Tecnologie per IoT

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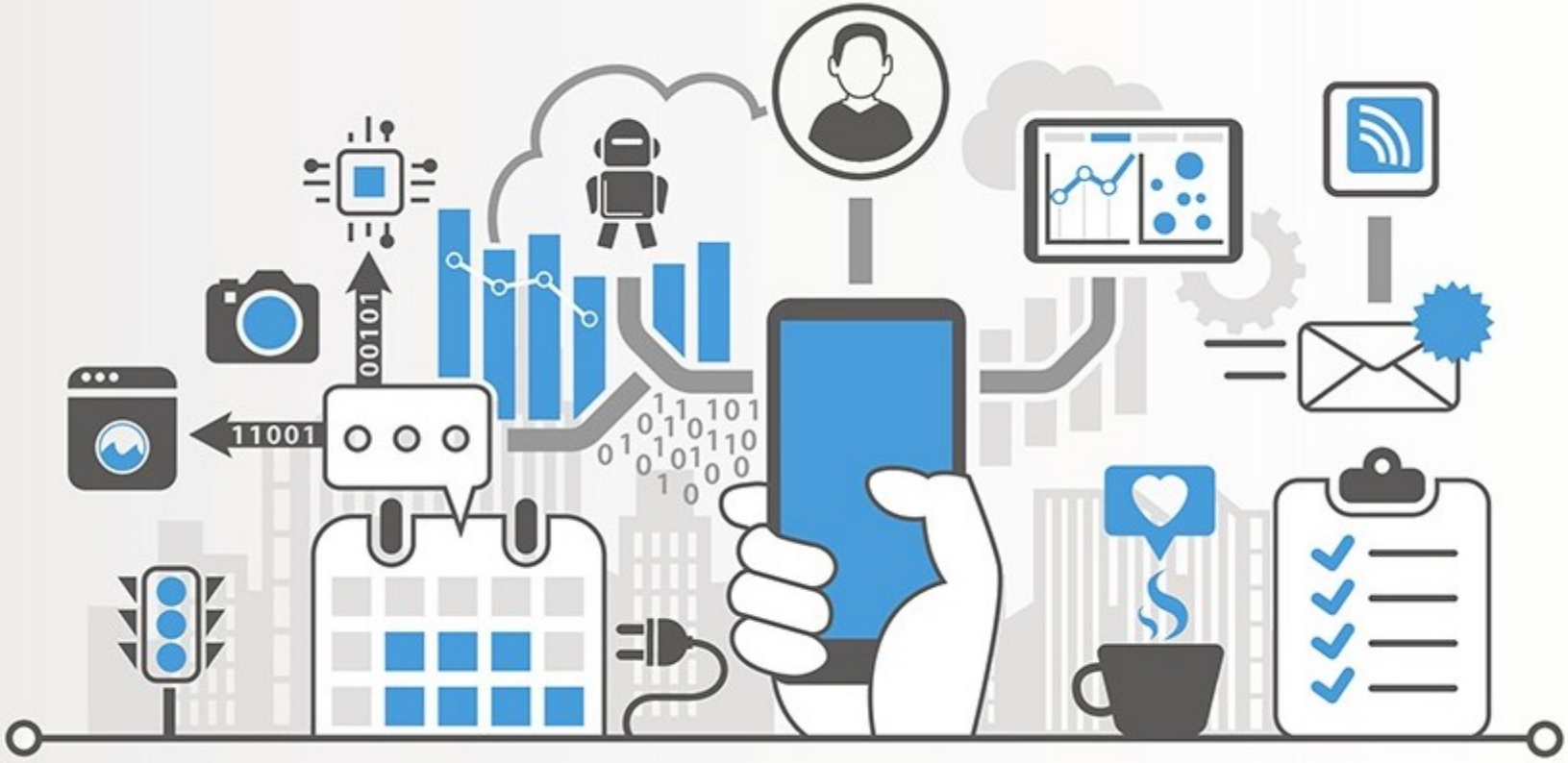
Lab1: Hardware



LAB ORGANIZATION

Lab Organization

- **1st part:**
  - 6 basic (guided) exercises to familiarize with the Arduino environment and with the sensors/actuators available in the kit
  - Dedicated class: 28/03 (today) 3h

- **2nd part:**
  - 1 complex exercise that uses the entire kit to implement a (simplified) "**smart-home controller**".
  - You'll receive only the specifications and you'll be able to implement the code as you want.
  - In this lab, the controller will be fully local (no Internet). Then, in the SW lab, you'll enhance its functionality by connecting it to the "cloud".
  - Dedicated classes: 31/03-04/04 1.5h + 3h = 4.5h

Lab Organization

- **3rd part:**
  - 3 basic (guided) exercises to learn how to connect the Arduino to the Internet, using either a Client/Server or a Publish/Subscribe communication paradigm.
  - Useful as a basis for the SW Lab
  - Dedicated class: 23/05 3h (tentative)

- In-between the 2st and 3nd parts you'll be introduced by prof. Patti to the Internet Protocol Suite (TCP/UDP/IP) and communication protocols (HTTP/MQTT), which are needed for Part 3.

Lab Organization

- No report, just code!
  - Send me the code in a *.zip file
- Deadlines:
  - Part 1: **04/04** (**one week** from today)
  - Part 2: **20/04** (2 weeks after the lab, since it's a bit more complex)
  - Part 3 (+ all SW labs): **23/06**

ARDUINO INTRODUCTION

What is Arduino?

*"Arduino is an **open-source electronics platform** based on **easy-to-use** hardware and software. **Arduino boards** are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the **Arduino programming language** (based on Wiring), and the **Arduino Software (IDE)**, based on Processing."*

(source: arduino.cc)

What is Arduino?

- **Inexpensive** - Arduino boards are relatively inexpensive (less than $50)
- **Cross-platform** - The Arduino Software (IDE) runs on Windows, Macintosh OSX, and Linux operating systems.
- **Simple, clear programming environment** - The Arduino Software (IDE) is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well
- **Open source and extensible software and hardware** - The language can be expanded through C++ libraries, and people wanting to understand the technical details can make the leap from Arduino to the AVR C programming language on which it's based. Similarly, you can add AVR-C code directly into your Arduino programs if you want to. Circuit designers can make their own version of a module, extending it and improving it.

Common Features

- Most Arduino boards are based on **Atmel AVR architecture** microcontrollers

- Arduino boards include **all auxiliary components** needed for the microcontroller to work, such as a crystal oscillator and a set of external peripherals and connectors.

Common Features

- Most Arduino boards use a USB port to:
  - Supply **power** to the entire board, through a voltage regulator
  - **Program** the microcontroller, tunneling JTAG data.
  - Let the microcontroller **communicate** with a PC, tunneling Serial (RS-232) data

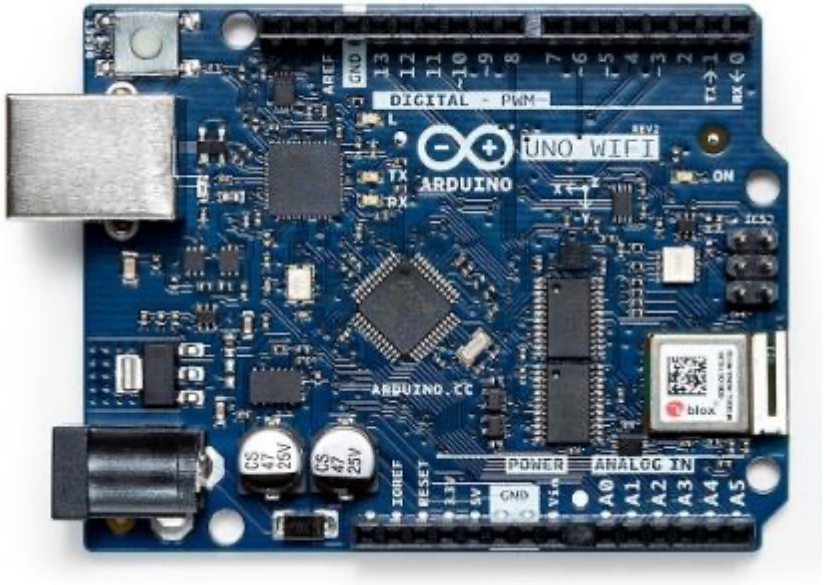
Common Features

- **GPIO pins** are made available through two rows of pin headers on the board to allow easy connection of external peripherals, for example through a breadboard.

- Most boards use a standard pinout and form factor, which allows the development of **shield boards.**
  - Shields are boards with the same form factor as the main Arduino board, which simplify the interface with complex peripherals .

Arduino Uno (WiFi)

- Based on the original Arduino board
- ATmega4809 8-bit microcontroller
- Onboard IMU (Inertial Measurement Unit)
- Wi-Fi Module with integrated TCP/IP stack



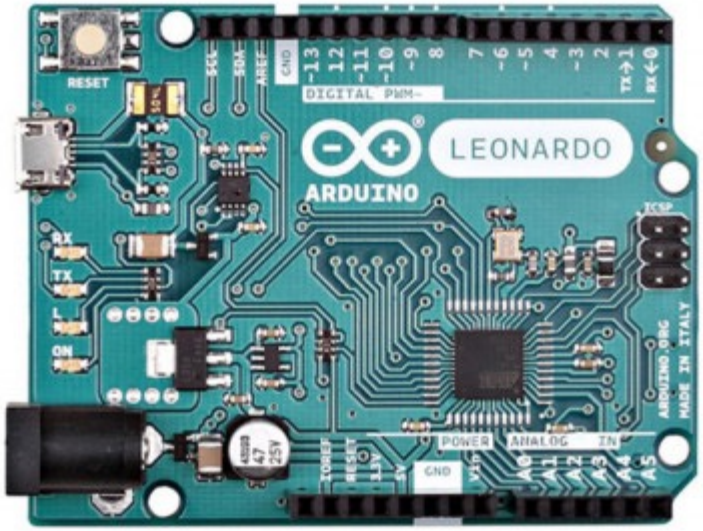
Arduino Uno (WiFi)

Microcontroller	ATmega4809 (datasheet)
Operating Voltage	5V
Input Voltage (recommended)	7 - 12V
Digital I/O Pins	14 — 5 Provide PWM Output
PWM Digital I/O Pins	5
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	48 KB (ATmega4809)
SRAM	6,144 Bytes (ATmega4809)
EEPROM	256 Bytes (ATmega4809)
Clock Speed	16 MHz

Other Arduinos

- Leonardo (ATmega32u4)

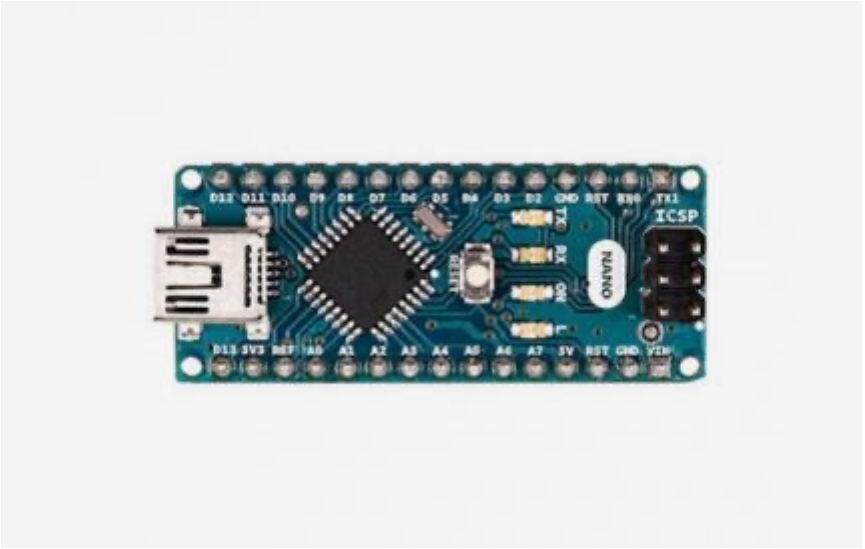
- Built-in USB peripheral capabilities (can act as a keyboard or mouse)

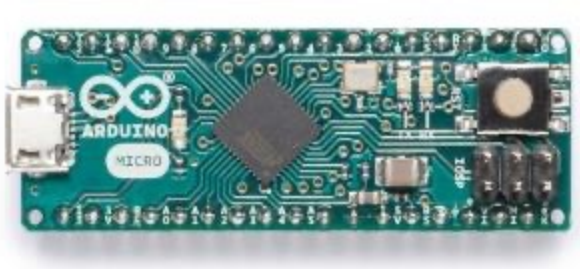


Other Arduinos

- Nano (ATmega328) and Micro (ATmega32U4)

- Similar to Uno and Leonardo respectively, but in a small form factor





Other Arduinos

- Modern Arduinos replaced the 8-bit AVR architecture with **32-bit ARM Cortex**

- Arduino Due (Cortex M3)

Other Arduinos

- Nano 33 IOT (Cortex-M0)
- Supports BLE and WiFi

Other Arduinos

- Etc...
- Many more official Arduino versions
- And even more unofficial «clones»:
  - Sometimes very similar (but cheaper)
  - Sometimes completely different, only sharing the programming environment
    - Example: ESP8266-based boards (Sparkfun Thing etc.)
    - Unofficial list.

Not just for hobbyists

- **Arduino Pro**: powerful boards for industrial applications
  - Machines sensing and control
  - Edge intelligence
  - Etc.

ARDUINO YÙN REV2

Arduino Yùn Rev 2

- Two processors:
  - Atmega 32U4 (AVR), for Arduino-style programming
  - Atheros AR9331 (MIPS), equipped with a minimal Linux (OpenWRT Linino), for advanced network connections and applications.

