

# IoT Engineering

## 2: Microcontrollers, Sensors & Actuators

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



### Overview

These slides introduce *microcontrollers*.

How to program them with Arduino.

How to use *sensors* and *actuators*.

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### Prerequisites

Install the Arduino IDE and set up microcontrollers:

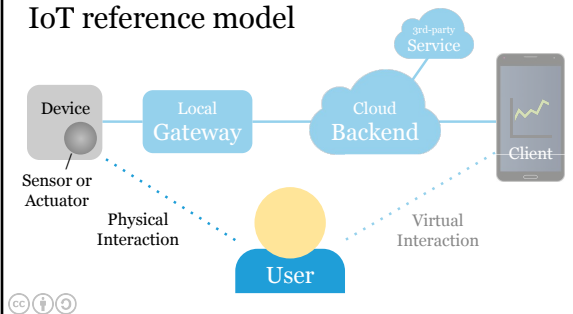
Check the Wiki entry on [Installing the Arduino IDE](#).

[Set up the Feather nRF52840 Express](#) for Arduino.

[Set up the Feather Huzzah ESP8266](#) for Arduino.

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### IoT reference model



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### 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.

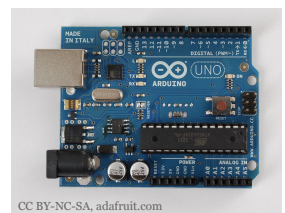
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### Arduino, a typical microcontroller

*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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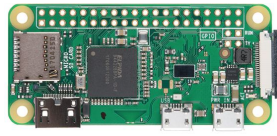
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## Raspberry Pi, a single-board computer

*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.



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## 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.

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## Feather Huzzah ESP8266

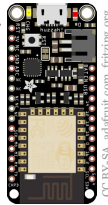
Microcontroller with Wi-Fi, used by hobbyists.

Esspressif [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](#).



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## Feather nRF52840 Express

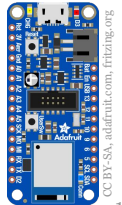
Microcontroller with [Bluetooth 5](#) (and more).

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

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

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

For details, check this [Wiki page](#).



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## 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".

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## Arduino IDE settings

Connect your board via USB and make sure that

*Tools > Board* is set to your microcontroller,

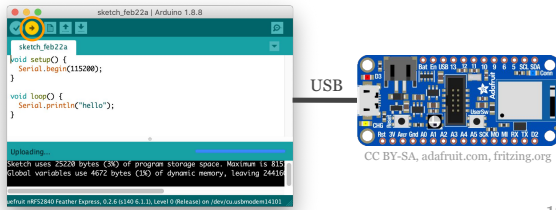
*Tools > Port* matches the current USB port.

Some boards require additional settings.

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## Arduino IDE program upload

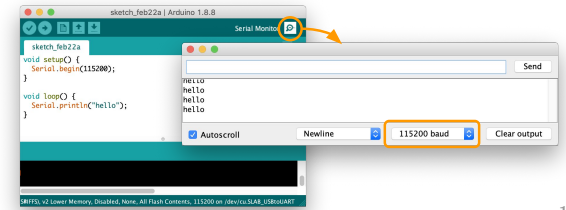
The *Upload* button compiles and uploads the code.



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## Arduino IDE serial console

