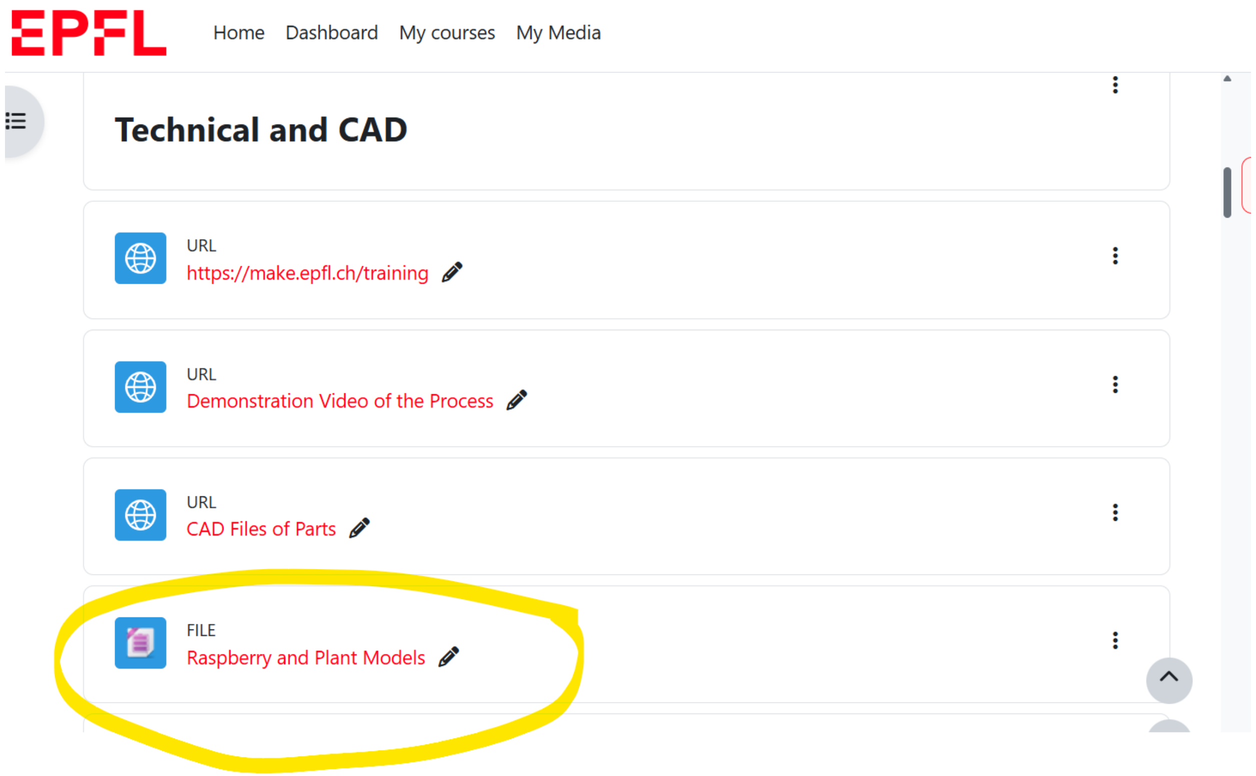
Product development & engineering design

ME-320

PROF. JOSIE HUGHES

Lecture 6: Sensing!!

Project Updates



- Raspberry CAD on Moodle
- Box details on Notion

The two boxes will be of the following size: **12.5 x 8.5 x 6.5 cm, 0.30 l**

This week

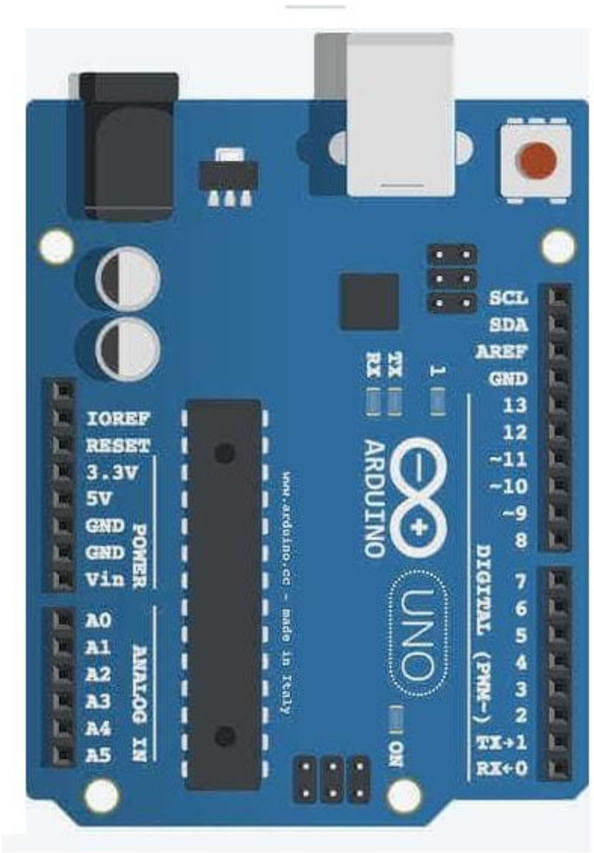
- Overview of sensing (8h15-9)
- 9h: Parts and general TA support (SPOT)
- 9h: Guided introduction to microcontrollers and sensors (SPOT)

Following Weeks

Week 4	01/10/2025	Design Pitch & Review with Tas	Review session in SPOT	
Week 5	08/10/2025	Mechanical Design	Lecture	
Week 6	15/10/2025	Control and integration	Lecture	
Week 7	*22/10/2025*	*Break*		
Week 8	29/10/2025	2nd Design Review with TAs	Review session in SPOT	
Week 9	05/11/2025	Electronics & prototyping	Lecture	
Week 10	12/11/2025	Engineering Drawings	Lecture	
Week 11	19/11/2025	Design for Manufacture, Sustainability	Lecture	
Week 12	26/11/2025	3rd Design Review with TAs	Review session in SPOT	

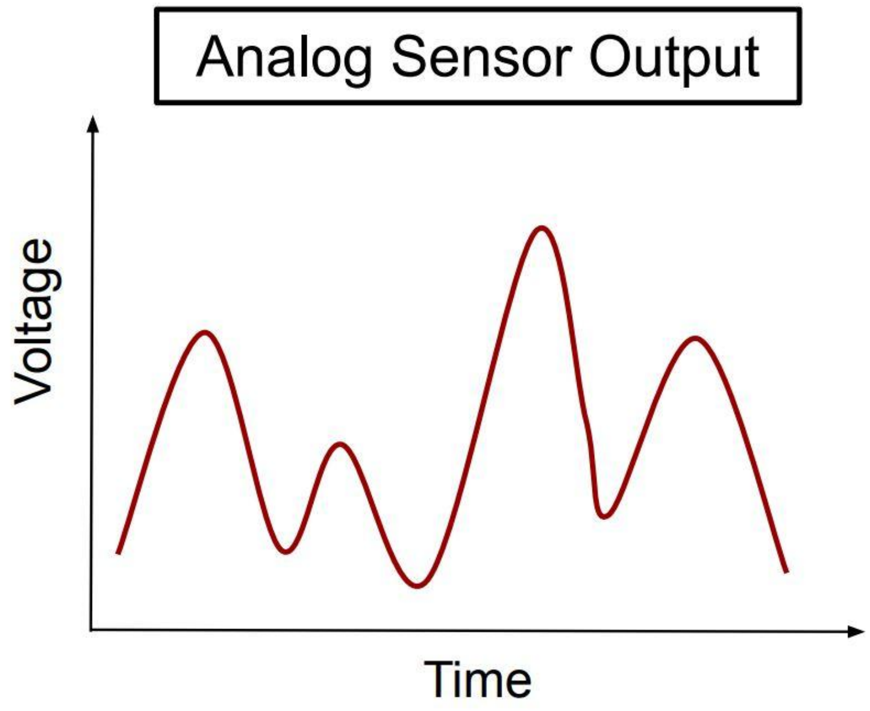
- Next week: Holiday
- 22/10: Design Review - get advice or feedback from TAs – ask questions!