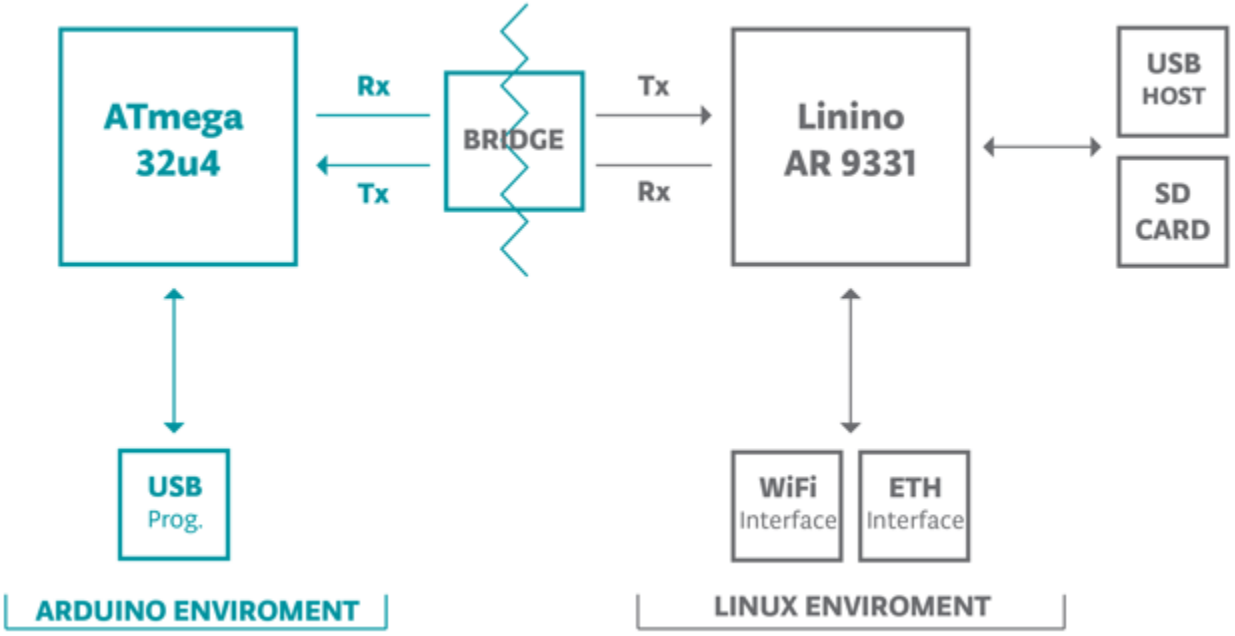
Yùn Specs

Microcontroller	ATmega32U4
Operating Voltage	5V
Input Voltage	5V
Digital I/O Pins	20
PWM Output	7
Analog I/O Pins	12
DC Current per I/O Pin	40 mA on I/O Pins; 50 mA on 3,3 Pin
Flash Memory	32 KB (of which 4 KB used by bootloader)
SRAM	2.5 KB
EEPROM	1 KB
Clock Speed	16 MHz

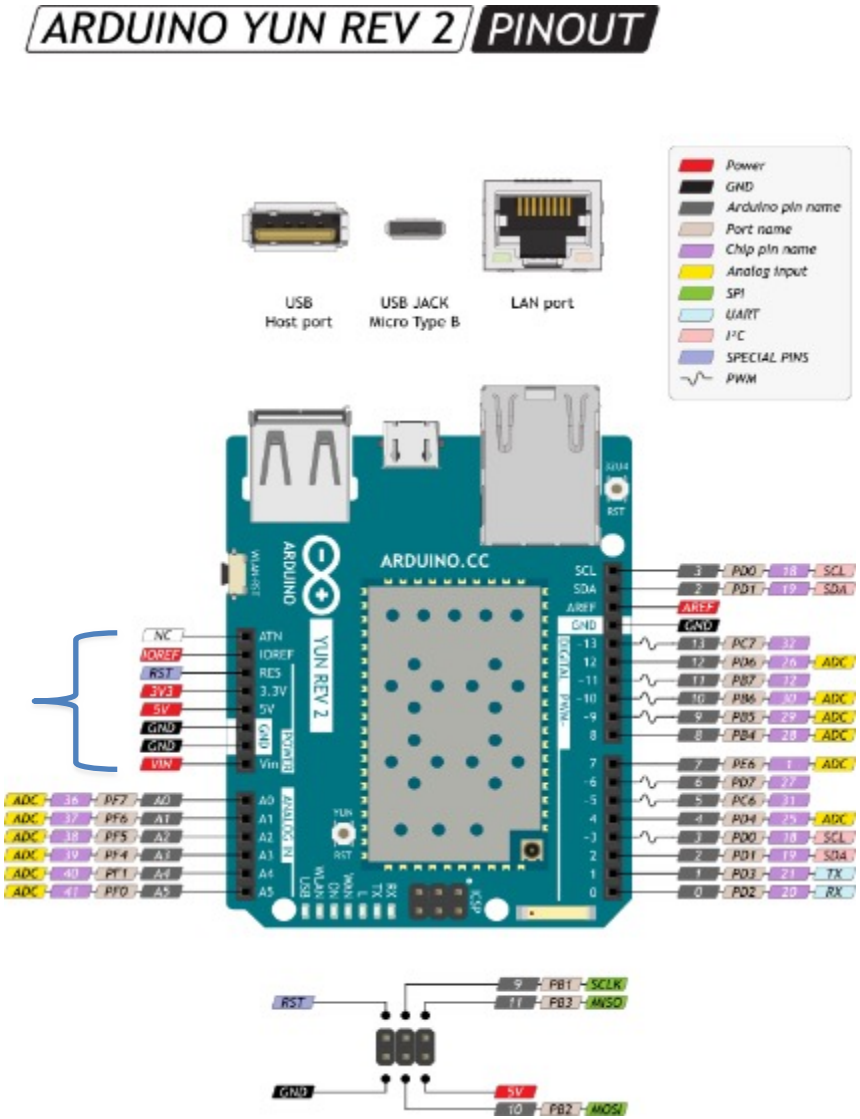
Processor	Atheros AR9331
Architecture	MIPS
Operating Voltage	3.3V
Ethernet	802.3 10/100Mbit/s
WiFi	802.11b/g/n 2.4 GHz
USB Type	2.0 Host
Card Reader	Micro-SD
RAM	64 MB DDR2
Flash Memory	16 MB
Clock Speed	400 MHz

Bridge Port

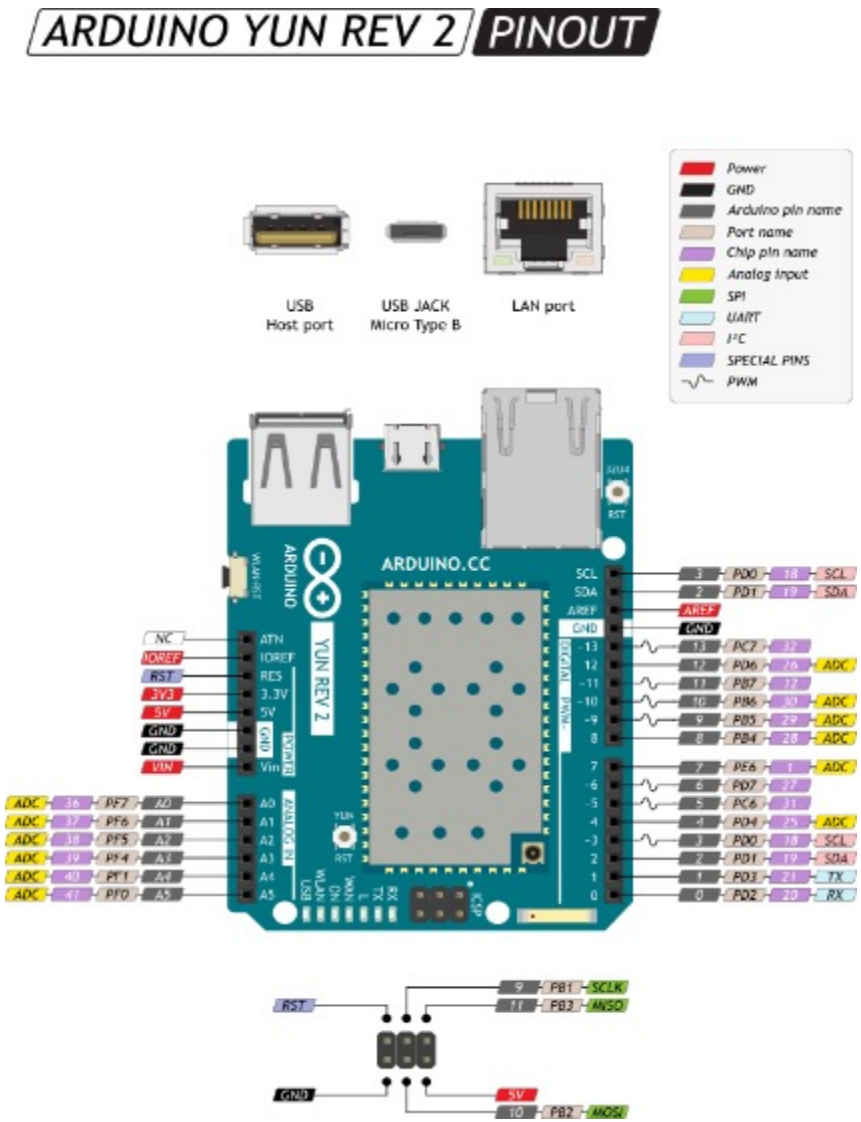
- The two processors communicate through a Bridge serial port



Yùn Pinout


ARDUINO YUN REV 2 PINOUT
USB Host port
USB JACK Micro Type B
LAN port
Power
GND
Arduino pin name
Port name
Chip pin name
Analog input
SPI
UART
I²C
SPECIAL PINS
PWM
ARDUINO.CC
YUN REV 2
WARNING!
Wired to D2 and D3!
Power, reset, etc.
14 Digital I/Os
6 Analog Inputs

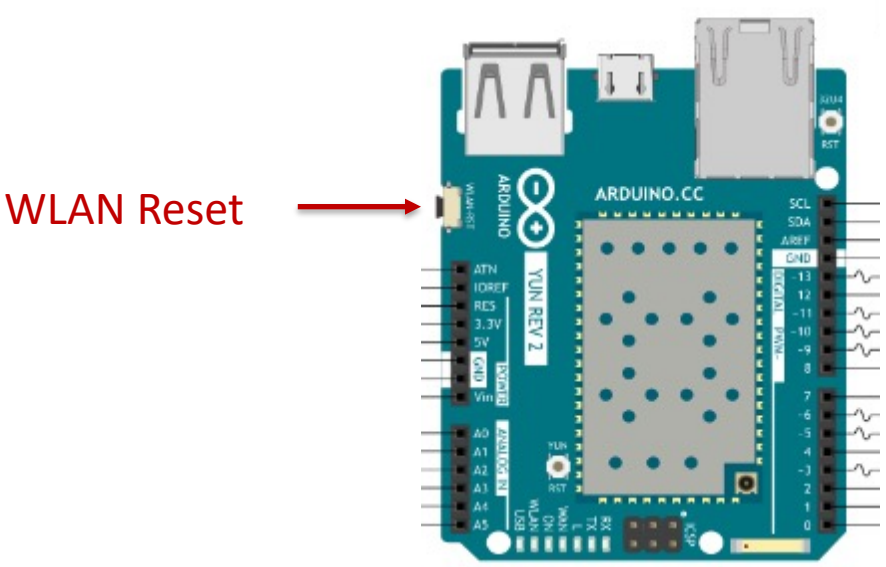
Yùn Pinout


ARDUINO YUN REV 2 PINOUT
Power
GND
Arduino pin name
Port name
Chip pin name
Analog input
SPI
UART
I²C
SPECIAL PINS
PWM
USB Host port
USB JACK Micro Type B
LAN port
ARDUINO.CC
YUN REV 2
WARNING! Serial1 pins, don't work when Bridge is used

ARDUINO YÙN FIRST SETUP

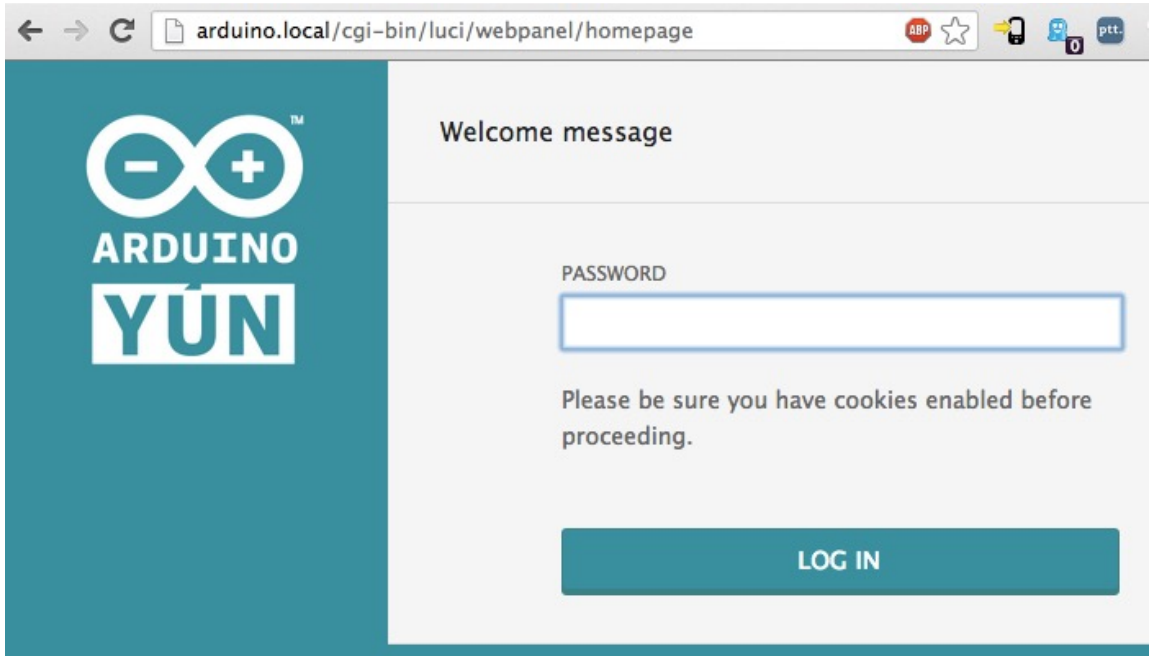
First Setup

- Do this part **at home!**
- Perform a factory restore holding the **WLAN reset** button for more than 30s



