IoT Engineering 2: Microcontrollers, Sensors & Actuators

Today

⅓ slides,

⅔ hands-on.

Slides, code & hands-on: tmb.gr/iot-2

Prerequisites

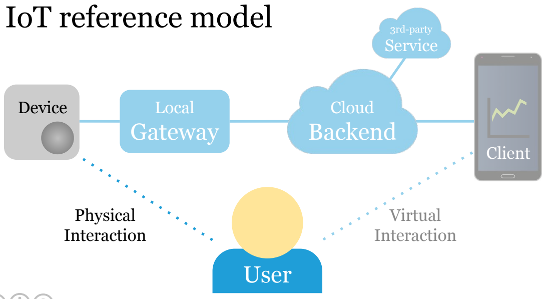
Install the Arduino IDE and set up microcontrollers:

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



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.

Microcontrollers

A *microcontroller* is a small, low power computer.

Sometimes it is also just called *controller* or *board*.

Runs a single program, there's no operating system.

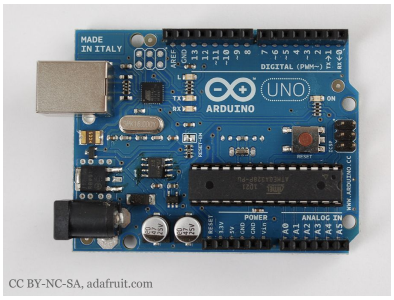
Pins for General Purpose Input and Output (GPIO).

We focus on Arduino compatible microcontrollers.

Arduino

An electronics prototyping platform.

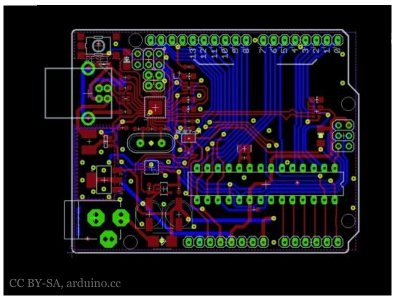
Here's a video about Arduino with Massimo Banzi.


CC BY-NC-SA, adafruit.com

Open source hardware

Layout and bill of materials are available under open licenses.

For details see, e.g. OSHWA.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Arduino compatible

Arduino *compatible* can mean different things:

Arduino *pin compatible*, for shield extensions.

Arduino IDE *programmable*, for ease of use.

We use Arduino IDE programmable controllers.

Microcontroller form factors

Prototyping hardware *form factors* allow extensions:

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 form factor

Microcontroller form factor, specified by Adafruit.

LiPo charging circuit and USB on each board.

Reasonably small, breadboard friendly.

Broad range of microcontrollers.

FeatherWing extensions.

Feather Huzzah ESP8266

Microcontroller with Wi-Fi, used by hobbyists.

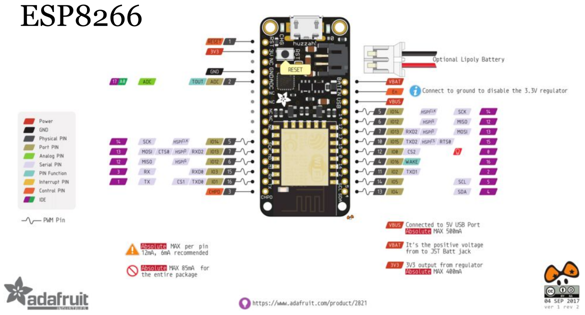
ESP8266 System on Chip (SoC) by Espressif.

32-bit Tensilica CPU, 2.4 GHz 802.11 b/g/n.

4 MB flash memory, 80 kB user data RAM.

For details, check the Wiki page.

ESP8266



Feather nRF52840 Express

Microcontroller with Bluetooth 5 (and more).

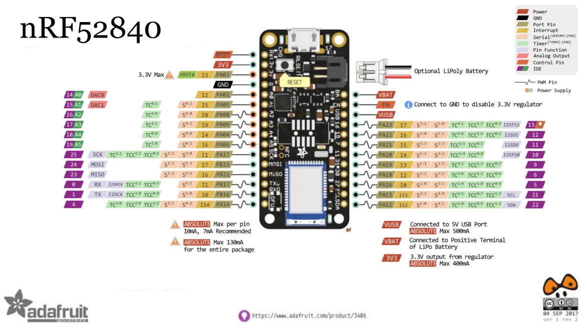
Nordic nRF52840 System on Chip (SoC).