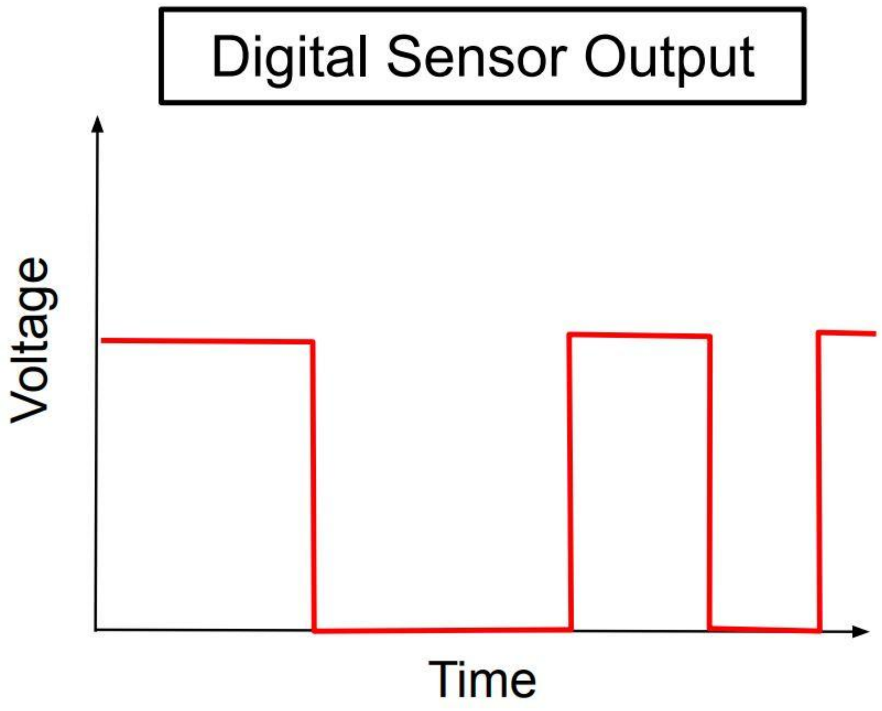
Sensing with a microcontroller



- Many different sensors
- Different input types
- Different transduction circuits

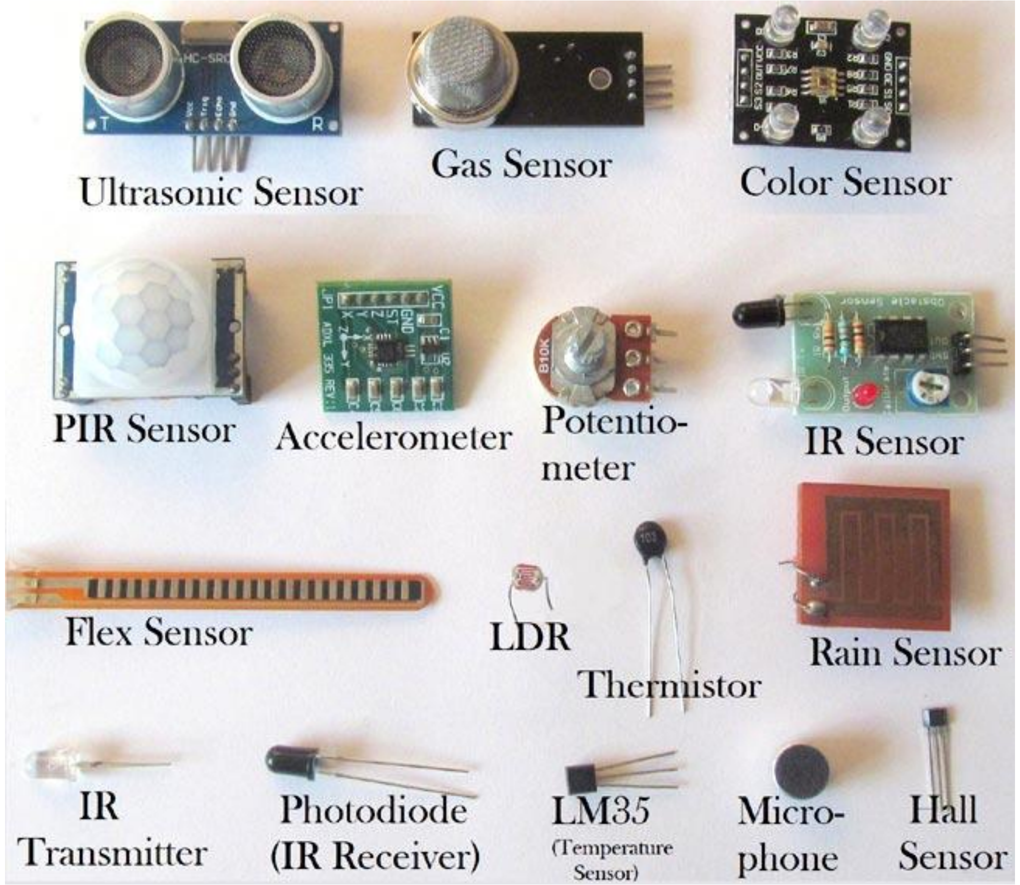
Analog vs. Digital





Analog Inputs

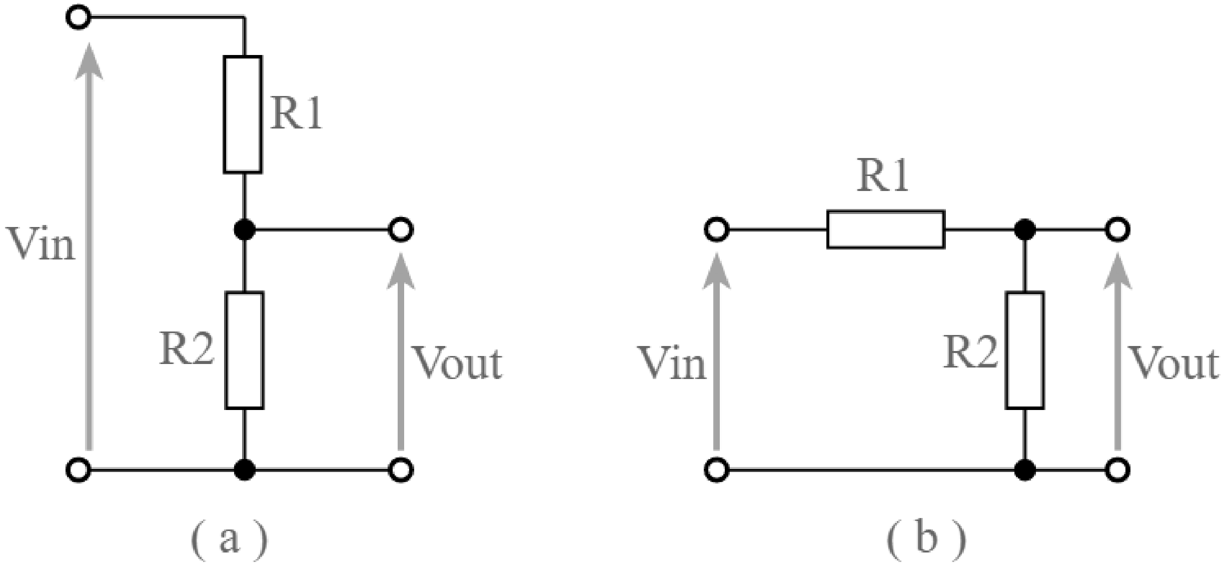
What types of sensors are analog?