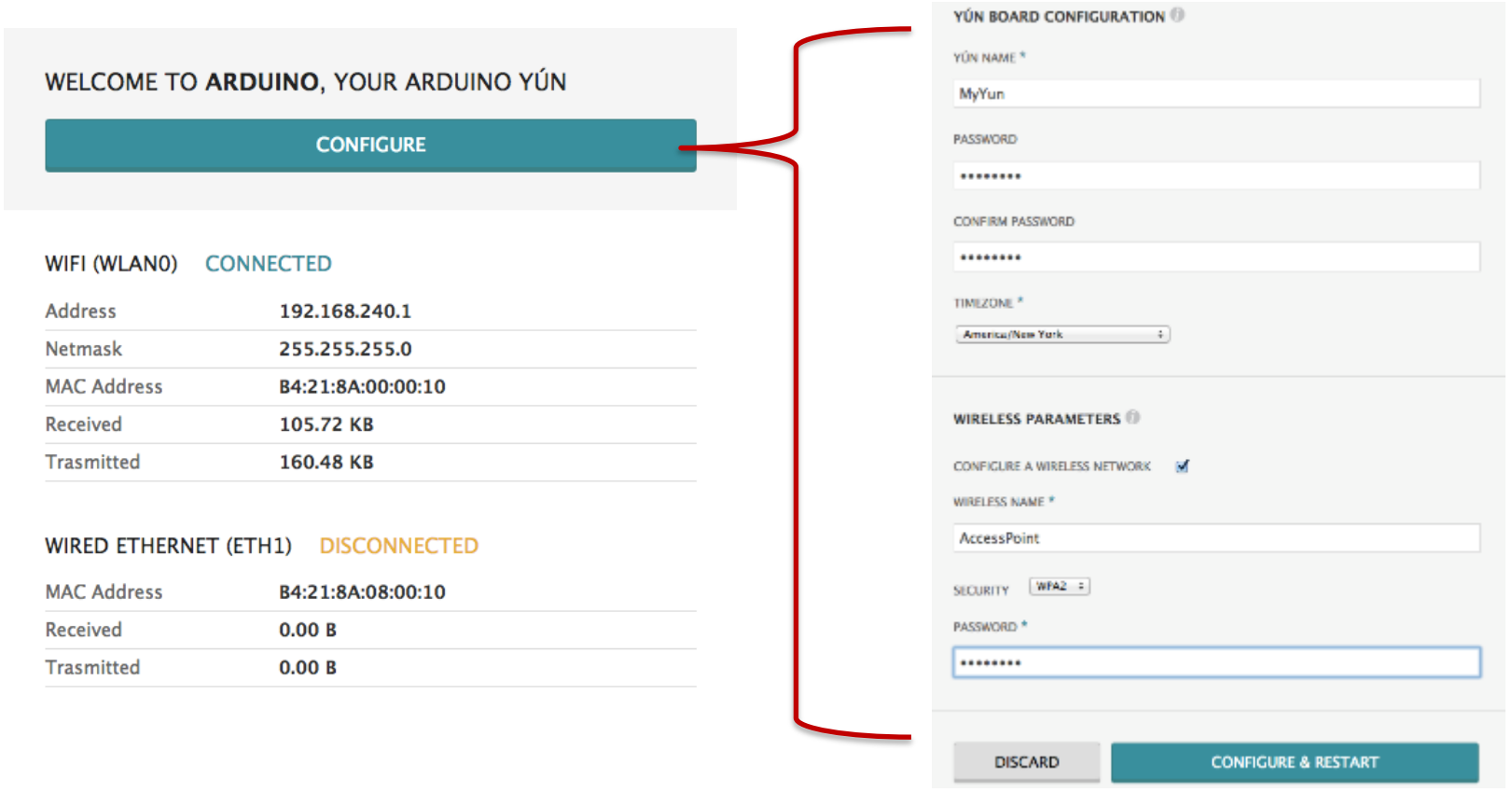
First Setup

- After that the Yùn creates a WiFi network called *ArduinoYun-XXXXXXXXXXXX*
  - Connect to it, open a browser and go to `http://arduino.local` or `http://192.168.240.1`
  - You should see this page (default password: **arduino**)



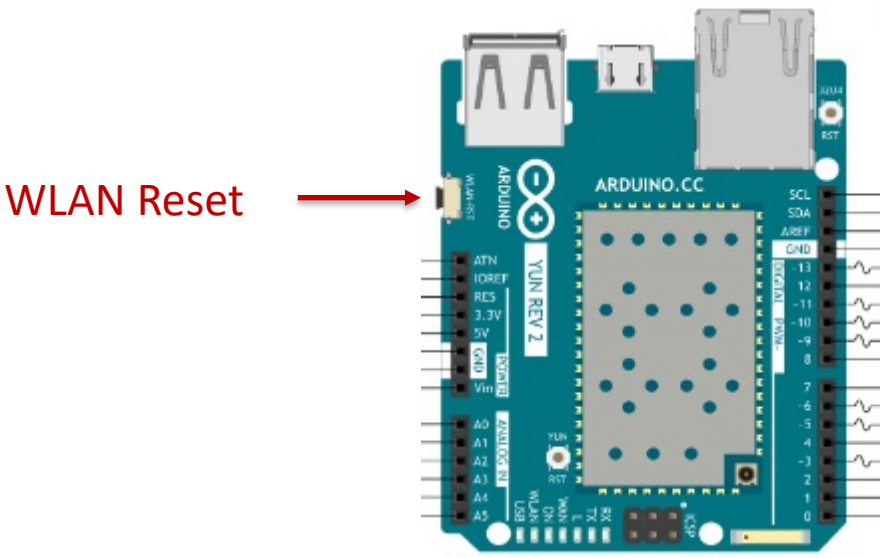
First Setup

- In the following configuration page, follow the instructions to configure the Yùn and let it connect to your home WiFi network or smartphone hotspot.



First Setup

- Other instructions for setup can be found here



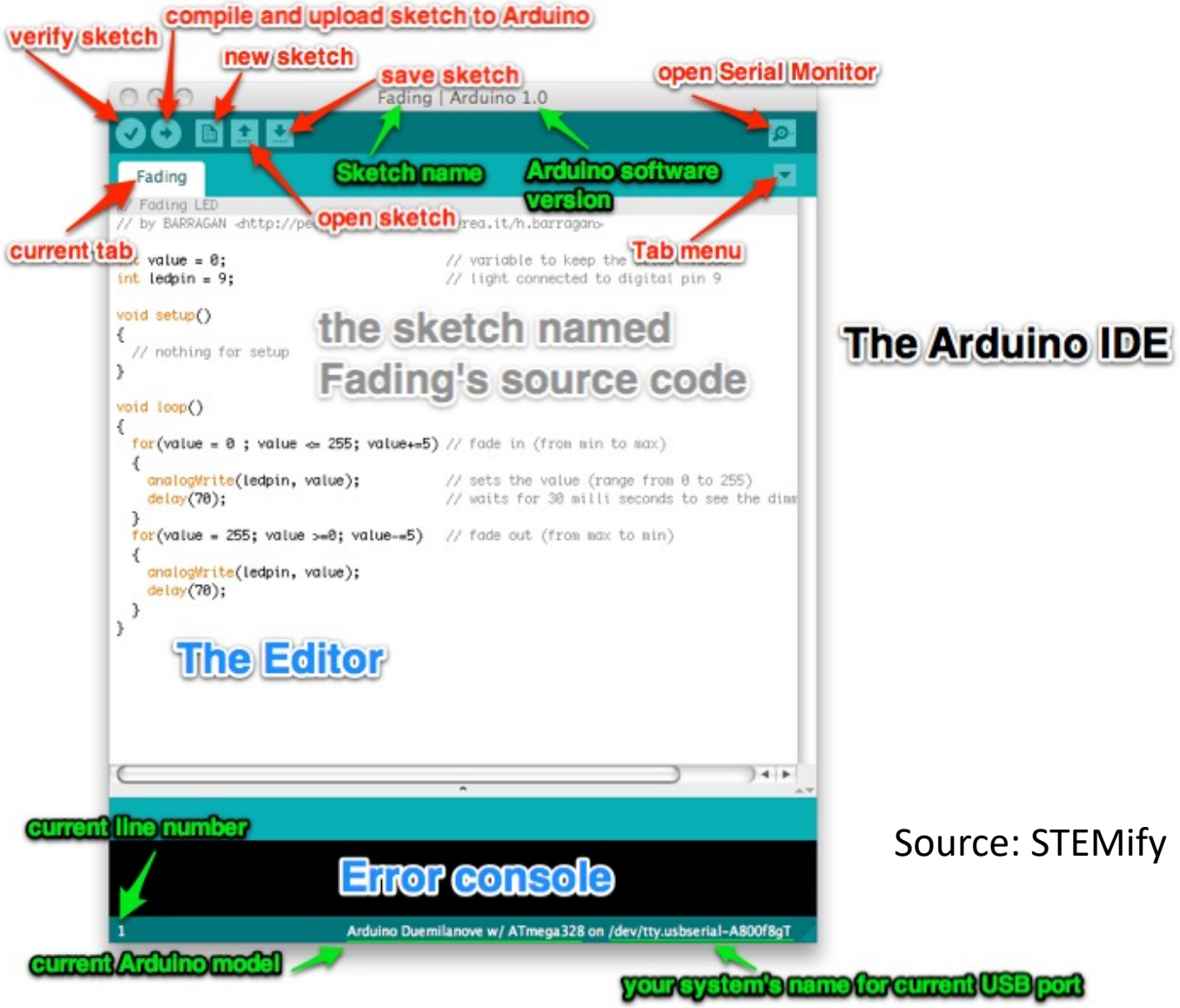
THE ARDUINO IDE

The Arduino IDE

- The next step is to download and run the **IDE installer** from here
  - We suggest using the desktop IDE for these labs

- A detailed «getting started» guide on the IDE can be found here

The Arduino IDE



The Arduino IDE

Source: STEMify

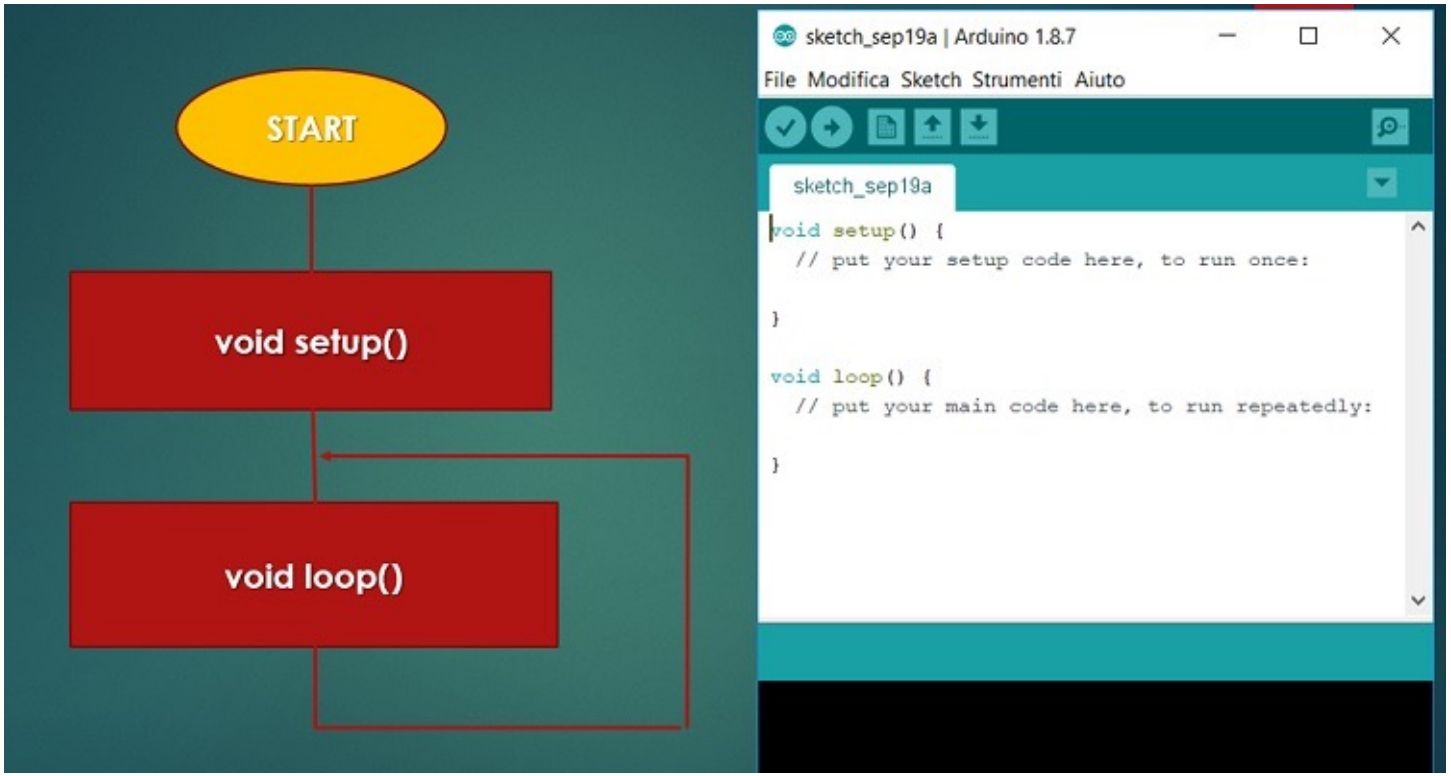
Arduino Sketches

- Arduino programs are called **sketches** and have `.ino` extension.