32-bit ARM Cortex-M4 CPU with FPU.

1 MB flash memory, 265 kB RAM.

For details, check the Wiki page.

nRF52840



Programming a microcontroller

Most microcontrollers are programmed via USB.

Some require a *programmer* hardware adapter*.

(Cross-) *compiling* happens on your computer.

The binary has to be *uploaded* to the board.

Uploaded "firmware" runs stand-alone.

*) We use hardware with USB, no programmer.

Arduino IDE

The Arduino IDE is open source and written in Java.

This tutorial is based on the desktop version *1.8.x*.

Board support URLs enable 3rd-party boards.

For details, check the Wiki page.

Arduino "Hello, World!"

This is the basic structure of an Arduino program:

```
void setup() { // called once
  Serial.begin(115200); // set baud rate
}
void loop() { // called in a loop
  Serial.println("Hello, World!");
}
```

Arduino settings

Connect your board via USB and make sure that

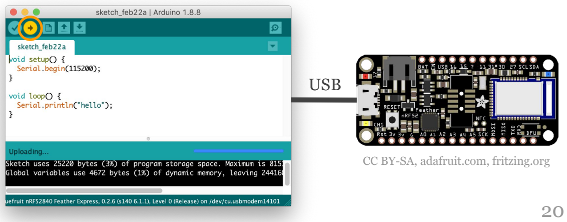
Tools > *Board* is set to your microcontroller,

Tools > *Port* matches the current USB port.

Some boards require additional settings.

Arduino program upload

The *Upload* button compiles and uploads the code.



```
void setup() {
  Serial.begin(115200);
}

void loop() {
  Serial.println("hello");
}
```

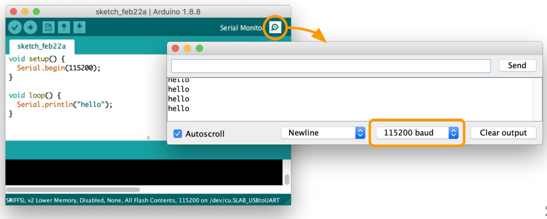
```
Sketch uses 25220 bytes (3%) of program storage space. Maximum is 815
Global variables use 4672 bytes (1%) of dynamic memory, leaving 24416
```

uefruit nRF52840 Feather Express, 0.2.6 (s140 6.1.1), Level 0 (Release) on /dev/cu.usbmodem14101

CC BY-SA, adafruit.com, fritzing.org

Arduino serial console

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



```
void setup() {
  Serial.begin(115200);
}

void loop() {
  Serial.println("hello");
}
```

```
hello
hello
hello
hello
```

S?IFFS), v2 Lower Memory, Disabled, None, All Flash Contents, 115200 on /dev/cu.SLAB_USBtoUART

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.

Input and output

Microcontrollers have an interface to the real world:

General purpose Input and Output (GPIO) pins.

GPIOs allow a controller to measure and control.

Measuring = *reading* sensor values from *input* pins.

Controlling = *writing* actuator values to *output* pins.

Sensors and actuators

Convert physical properties to/from electrical signals.

Signals are *digital* (0 or 1) or *analog* (e.g. 0-255).

We look at two ways to wire sensors/actuators:

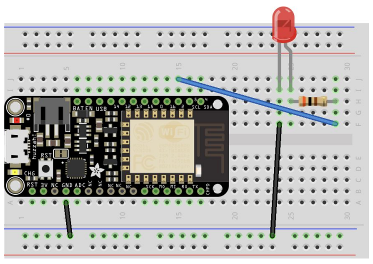
Breadboard and jumper wire connections.

Grove connectors with 4-stranded wires.

Breadboard

Wires electronic components, no soldering.

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

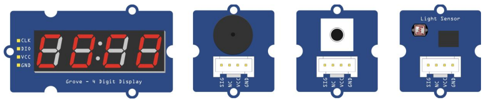


Grove

Grove is a simple way to connect sensors/actuators.

This wiring standard is specified by Seeed Studio.