- Many sensors can provide ADC outputs
- Universal method of sensing
- Can require additional amplification or transduction

Analog Inputs

Resistive sensors



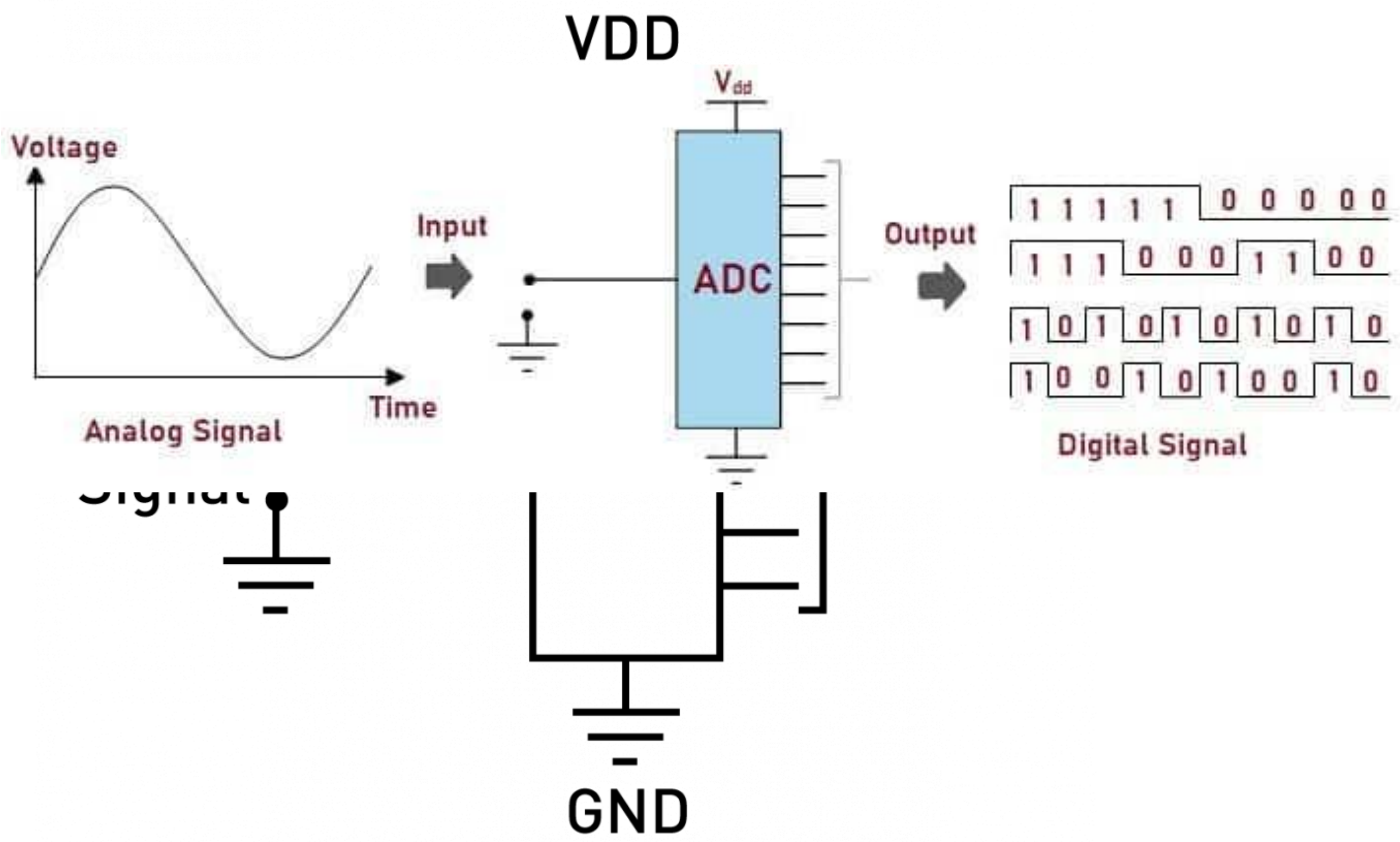
$$V_{\text{out}} = V_{\text{in}} \left(\frac{R_t}{R_1 + R_t} \right)$$

But how can binary machines (e.g. micro-controllers) deal with these analog signals?

Analog Inputs

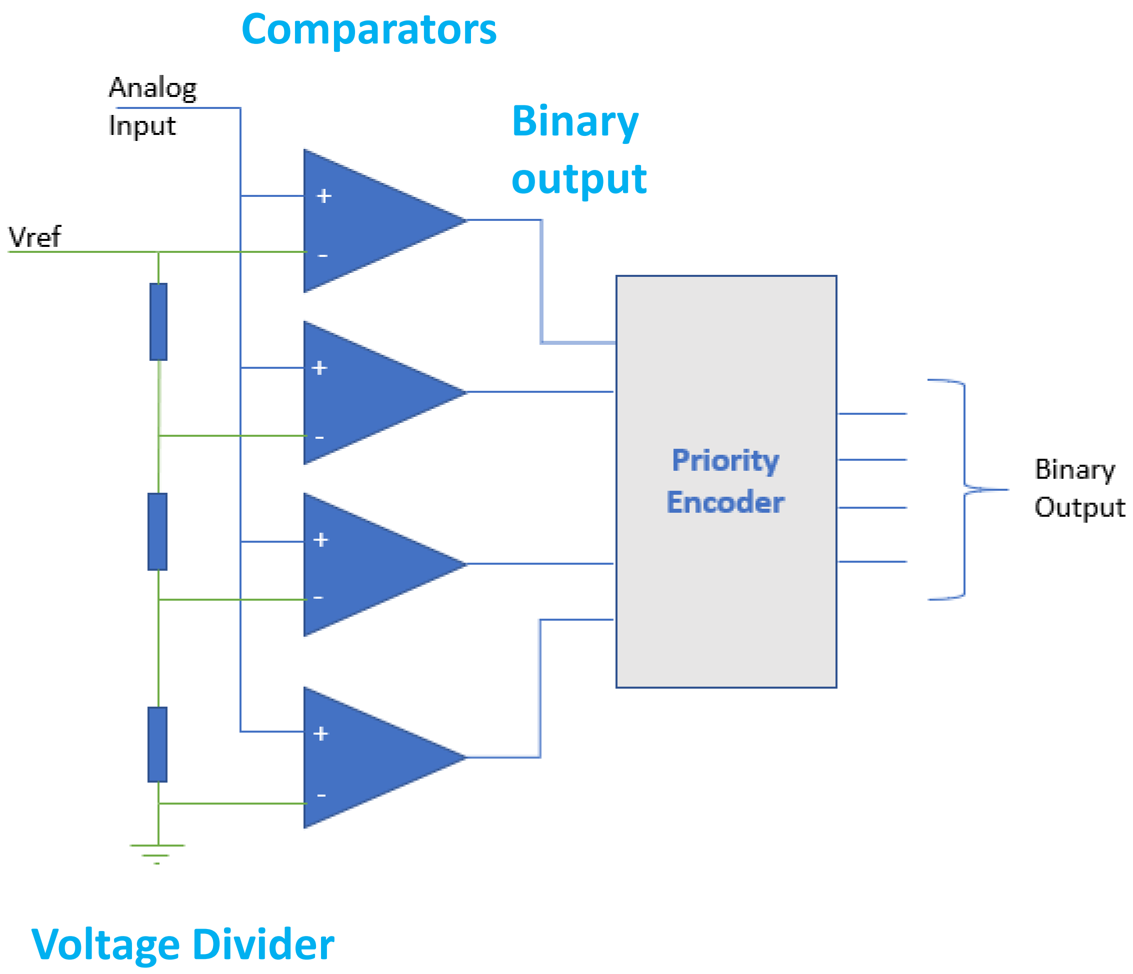
How do we read analog sensors?