- They are based on a programming language called itself **Arduino**, based on Wiring
  - Under the hood, **it's actually C/C++**
  - With a simplified program structure to speed-up development

Arduino Sketches

- Two required functions: `setup()` and `loop()`
  - Plus any number of programmer-defined functions



Arduino Sketches

- `setup()`: initial settings
  - Set GPIO pin as input or output
  - Initialize serial connection
  - Write initial commands to configure I2C peripheral
  - Etc.

- `loop()`: repeated main loop of operations
  - Read value from a sensor
  - Drive an actuator
  - Send periodic info to a Serial connection
  - Etc.
  - Each loop() invocation corresponds to one iteration, so **global variables** are needed for data persistence across iterations.

Arduino Sketches

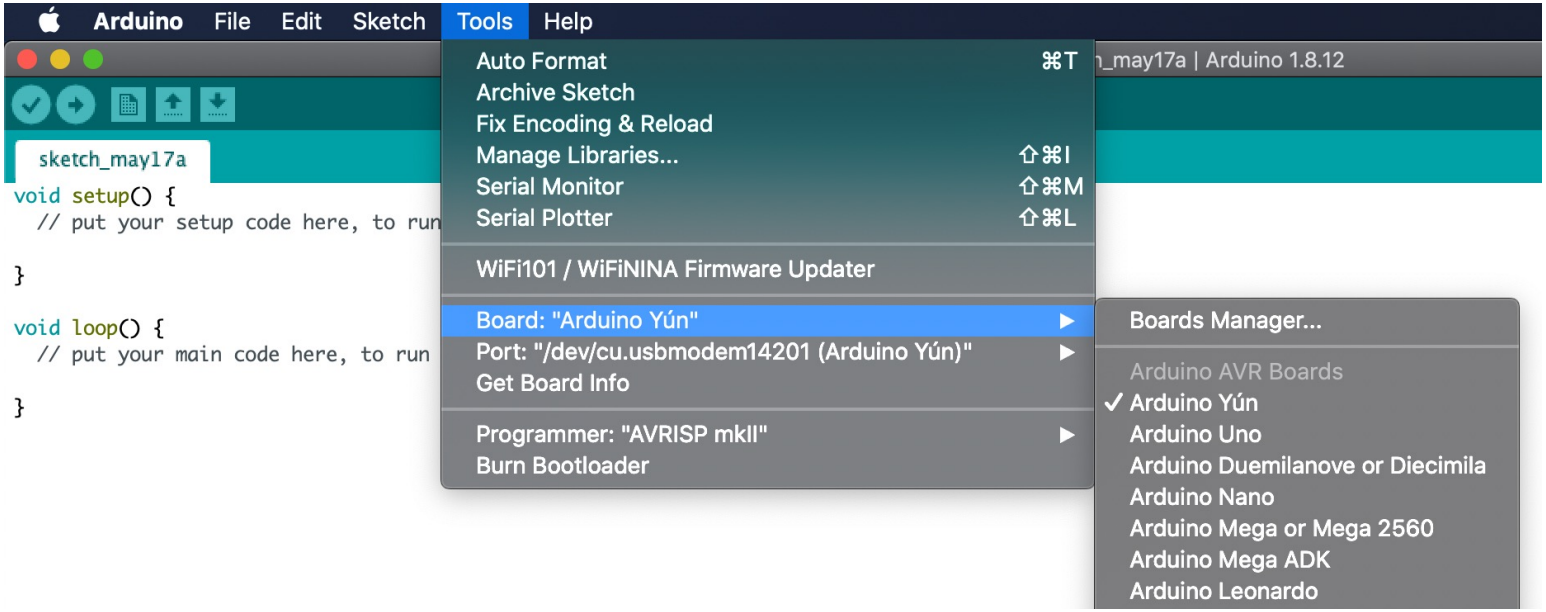
- The basic Arduino library includes functions to perform common operation, such as:
  - Get the time elapsed since the start of execution: `micros()` / `millis()`
  - Wait for some time: `delay()` / `delayMicroseconds()`
  - Set GPIO pins mode: `pinMode()`
  - Read/Write digital or analog values from GPIOs: `digitalRead()` / `digitalWrite()` and `analogRead()` / `analogWrite()`
  - Attach ISRs to digital GPIO inputs: `attachInterrupt()`
  - Perform math operations: `abs()`, `max()`, `min()`, `cos()` …

- We cannot explain every function in detail and you are (soon going to be) engineers, so you'll have to check the documentation yourselves here.

FIRST SKETCH

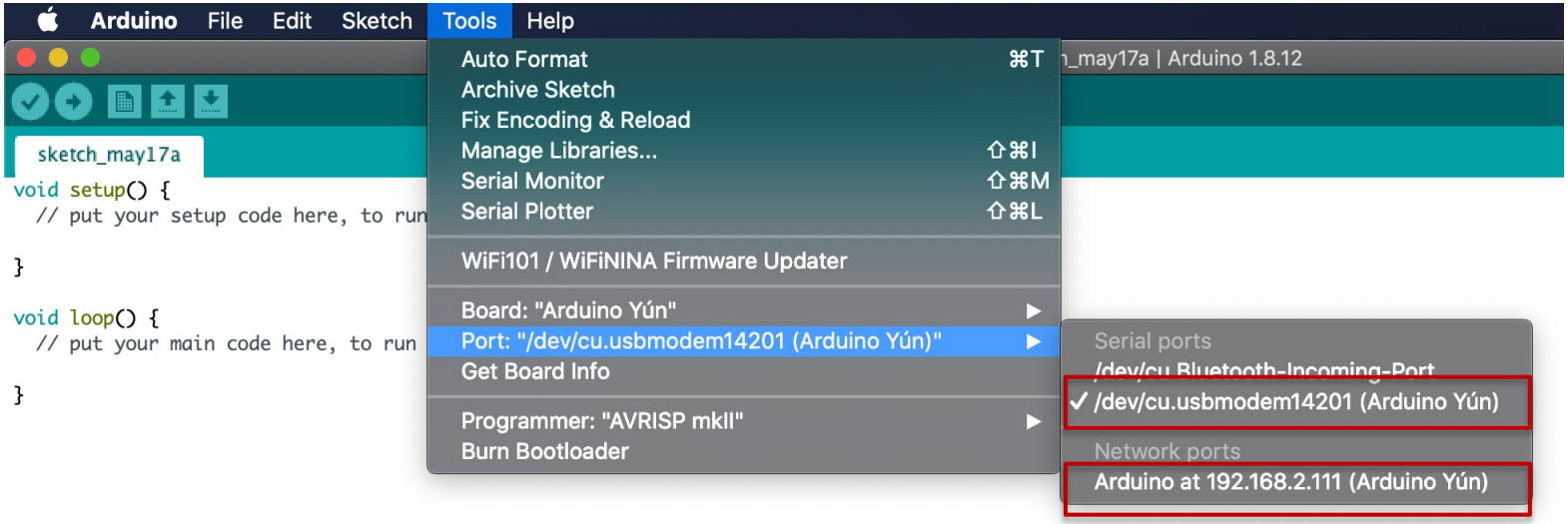
First Sketch

- Let's test if we can program the Yùn
  1. Connect the Yùn to your PC using a micro-USB cable
  2. In the Arduino IDE, under "Tools/Board", select the Yùn.



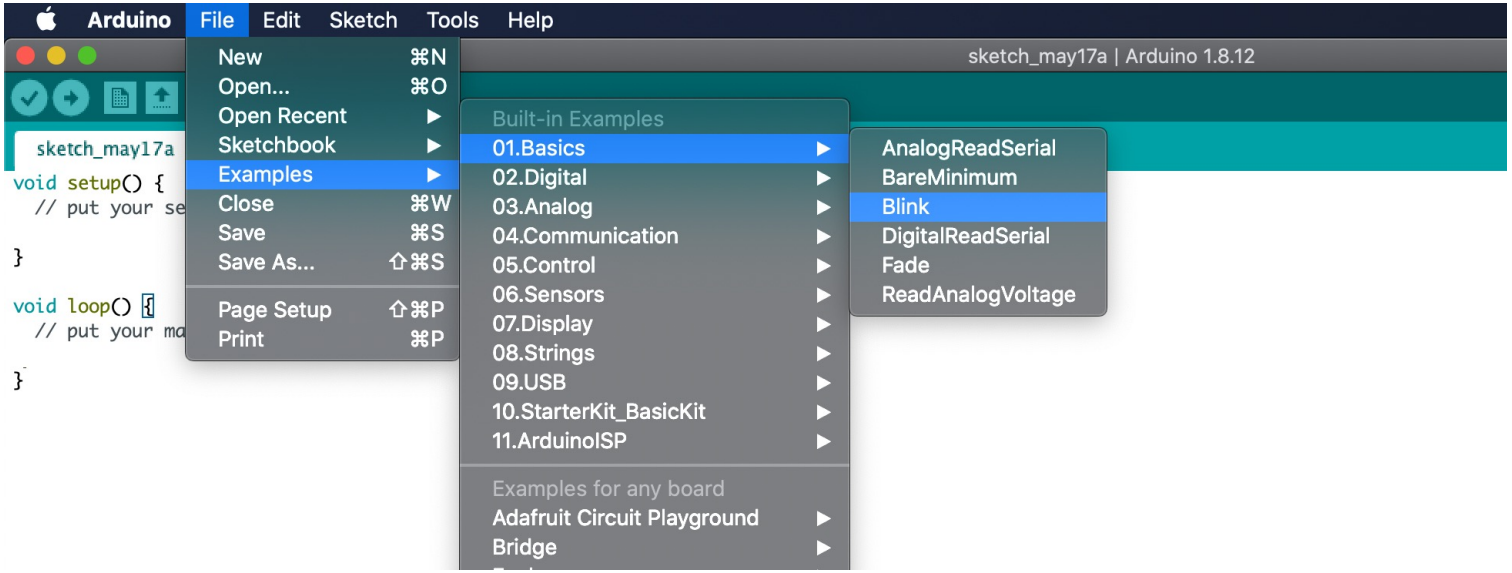
First Sketch

- Let's test if we can program the Yun
  3. Under "Tools/Port" select the appropriate port:
     - Normally, we will use the Serial port
     - Network programming is useful if the Yùn is not physically connected to your PC.



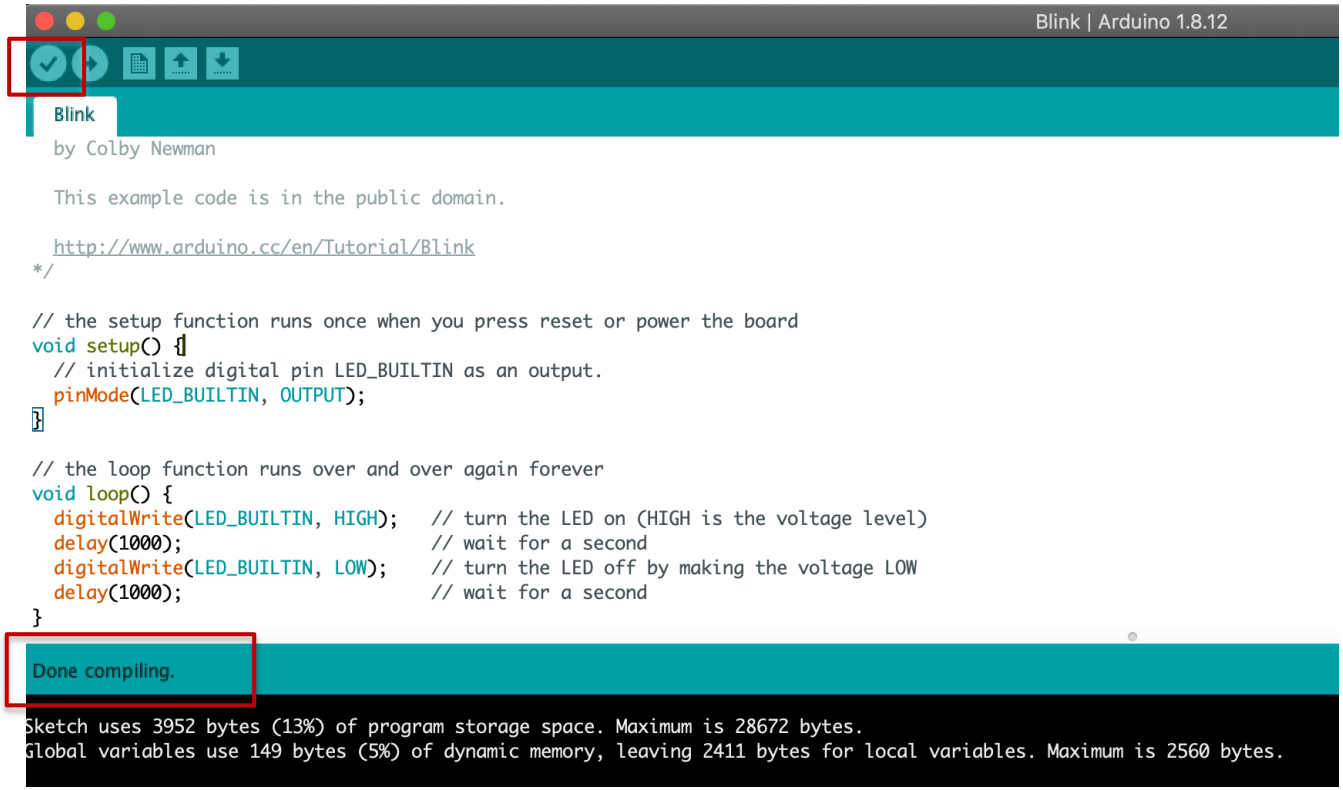
First Sketch

- Let's test if we can program the Yun
  4. Under "File/Examples/01. Basics/" Select the Blink example