All modules designed by Seeed are open source.



Blinking LED

The "Hello, World!" of embedded programming.

```
void setup() { // called once
  pinMode(2, OUTPUT); // configure pin 2
}
void loop() { // called in a loop
  digitalWrite(2, HIGH); // set pin 2 = on
  delay(500); // sleep 500 ms
  digitalWrite(2, LOW); // set pin 2 = off
  delay(500); // sleep 500 ms
}
```

Arduino example code

Each Arduino library comes with example code.

There are also a number of basic examples.

See *Arduino IDE* > *File* > *Examples*

GPIO pin numbers may vary.

Use the pin mapping.

Hands-on, 5': LED (digital output)

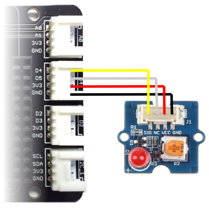
nRF52840 or ESP8266 w/ Grove:

Find code examples in the Wiki.

Connect to adapter port *D4*.

Maps to ESP8266 pin *0*.

Or nRF52840 pin *9*.



The same code works for the buzzer.

Hands-on, 5': Button (digital input)

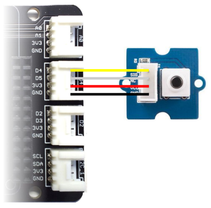
nRF52840 or ESP8266 w/ Grove:

Find code examples in the Wiki.

Connect to adapter port *D4*.

Maps to ESP8266 pin *0*.

Or nRF52840 pin *9*.



Use the serial console to see output.

Hands-on, 15': Button-triggered LED

This works with nRF52840 or ESP8266, w/ Grove.

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

Combine the previous examples to switch the LED.

Look up the pin mapping to adapt the pin numbers.

*) On the ESP8266, remove LED for programming.

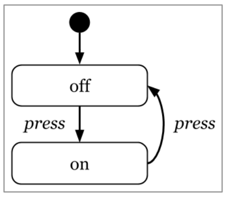
Commit the resulting code to the hands-on repo.

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

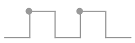


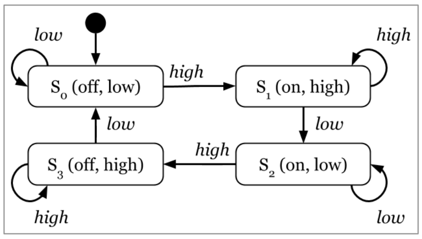
State machine (detail)

Button is *high* or *low*.

Light is *on* or *off*.

Pressed = *low* → *high*.





State machine (code)

```
int b = digitalRead(buttonPin); // local
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; // note: actions are idempotent
} // not shown: global int s = 0; …
```

Hands-on, 5': 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.

Hands-on, 5': Light sensor (analog input)

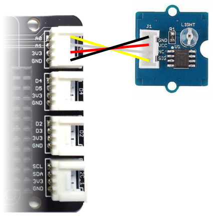
nRF52840 or ESP8266 w/ Grove:

Find code examples in the Wiki.

Connect to adapter port *A0*.

Maps to ESP8266 pin *A0*.

Or nRF52840 pin *A0*.



Use the serial console or serial plotter to see output.

Map input to value range

Sometimes mapping sensor value ranges helps, e.g.

0 - 1024 analog input => 0 - 10 brightness levels.

Arduino has a simple map() function for this:

```
int map(value, // measured input value
  fromLow, fromHigh, // from range
  toLow, toHigh); // to range
int x = …; x = map(x, 0, 1024, 0, 10);
```

Hands-on: Temperature (DHT11)

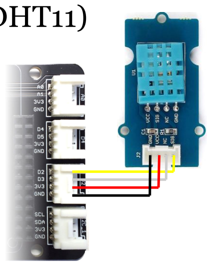
DHT11 sensors require a library.

Setup and examples in the Wiki.

Connect to adapter port *D2*.

Maps to ESP8266 pin *2*.

Or nRF52840 pin *5*.



New to libraries? See Arduino library guide.

Hands-on, 30': 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 or finish the kitchen timer you designed.

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?

Find me on https://fhnw-iot.slack.com/

Or email thomas.amberg@fhnw.ch

Slides, code & hands-on: tmb.gr/iot-2