Machines work in binary (1s and 0s) - how do we obtain a binary output?

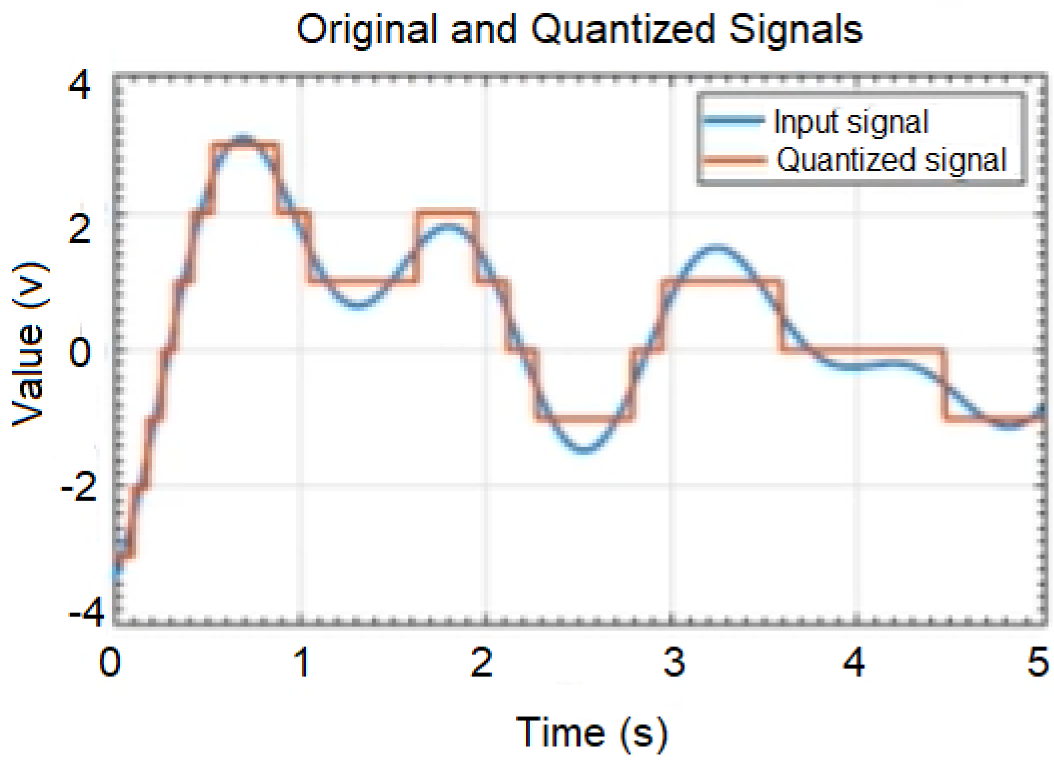


Analog Inputs

How do we read analog sensors?



Analog Inputs
Quantization



$$\text{Maximum Quantization Error} = \frac{(V_H - V_L)}{2\,(2^n)}$$

where n is the number of bits of resolution of the ADC

Arduino Uno → 10-bit ADC means it will give digital value in the range of 0 – 1023 (2^10)

Analog Inputs: Summary

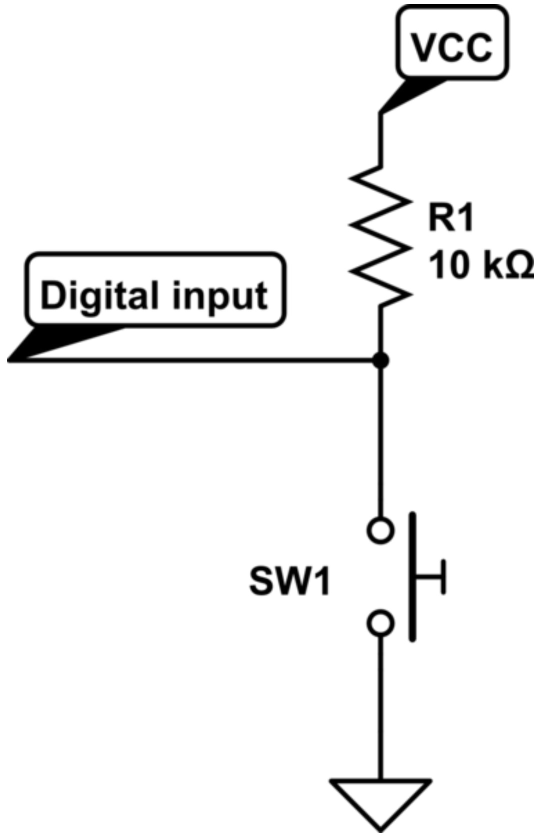
- Analogue inputs are really useful to acquire data
- Quantization error depends on ADC resolution
- Not a scalable approach – for each sensor you need ad additional ADC port
- ADCs can be expensive (for high resolution)
- Sampling rate can be limited
- Sensitive to external noise

How can we deal with more complex inputs, and achieve higher scaleability?

Digital Inputs

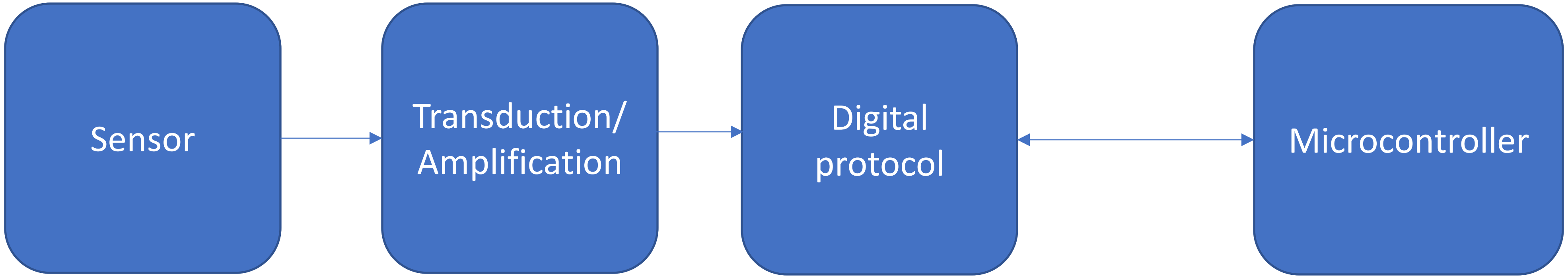
What would be an example of a digital sensor?