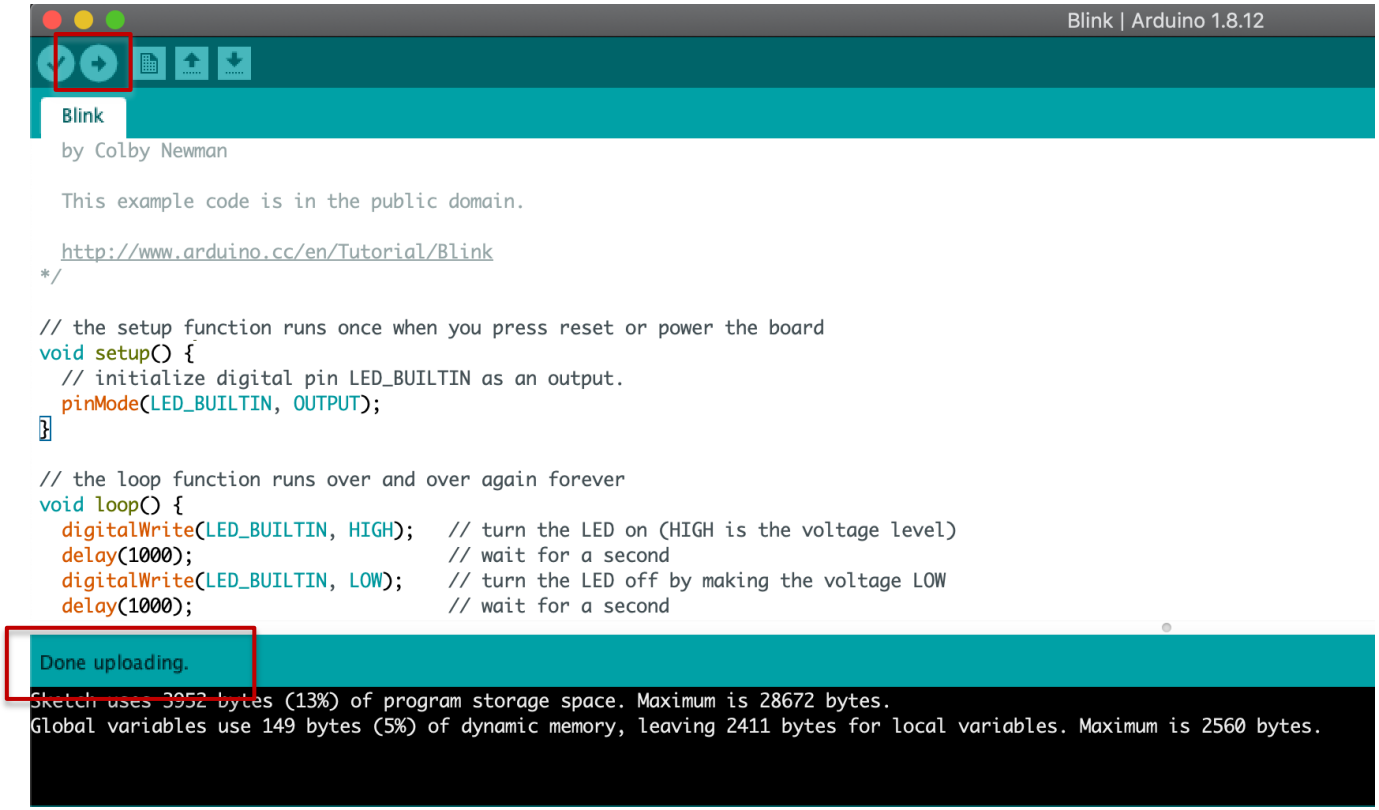
First Sketch

- Let's test if we can program the Yun
  5. Verify (i.e. compile) the sketch



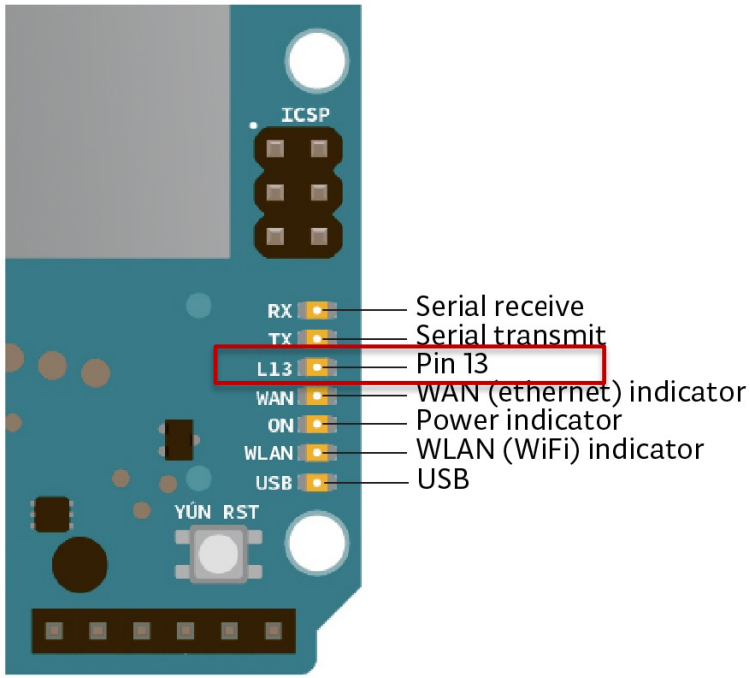
First Sketch

- Let's test if we can program the Yun
  6. Upload the sketch to the Yùn



First Sketch

- Let's test if we can program the Yun
  6. Check if the sketch is working
     - Internal LED (pin 13) blinking with a 2s period.



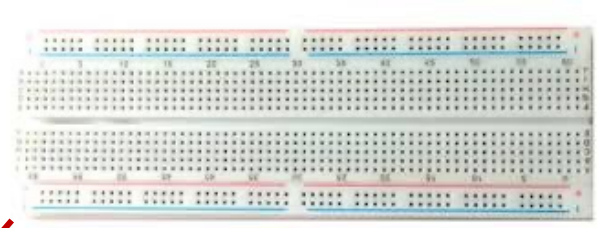
PART 1: EXERCISE 1

Exercise 1

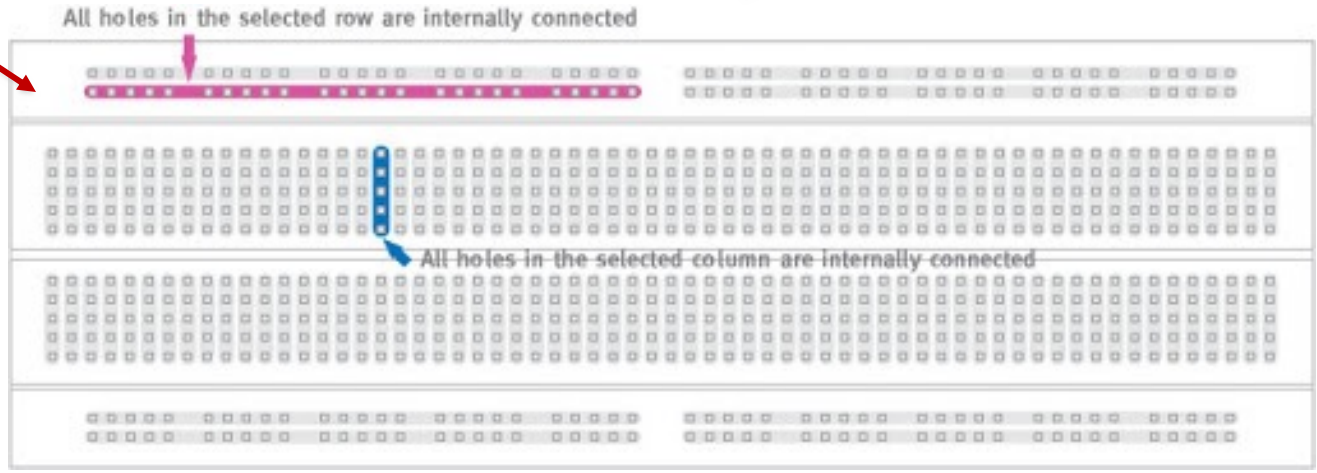
- HW components involved:
  - Breadboard
  - LEDs
  - Resistors
- SW components involved:
  - Digital GPIO outputs
  - Interrupts

Breadboard

- Build simple circuits without soldering

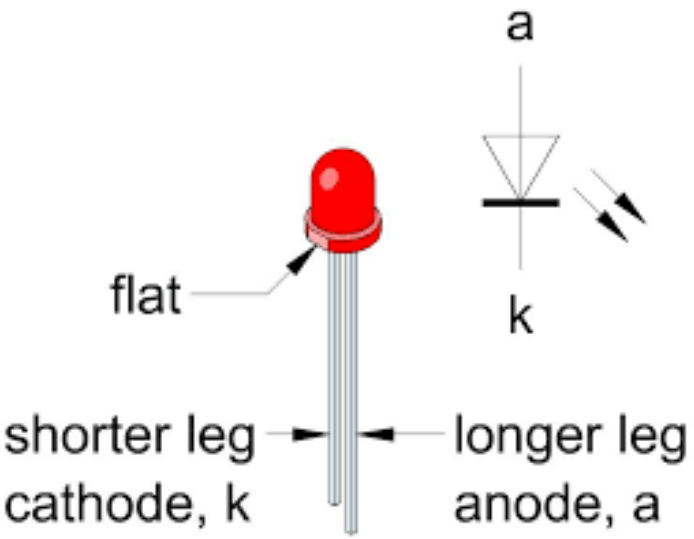


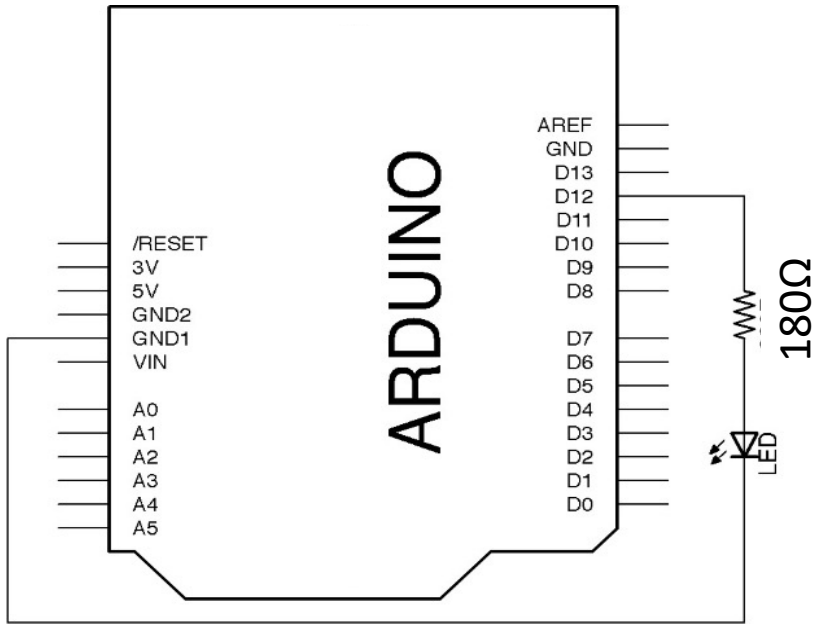
Normally for
VCC/GND



LED Connection

- A LED is a diode, so we need a series resistor to limit the amount of current flowing through it (i.e. avoid a short circuit between VCC and GND).



