refined)

Button is  
*high* or *low*.

Light is  
*on* or *off*.

Pressed =  
*low*  $\rightarrow$  *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 2<sup>nd</sup> press is *long*.

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

Commit the resulting code to the hands-on repo.

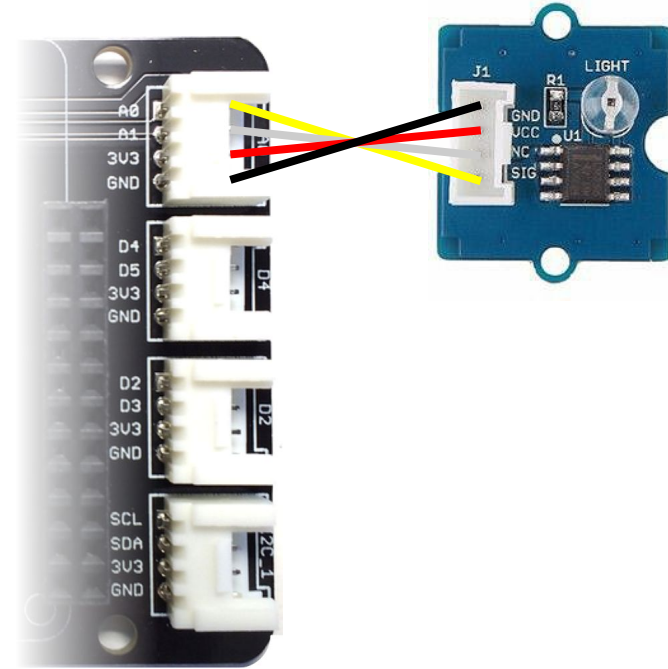
# Reading a light sensor (analog input)

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.

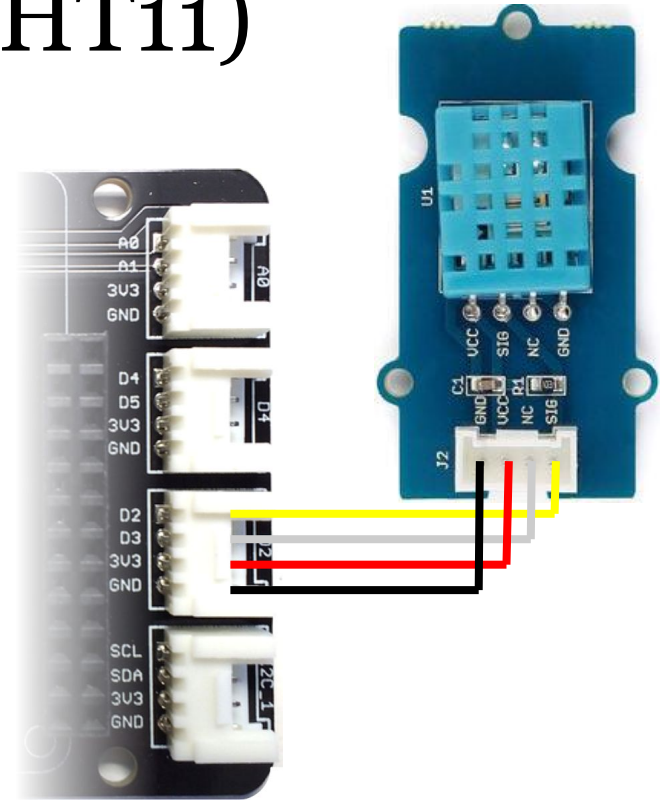
Setup and [examples in the Wiki](#).

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.



# Homework, max. 3h

Implement the kitchen timer you designed above.

Document the timer state machine (PDF or PNG).

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 <https://fhnw-iot.slack.com/>

Or email [thomas.amberg@fhnw.ch](mailto:thomas.amberg@fhnw.ch)

Thanks for your time.