Digital Inputs



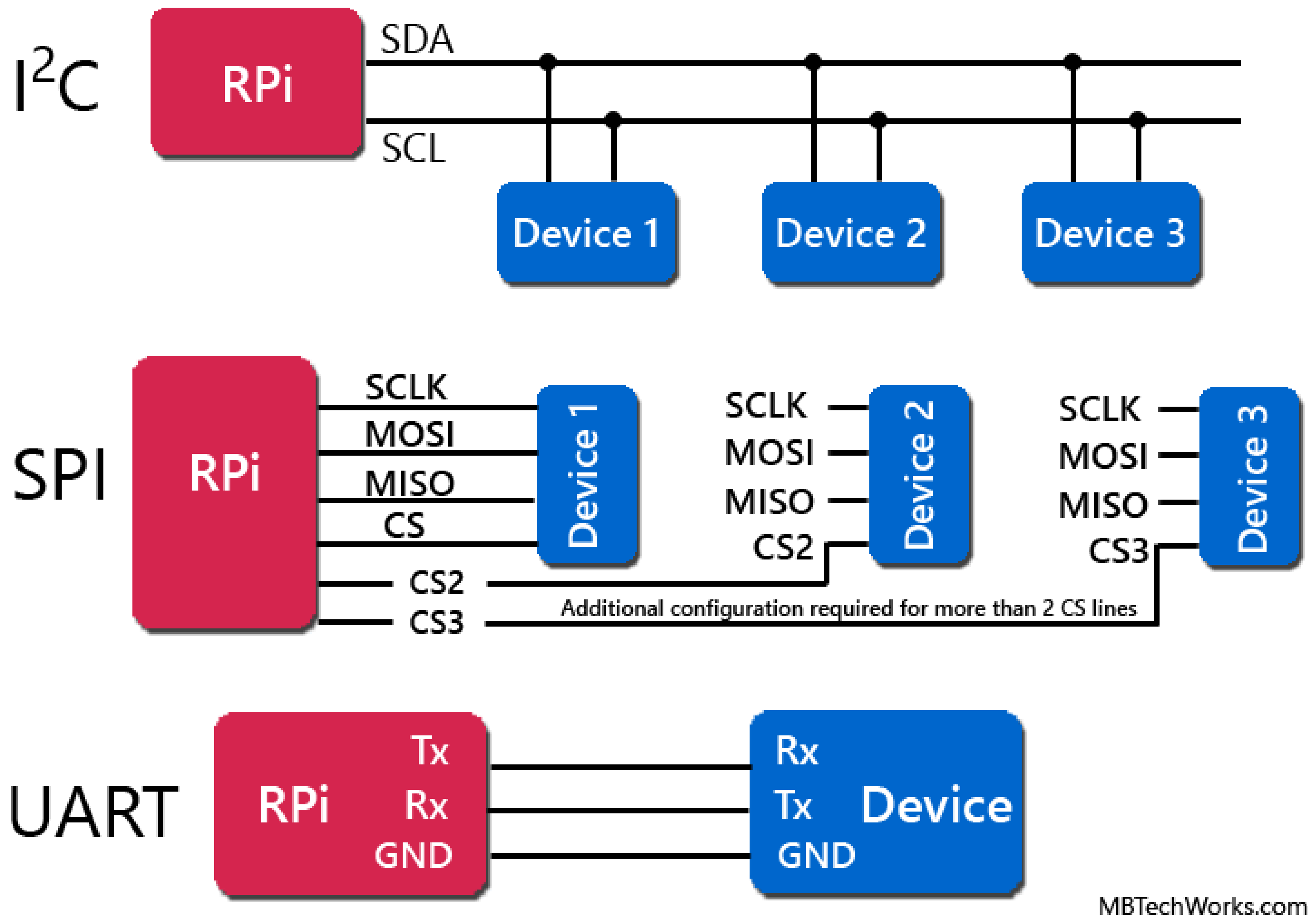
Can we use temporal/digital transmission of data?