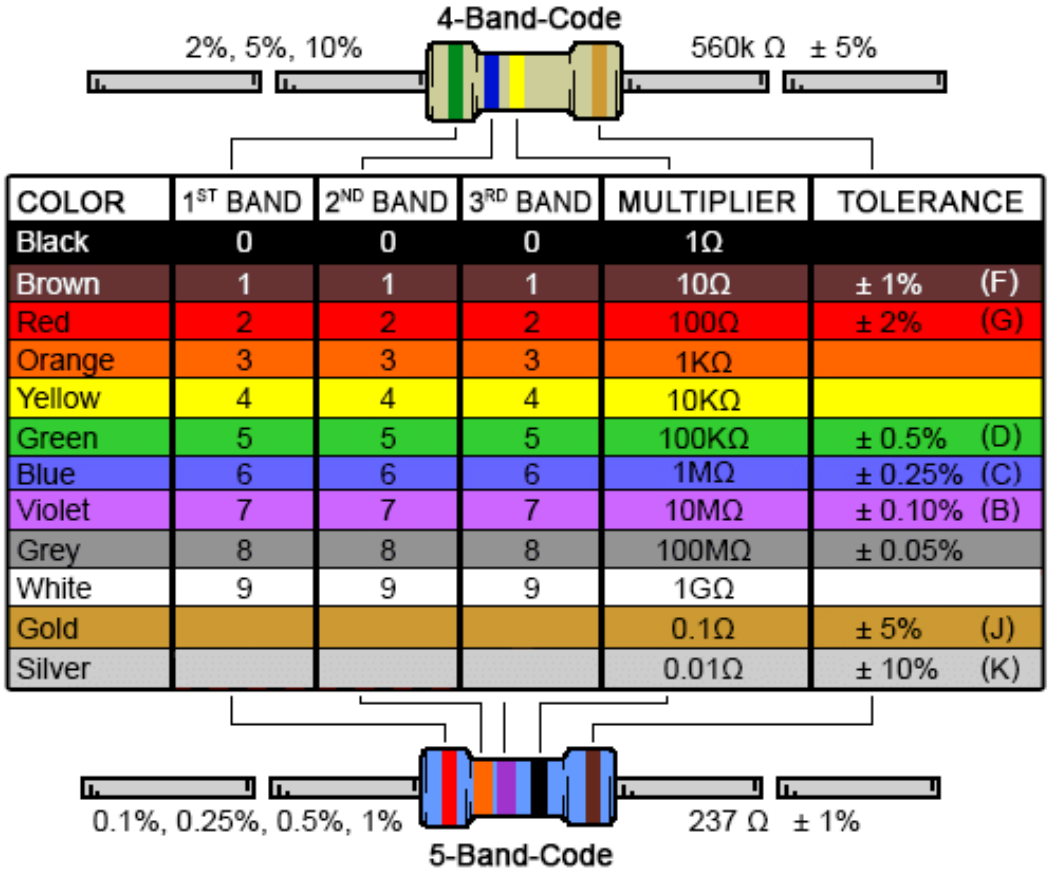


Circuit

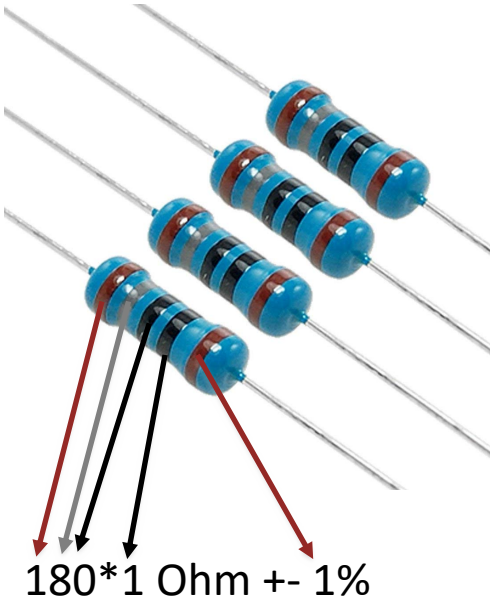
Caution: longer leg is the anode

Resistors Color-coding

- We use 180 Ohm resistor: 5V/180Ohm = 27mA < 40mA (max per GPIO pin)

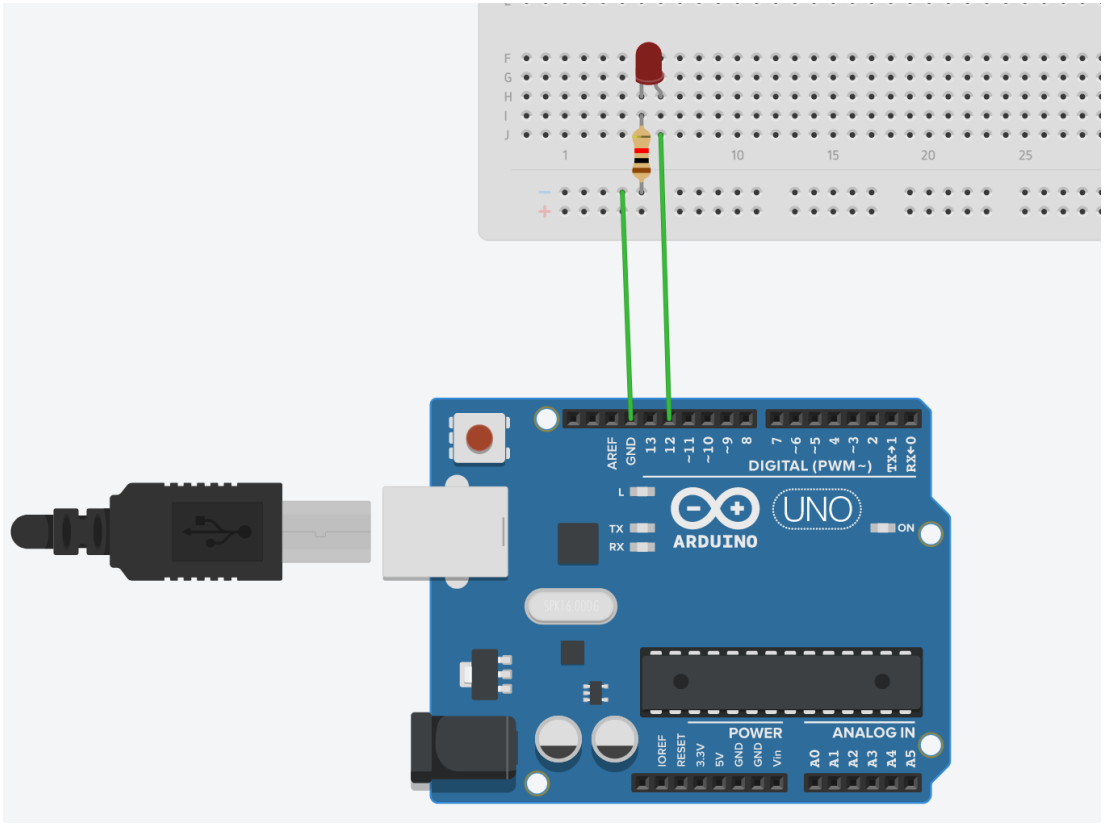


COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8	100MΩ	± 0.05%
White	9	9	9	1GΩ	
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)



LED Connection

- Breadboard connection (with minimal wires)



LED Connection

- **For those who don't have the kit**:
  - You can play with simple Arduino circuits using an online emulator on Tinkercad Circuits.
  - You'll be able to use a breadboard to connect components as well as writing and emulating the Arduino code
  - Unfortunately, it only supports other Arduino models, not the Yùn. Also, some of the most complex sensors/actuators that we'll use are not there
  - However, you can try these first examples using the Uno and the generic components available (LEDs, resistors, etc.)

Code

```
#include <TimerOne.h>

const int RLED_PIN = 12;
const int GLED_PIN = 11;

const float R_HALF_PERIOD = 1.5;
const float G_HALF_PERIOD = 3.5;

int greenLedState = LOW;
int redLedState = LOW;
```

- `TimerOne.h` allows to attach interrupts to the MCU's Timer1
  - Normally used to generate PWM signals
  - If you want to use the library and also use PWM outputs you have to take care (see library documentation here).
- GPIO pins are identified by integer constants
- global variables to store the current state of the two LEDS
  - LOW and HIGH MACROS for 0 and 1 respectively

Code

- In the setup() function:
  - set the two LED pins as outputs
  - Initialize the timer
  - Attach an ISR function to the timer expiration

```
void setup() {
  pinMode(RLED_PIN, OUTPUT);
  pinMode(GLED_PIN, OUTPUT);
  Timer1.initialize(G_HALF_PERIOD * 1e06);
  Timer1.attachInterrupt(blinkGreen);
}
```

Code

- In the ISR: toggle one LED state asynchronously w.r.t. loop()

```
void blinkGreen() {
  greenLedState = !greenLedState;
  digitalWrite(GLED_PIN, greenLedState);
}
```

Code

- In the loop() function: toggle the other LED state using the delay() function

```
void loop() {
  redLedState = !redLedState;
  digitalWrite(RLED_PIN, redLedState);
  delay(R_HALF_PERIOD * 1e03);
}
```

Complete Code

```
#include <TimerOne.h>

const int RLED_PIN = 12;
const int GLED_PIN = 11;

const float R_HALF_PERIOD = 1.5;
const float G_HALF_PERIOD = 3.5;

int greenLedState = LOW;
int redLedState = LOW;

void blinkGreen() {
  greenLedState = !greenLedState;
  digitalWrite(GLED_PIN, greenLedState);
}

void setup() {
  pinMode(RLED_PIN, OUTPUT);
  pinMode(GLED_PIN, OUTPUT);
  Timer1.initialize(G_HALF_PERIOD * 1e06);
  Timer1.attachInterrupt(blinkGreen);
}

void loop() {
  redLedState = !redLedState;
  digitalWrite(RLED_PIN, redLedState);
  delay(R_HALF_PERIOD * 1e03);
}
```

PART 1: EXERCISE 2

Exercise 2

- HW components involved:
  - Same as 1, plus Serial port
- SW component involved:
  - Arduino Serial library

New Code Elements

```
void setup() {
  Serial.begin(9600);
  while (!Serial);
  Serial.println("Lab 1.2 Starting");
  //etc...
```

- Create a Serial connection with a specified baud rate
- Wait until the connection is estabilished
  - The program will not start until you open the Serial monitor in the IDE
- Print a newline-terminated string.

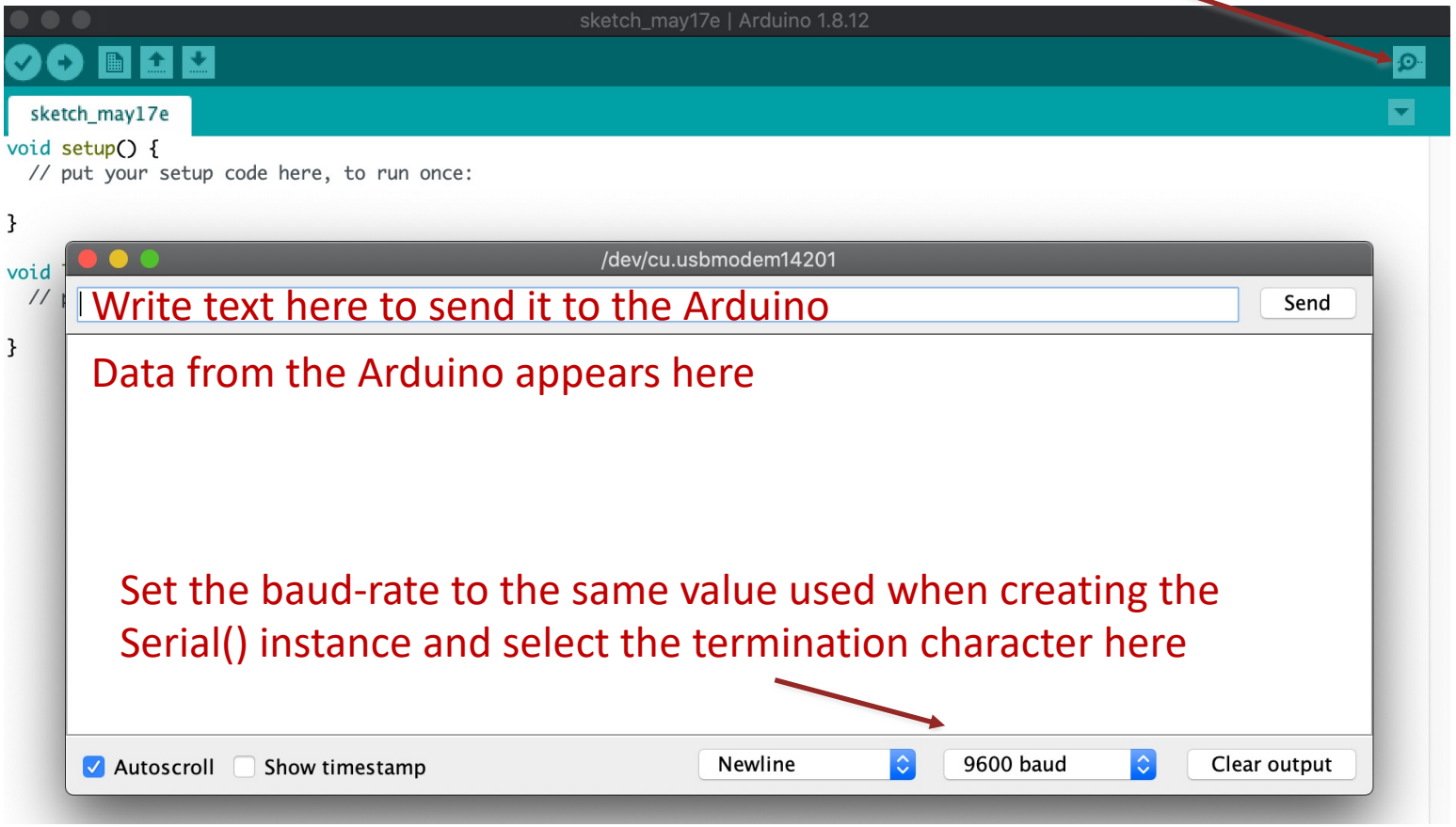
```
void serialPrintStatus() {
  if (Serial.available() > 0) {
    int inByte = Serial.read();

    if(inByte == ...) {
      //etc
```

- Check if there are bytes available on the Serial buffer.
- Read a single byte from the buffer

Serial Monitor

Click here (or Tools/Serial Monitor) to open the monitor for the select Port



New Code Elements

- The full reference for the `Serial` class can be found here:
  - Many more utility functions to read/write various kinds of data
  - Example: attach ISR when new data is available: `serialEvent()`
  - Parse integers or floats from the buffer: `parseInt(), parseFloat()`
  - Flush the buffer: `flush()`
  - Etc.