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



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## 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!");
}
```

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## 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](#).

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## 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.

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## GPIO pin names

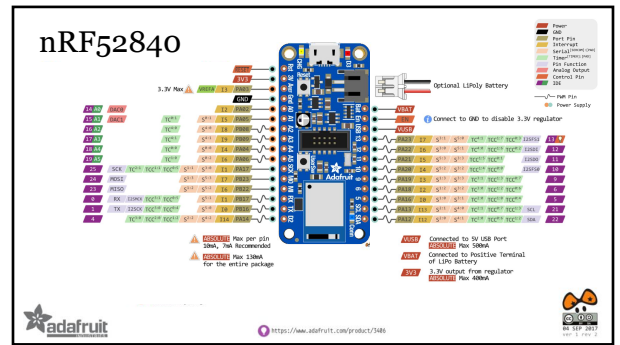
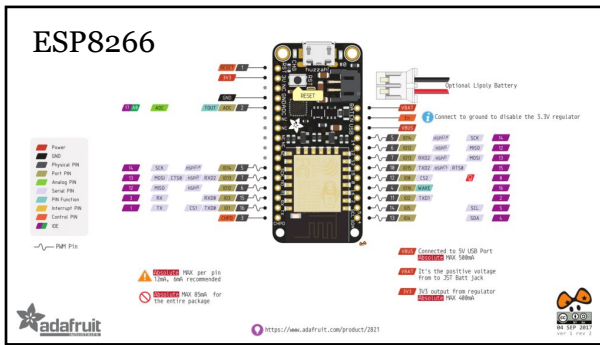
In Arduino, digital *pin names* are just numbers, e.g. pin 2, while analog pins start with an A, like pin A0.

Which pins are available depends on the device.

The map of available pins is called *pinout*.

A pin can have multiple functions.

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## 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<sup>10</sup>).  
Measuring = *reading* sensor values from input pins.

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## 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.

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## 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\*.

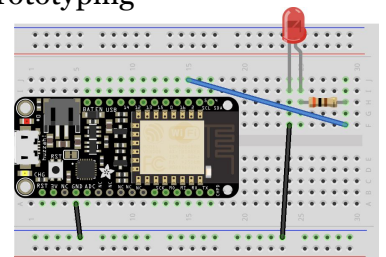
\*See slides on [Prototype to Product](#).

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## Breadboard prototyping

Wire electronic components, no soldering.

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

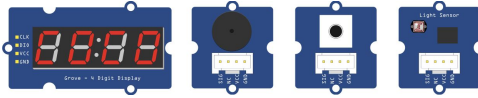


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## Grove wiring standard

**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.



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## 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](#).

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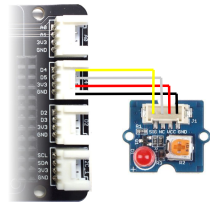
## Blinking a LED (digital output)

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.

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## 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
}
```

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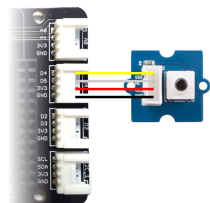
## Reading a button (digital input)

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.

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## 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
}
```

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## 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.

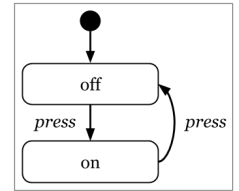
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## State machine

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

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

E.g. 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.



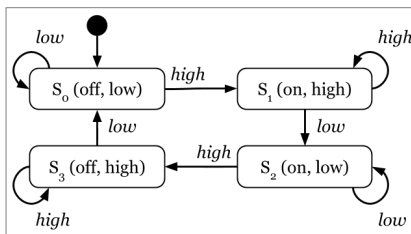
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## State machine (refined)

Button is  
*high* or *low*.

Light is  
*on* or *off*.

Pressed =  
*low* → *high*.



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## 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;
}
```

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## 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.

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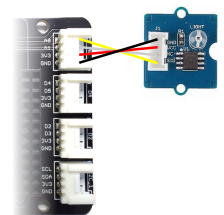
## Reading a light sensor (analog input)

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](#).

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## 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);
```

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## Measuring temperature (DHT11)

*DHT11* sensors require a library.

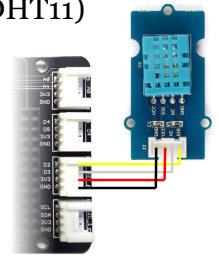
Setup and [examples in the Wiki](#).

Connect to adapter port *D2*.

It maps to ESP8266 pin 2.

Or nRF52840 pin 5.

New to libraries? See [Arduino library guide](#).



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## 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()`.

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## 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.

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## 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.

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## 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.

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