Digital Protocols

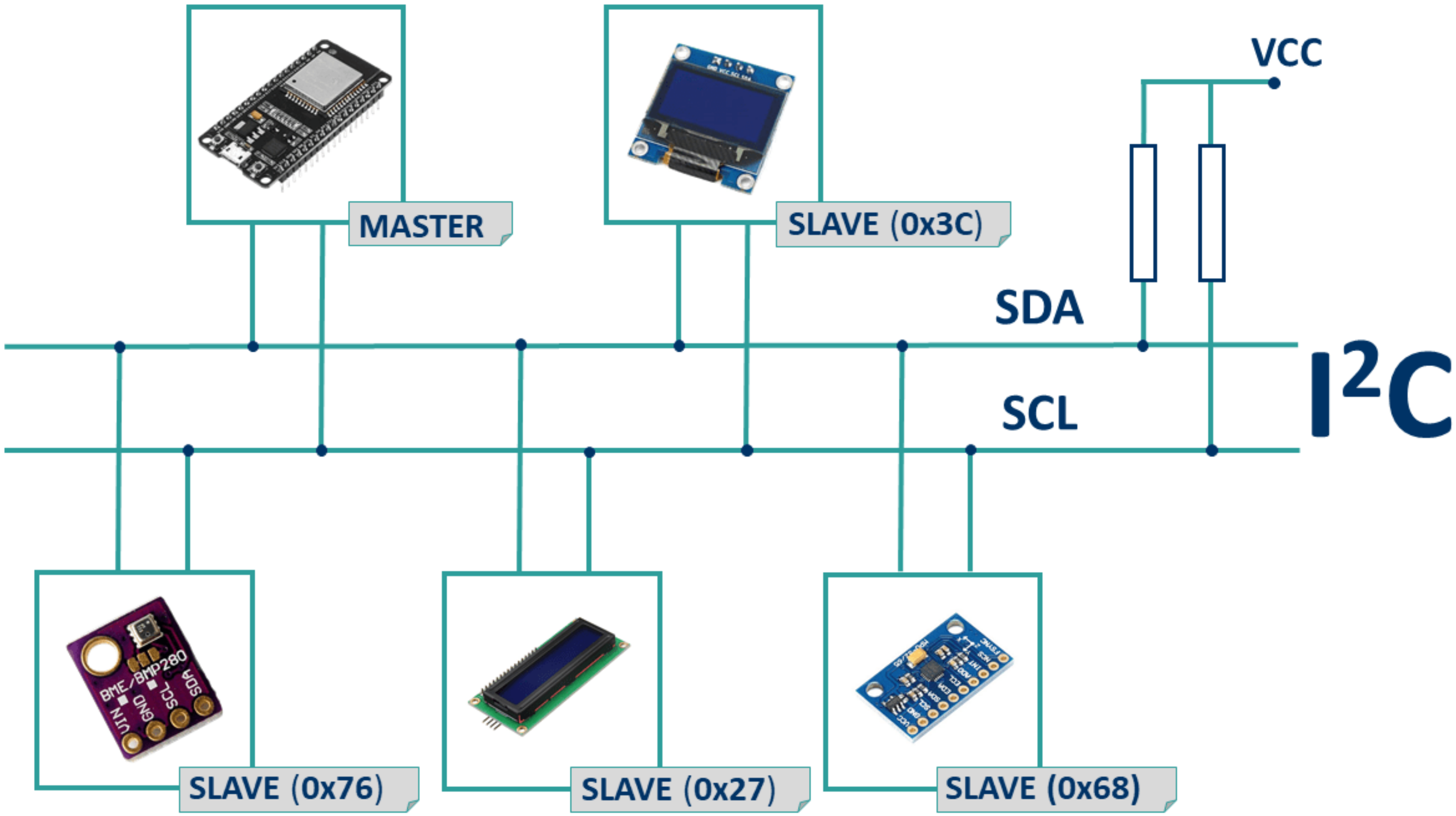


Digital Protocols

- I2C
- SPI
- UART
- CAN Bus

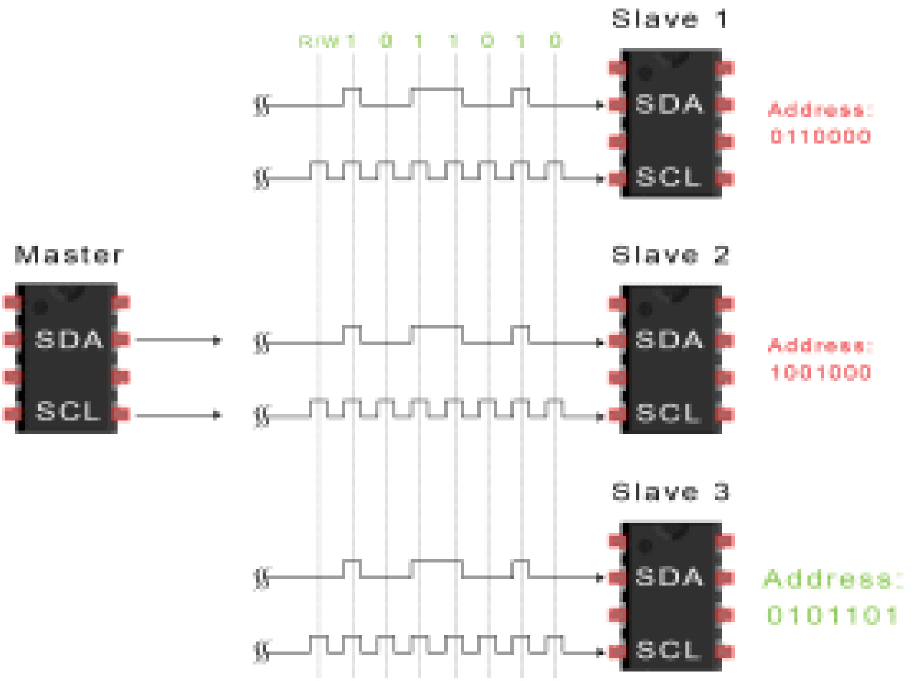


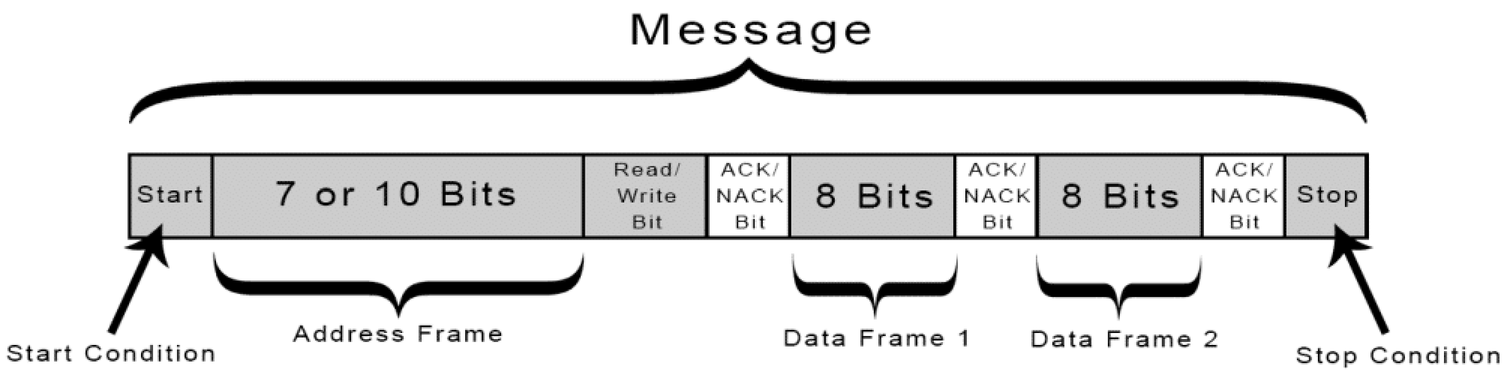
I2C



MASTER
SLAVE (0x3C)
VCC
SDA
SCL
I²C
SLAVE (0x76)
SLAVE (0x27)
SLAVE (0x68)

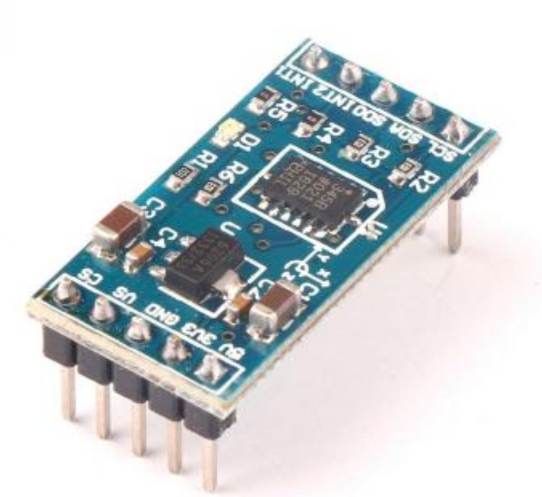
I2C


Slave 1
SDA
SCL
Address:
0110000
Master
SDA
SCL
Slave 2
SDA
SCL
Address:
1001000
Slave 3
SDA
SCL
Address:
0101101


Message
Start
7 or 10 Bits
Read/
Write
Bit
ACK/
NACK
Bit
8 Bits
ACK/
NACK
Bit
8 Bits
ACK/
NACK
Bit
Stop
Start Condition
Address Frame
Data Frame 1
Data Frame 2
Stop Condition