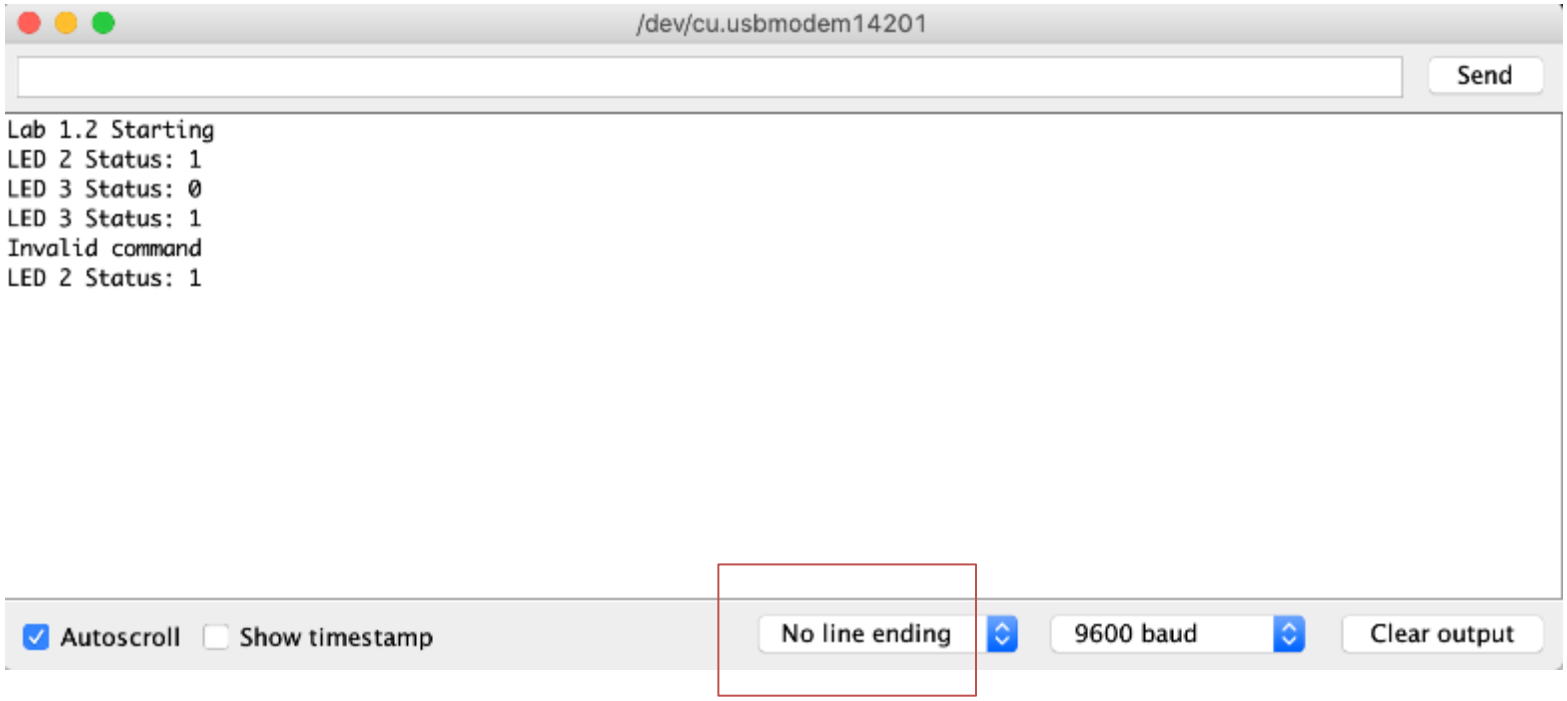
- Arduino can use char-based C-style strings but also supports a more flexible `String` class:
  - Easier concatenation and processing… but **more memory!!**

New Code Elements

- Important: variables used both by the `loop()` function and by the ISR should be declared as `volatile`
  - This qualifier tells the compiler to avoid register-based optimizations for the variable
  - The variable is always written-back to memory
  - It prevents Read-After-Write dependency violations.

- Additionally, if there are pieces of code that cannot be interrupted, you can use the `noInterrupts()` and `interrupts()` functions to disable and re-enable interrupts as needed

Exercise 2: Output Example



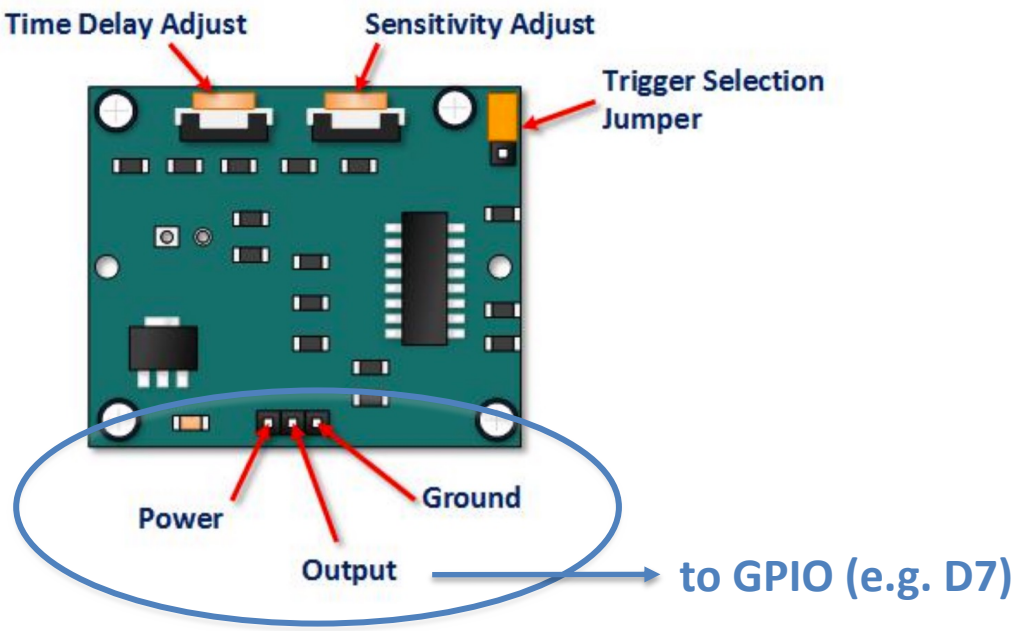
PART 1: EXERCISE 3

Exercise 3

- HW components involved:
  - PIR Sensor
  - Serial port
- SW component involved:
  - GPIO interrupts

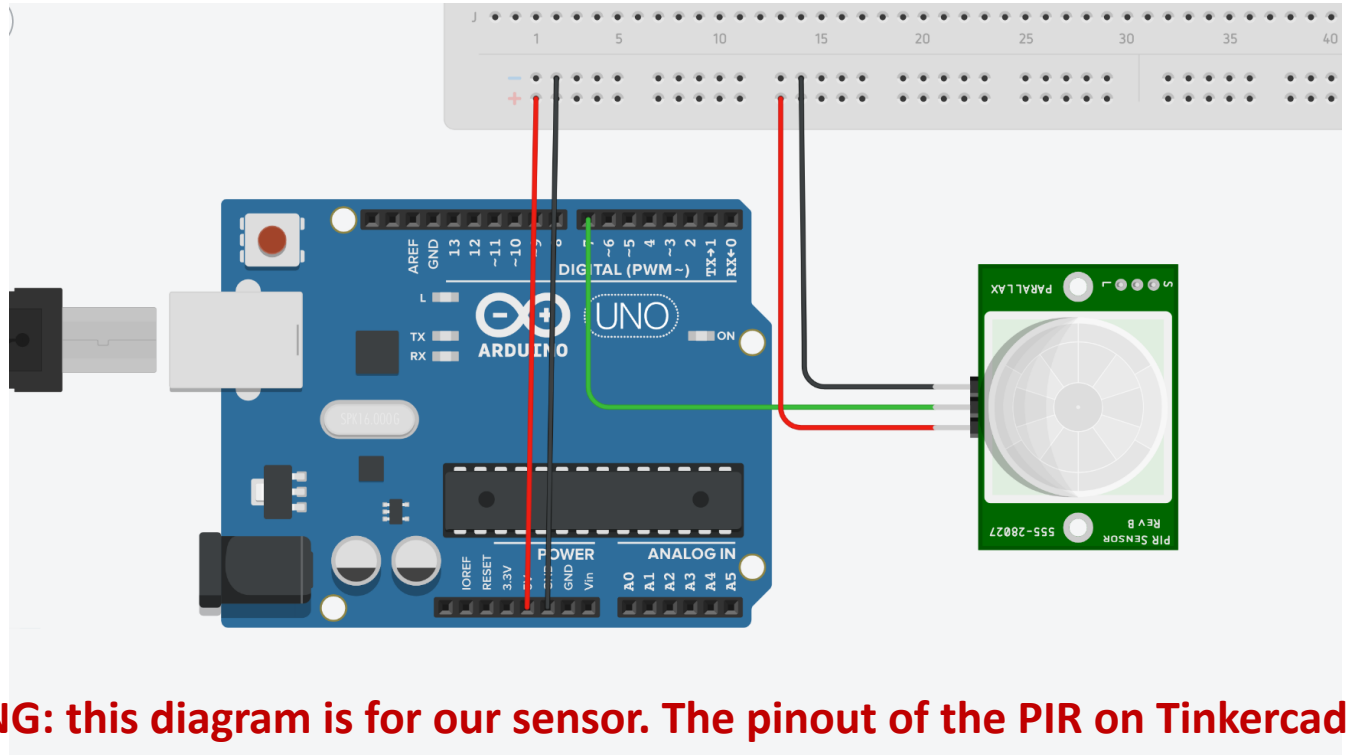
PIR Motion Sensor: HC-SR501

- Two potentiometers to set the length of the detection and the sensitivity
- One jumper to select between 2 operating modes (single and repeatable trigger)
- Use the datasheet to understand each configuration parameter: link



PIR Sensor connection

- Suggestion: add new components without disconnecting the previous ones (LEDs). In part 2 you'll use them all together



WARNING: this diagram is for our sensor. The pinout of the PIR on Tinkercad is different!

New Code Elements

- Not all GPIO pins support interrupts (see the numbers for “Micro, Leonardo, other 32u4-based” at this page)
- `tot_count` is touched by ISR and `loop()` → `volatile`

```
const int LED_PIN = 12;
const int PIR_PIN = 7;

volatile int tot_count = 0;
```

- Attach the ISR function to the appropriate GPIO interrupt.

```
void setup() {
  pinMode(PIR_PIN, INPUT);
  attachInterrupt(digitalPinToInterrupt(PIR_PIN), checkPresence, CHANGE);
  // etc...
```

PIN number to Interrupt number

ISR function pointer

RISING, FALLING, CHANGE, etc.

Exercise 3: Output Example

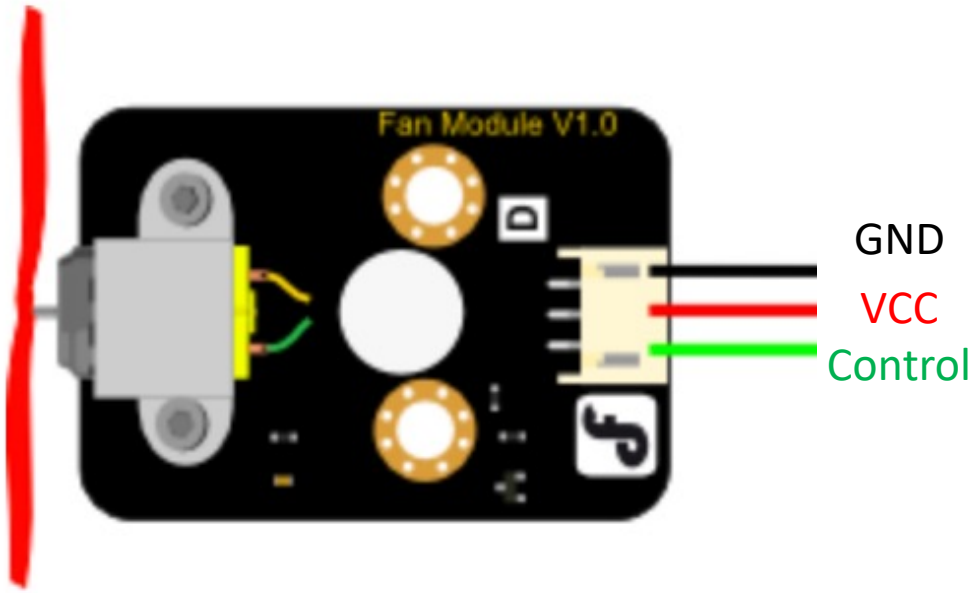
PART 1: EXERCISE 4

Exercise 4

- HW components involved:
  - DC Motor (fan)
  - Serial port
- SW component involved:
  - PWM outputs

PWM Fan: DFR0332

- Datasheet: link



- Breadboard connection very similar to PIR
  - Unfortunately, 3-input DC motor is not available on Tinkercad

New Code Elements

- Not all GPIOs support PWM. Those that do, have a “tilde” symbol (~) next to the PIN number
- To specify a duty cycle, simply do an `analogWrite()` to the PIN
  - DC values are integers between 0 (0%) and 255 (100%)

```
float current_speed = 0;

void setup() {
  pinMode(FAN_PIN, OUTPUT);
  analogWrite(FAN_PIN, (int) current_speed);
  //etc.
```

Exercise 4: Output Example

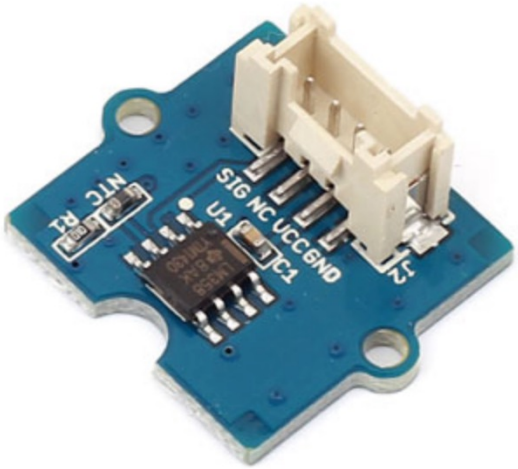
PART 1: EXERCISE 5

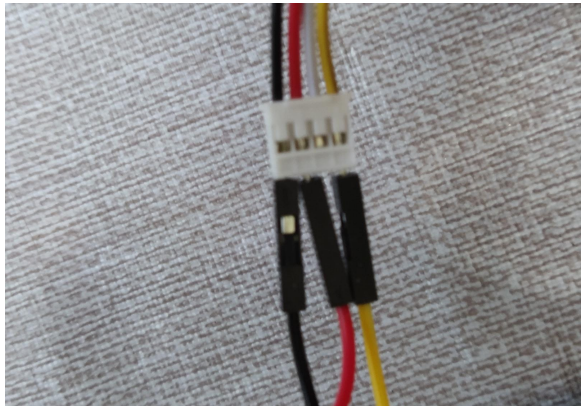
Exercise 5

- HW components involved:
  - Temperature Sensor
  - Serial port
- SW component involved:
  - Analog inputs

Grove Temperature Sensor

- Entire sensor “datasheet”: link
- Thermistor datasheet: link





- Breadboard connection again very similar to previous sensors
  - You can plug your jumper cables in the output of the provided cable if needed (to use male/male cables instead of female/male)

Grove Temperature Sensor

- The sensor produces an output **voltage** which depends (through a variable **resistence**, i.e. the thermistor) on the **temperature**
  - We read the voltage, we need to recover the temperature

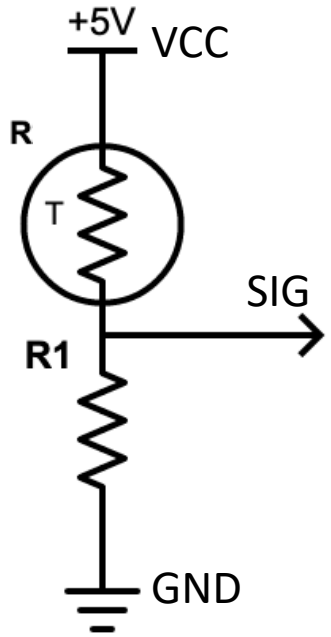
- Two-step process:
  1. From voltage to resistance
  2. From resistance to temperature

- The sensor has two main parameters:
  - **R0 = 100KOhm;** thermistor resistance at nominal T0 = 25^{o} C
  - **B = 4275K;** defines the shape of the (non-linear) relation between resistance and temperature. A definition can be found here.

Grove Temperature Sensor

- Step 1:
  - R1 = R0 = 100KOhm
  - We can extract R from V_{sig} using a simple resistive divider equation:

$$V_{sig} = \frac{R_1}{R + R_1} * VCC \Rightarrow R = (\frac{VCC}{V_{sig}} - 1) * R_1$$



  - The Arduino ADCs have 10-bit resolution
  - GND = 0, VCC = 1023

Grove Temperature Sensor

- Step 2:
  - The conversion from R to T can be obtained inverting the definition of B from the datasheeet:

$$B = \frac{\ln\left(\frac{R}{R_0}\right)}{\frac{1}{T} - \frac{1}{T_0}} \quad \Rightarrow \quad T = \frac{1}{\frac{\ln\left(\frac{R}{R_0}\right)}{B} + \left(\frac{1}{T_0}\right)}$$

  - Warning: in this equation both T an T0 are in Kelvin
  - We want to print all temperature values in Celsius

New Code Elements

- Analog pins are identified with the MACRO Ax where x is the PIN number on the board.

```
const int TEMP_PIN = A1;
const int B = 4275;
const long int R0 = 100000;
```

- Simply call `analogRead()` to read the voltage value from the sensor.

```
void loop() {
  int a = analogRead(TEMP_PIN);
```

Exercise 5: Output Example

- Touch the thermistor on blow gently on it to see the temperature change

PART 1: EXERCISE 6

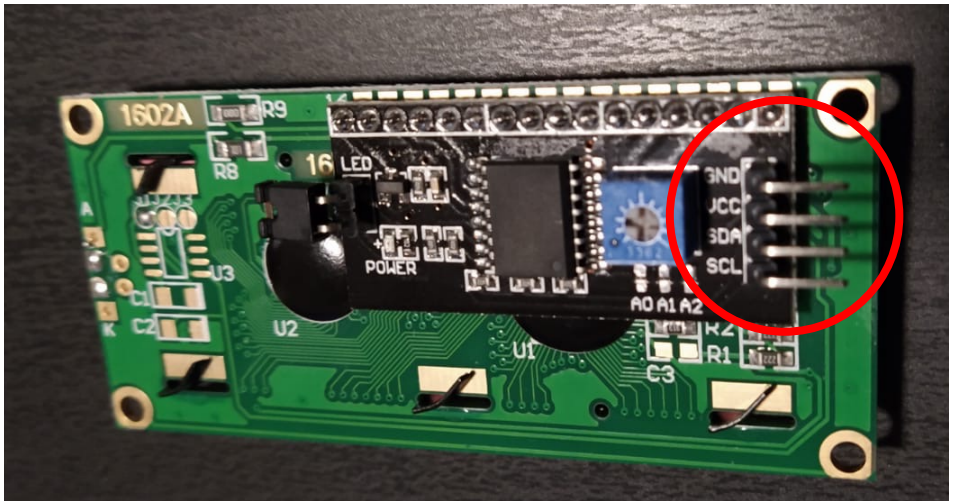
Exercise 6

- HW components involved:
  - Temperature Sensor
  - LCD Display (with I2C connection)

- SW component involved:
  - LCD library (based on Wire)

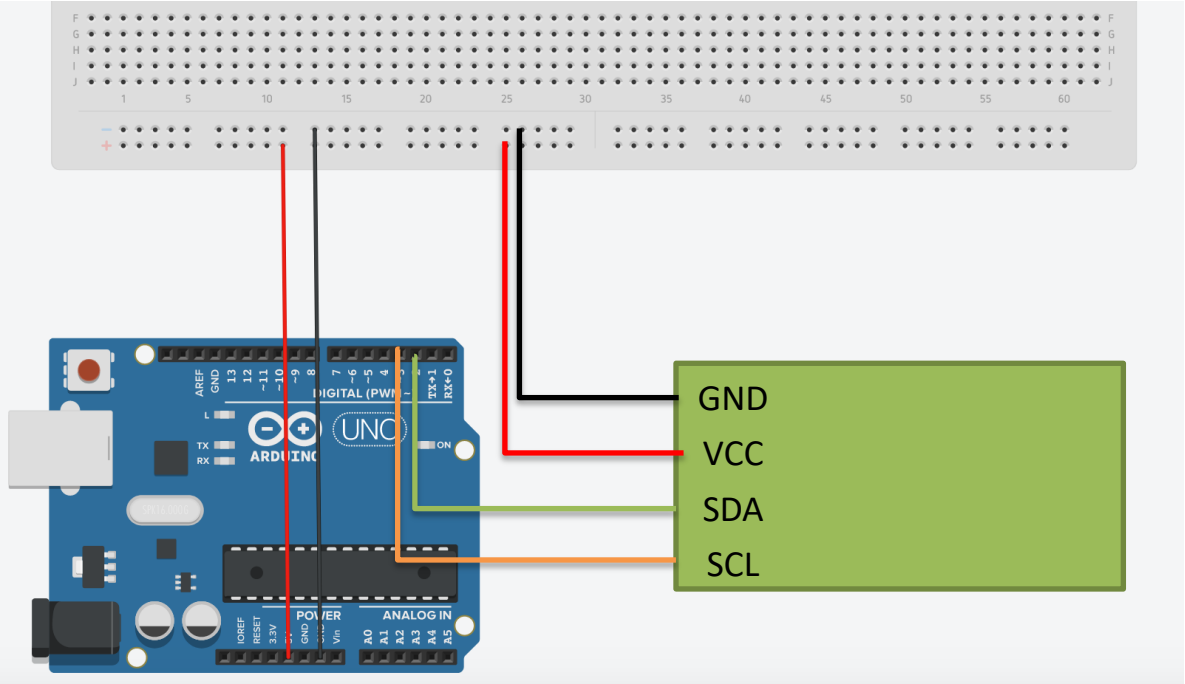
DFRobot I2C Display

- A “sort” of datasheet can be found here
  - **Careful:** we won’t use the library provided at that link, but a standard library provided by the Arduino IDE’s Library Manager, compatible with this display
  - So don’t copy the code! It won’t work



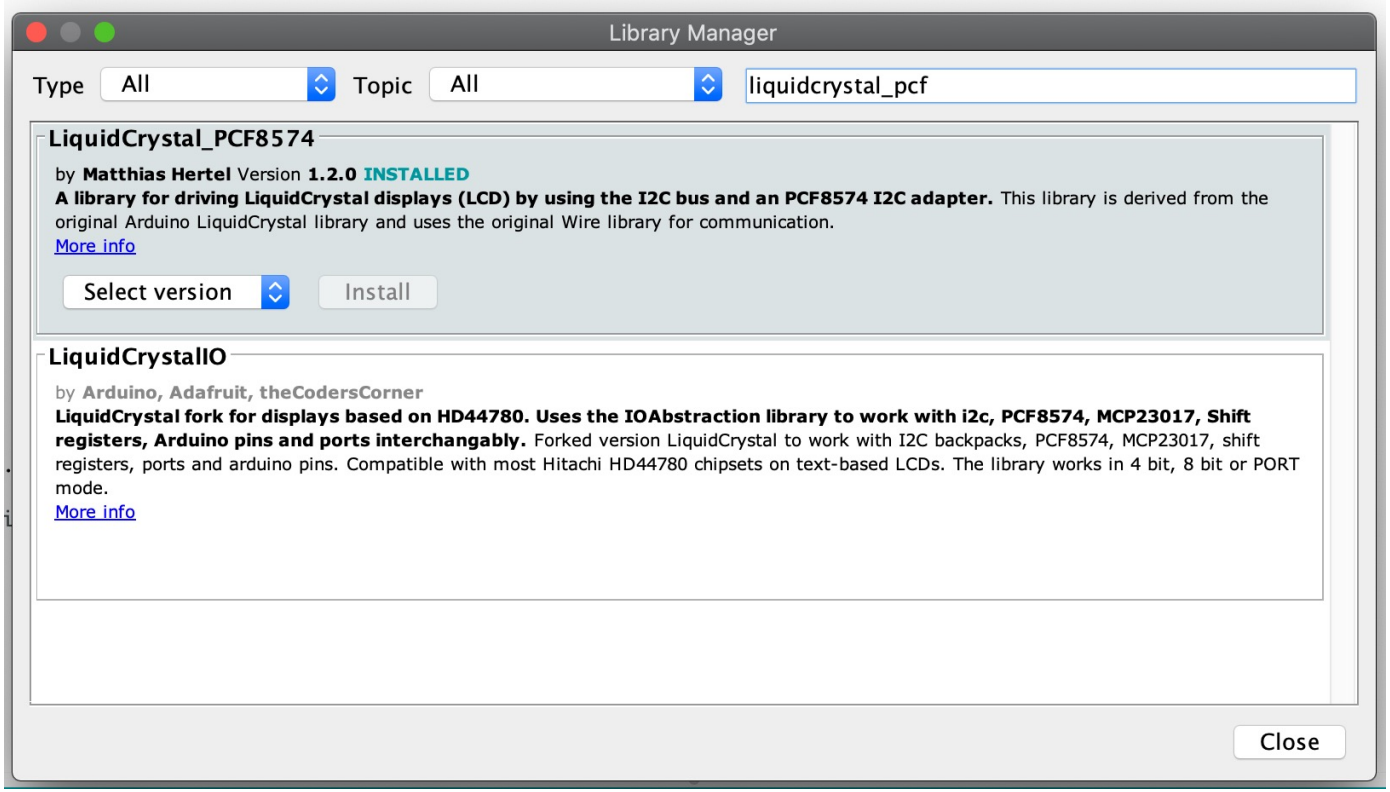
Breadboard Connection

- The Yùn has two additional slots for SDA and SCL pins (for shields) but these are wired to D2 and D3 respectively!
  - Check pinout slide at the beginning



LCD Library

- In the Arduino IDE, select “Tools/Manage Libraries…”
- Look for the `LiquidCrystal_PCF8574` library and install the latest version



LCD Library

- The library contains a lot of methods to control the LCD display via I2C
  - `init()` to initialize the display
  - `clear()` clear the display content
  - `home()` set the cursor to row 0, column 0
  - `setCursor(row, col)` sets the cursor to row, col
  - `setBacklight(brightness)` sets the brightness level (0 to 255)
  - etc.
  - You can inspect the source code directly to view the available methods

LCD Library

- The display class defined in the library inherits from the `Print` class
  - Which means that you can call the `print()` method to print strings directly
  - You don't need to `write()` individual chars one by one.

- The library is based on the `Wire` library for I2C communication.
  - On the Yùn, this library uses pins D2/D3 by default

New Code Elements

- Include the library and create a display class instance
  - The “datasheet” says that the default I2C address is 0x20 but this is **wrong!**.
  - Indeed, the three jumpers A2, A1 and A0 on the rear of the display are all disconnected → Address = 0x27

```
#include <LiquidCrystal_PCF8574.h>

LiquidCrystal_PCF8574 lcd(0x27);
```

New Code Elements

- In `setup()` initialize the comunication with the display, set backlight and clear the screen. Then, print a message

```
void setup() {
  lcd.begin(16, 2);
  lcd.setBacklight(255);
  lcd.home();
  lcd.clear();
  lcd.print("Temperature:");
}
```

Exercise 6: Output Example