I2C

HMC5883L
Magnetometer

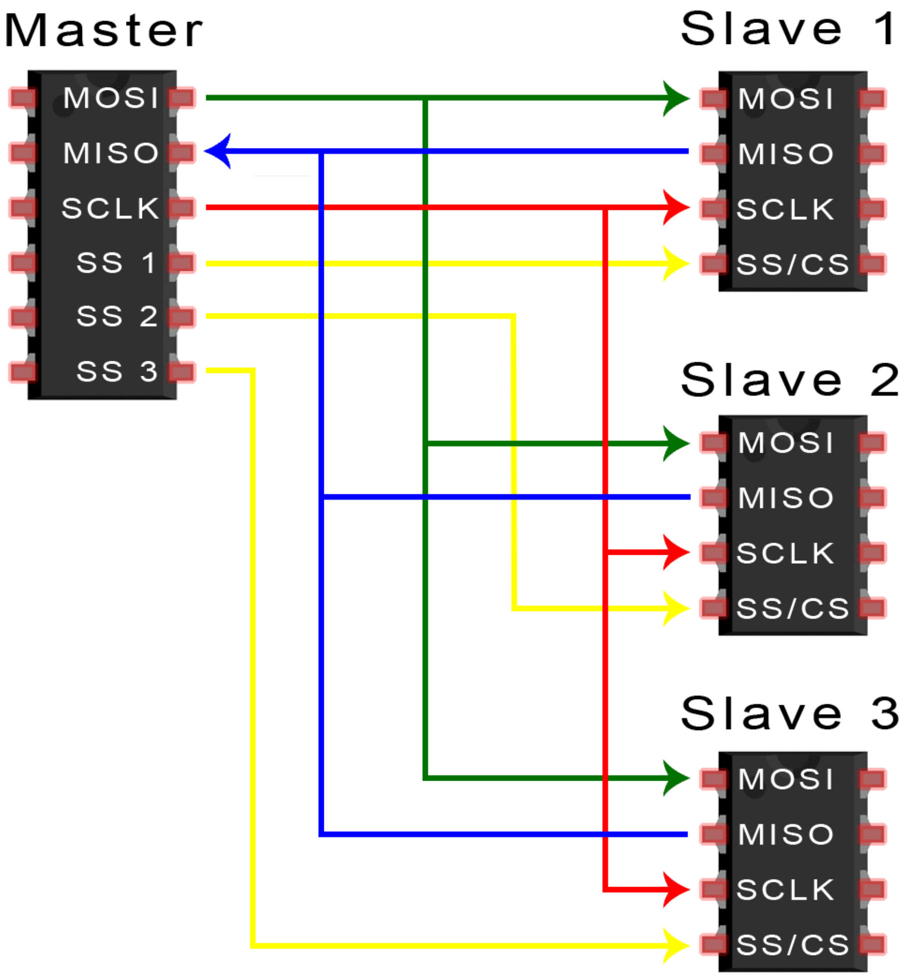


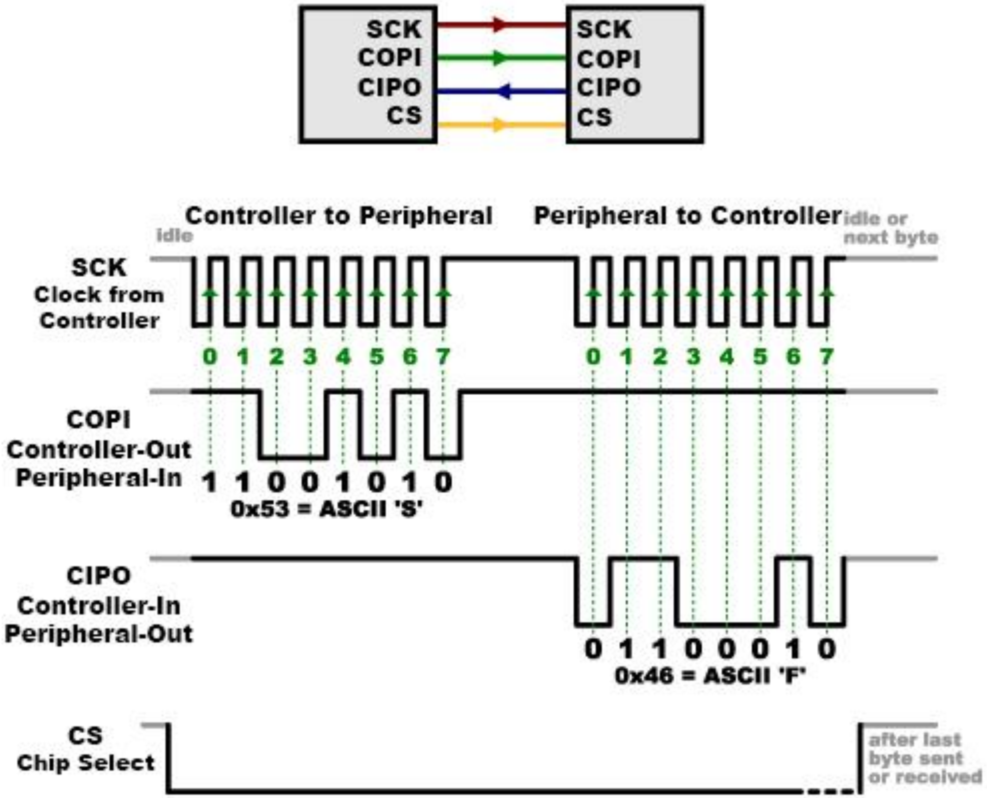
ADXL345
Accelerometer

MMA7660FC
Accelerometer

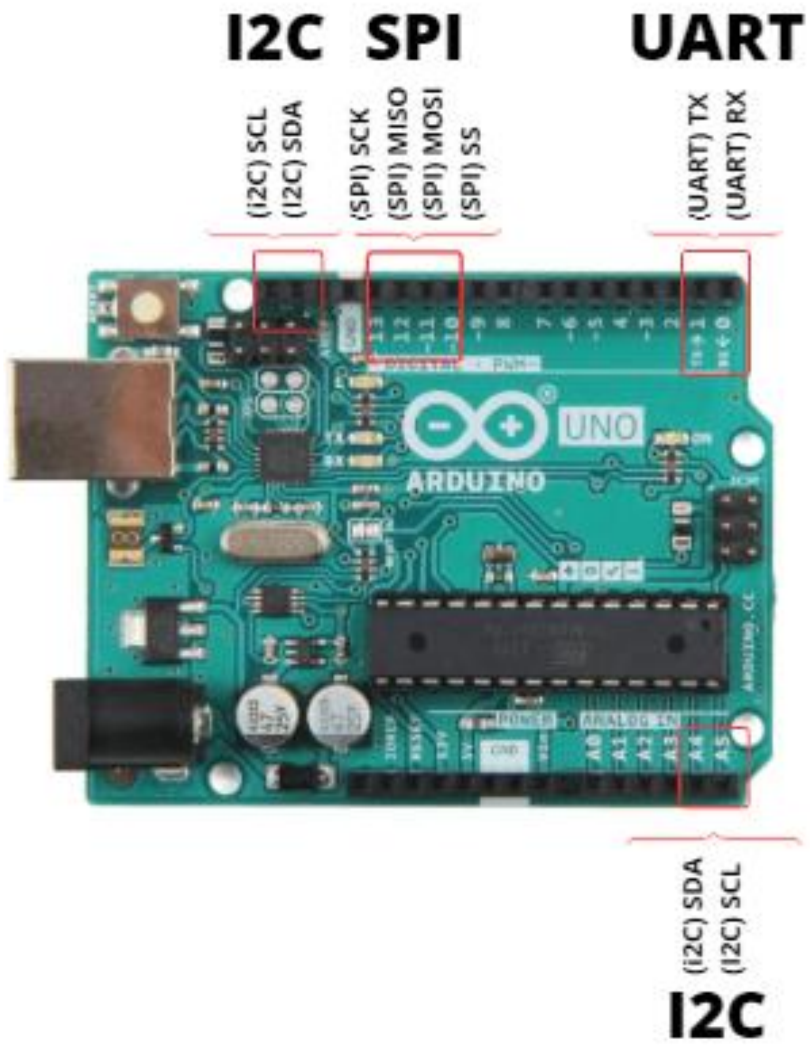
MPU6050
Accelerometer + Gyroscope

SPI (Serial Peripheral Interface)





Digital Protocols



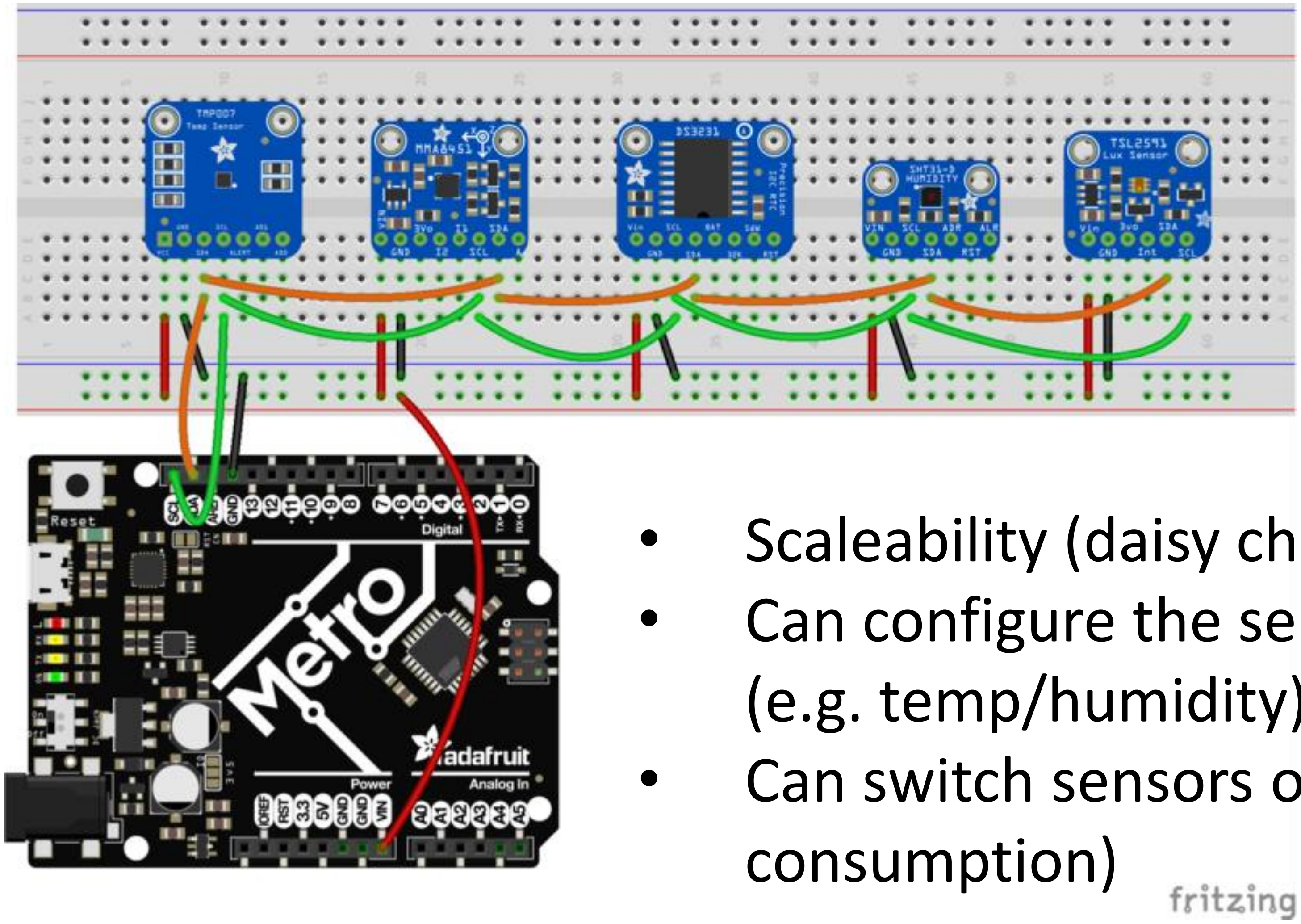
- Microcontrollers have dedicated digital pins for I2C, SPI, UART
- Can have multiple I2C ports
- Many sensors offer SPI or I2C connectivity

Digital Protocols

Characteristic	I2C	SPI	Bottom line
Speed	(100k, 400k, 1M, 3.4M) [Hz]	up to 25 [MHz]	SPI is much faster than I2C.
Scalability	Up to 127, 255, 1024 devices on the single bus depending on addressing. Note that one bus is only 2 wires (SDA, SCL)! Many sensors allow you to connect multiple numbers of the same device to the single bus with different addresses.	Hardly scalable. Every new device on the bus requires additional CS line to control this slave device.	I2C is much more scalable than SPI.
Bus length	Up to 1 meter long for 100kHz, shorter for higher speeds.	Best for short distances.	I2C is more suitable when distance between master and slave is significant.

The appropriate sensor + protocol should be selected for the application

Why are these digital data protocols useful?



- Scaleability (daisy chain)
- Can configure the sensors (data-rate), what to send (e.g. temp/humidity)
- Can switch sensors on/off (reduce power consumption)

What do we need to think about when incorporating sensors into products?

Sensor Design Selection…

- Form factor
- Sensitivity
- Protocol (analog, digital protocol?)
- Robustness
- Power draw
- Signal-to-noise ratio
- Cost
- Amount of signal processing required

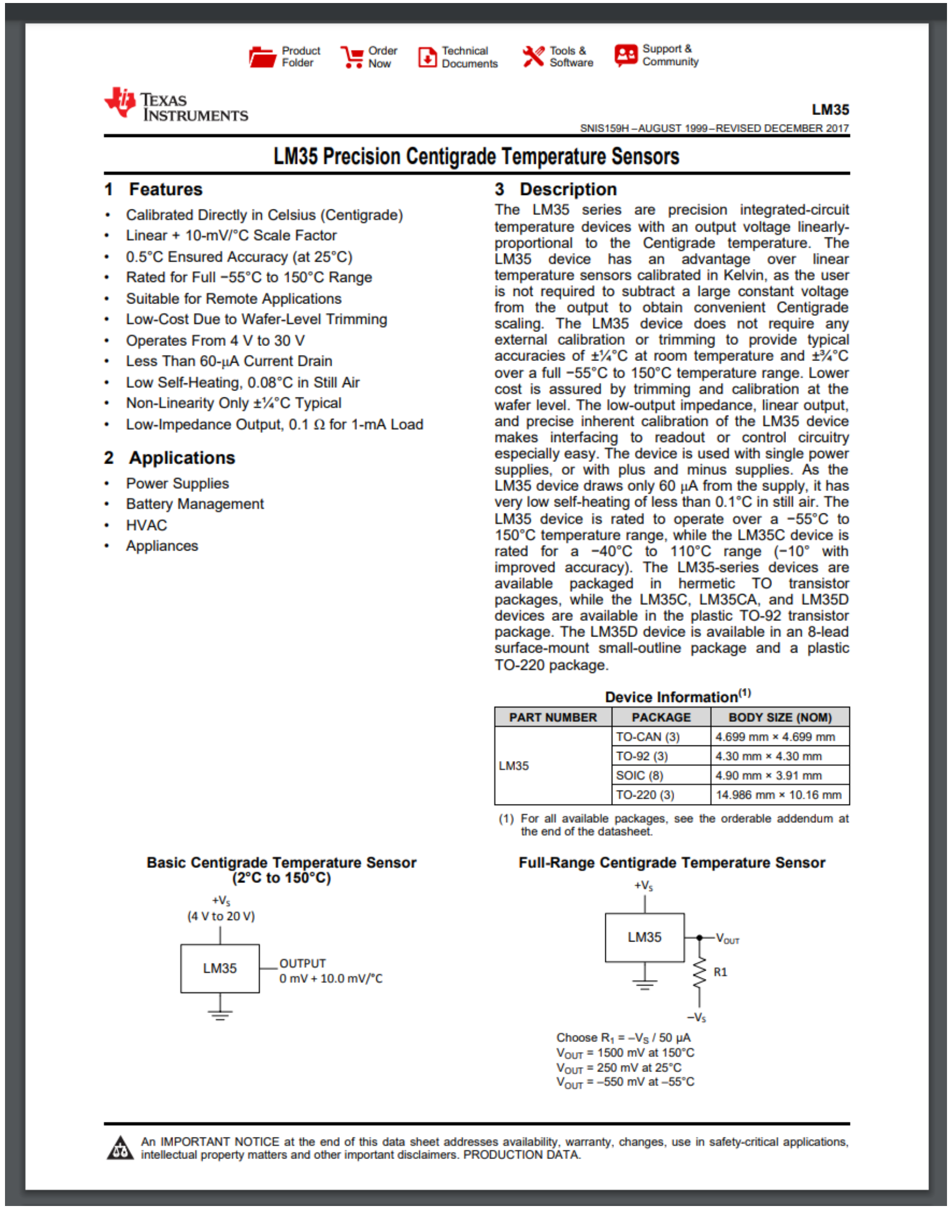
Sensor Design Selection…

- Form factor
- Sensitivity
- Robustness
- Power draw
- Signal-to-noise ratio
- Cost
- Amount of signal processing required

Can be found on data-sheets
- Component websites (mouser, digikey, RS, Farnell etc.)

Sensors: Data-sheets

LM35



LM35

SNIS159H – AUGUST 1999 – REVISED DECEMBER 2017

LM35 Precision Centigrade Temperature Sensors

1 Features

- Calibrated Directly in Celsius (Centigrade)
- Linear + 10-mV/°C Scale Factor
- 0.5°C Ensured Accuracy (at 25°C)
- Rated for Full −55°C to 150°C Range
- Suitable for Remote Applications
- Low-Cost Due to Wafer-Level Trimming
- Operates From 4 V to 30 V
- Less Than 60-μA Current Drain
- Low Self-Heating, 0.08°C in Still Air
- Non-Linearity Only ±¼°C Typical
- Low-Impedance Output, 0.1 Ω for 1-mA Load

2 Applications

- Power Supplies
- Battery Management
- HVAC
- Appliances

3 Description

The LM35 series are precision integrated-circuit temperature devices with an output voltage linearly-proportional to the Centigrade temperature. The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. The LM35 device does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full −55°C to 150°C temperature range. Lower cost is assured by trimming and calibration at the wafer level. The low-output impedance, linear output, and precise inherent calibration of the LM35 device makes interfacing to readout or control circuitry especially easy. The device is used with single power supplies, or with plus and minus supplies. As the LM35 device draws only 60 μA from the supply, it has very low self-heating of less than 0.1°C in still air. The LM35 device is rated to operate over a −55°C to 150°C temperature range, while the LM35C device is rated for a −40°C to 110°C range (−10° with improved accuracy). The LM35-series devices are available packaged in hermetic TO transistor packages, while the LM35C, LM35CA, and LM35D devices are available in the plastic TO-92 transistor package. The LM35D device is available in an 8-lead surface-mount small-outline package and a plastic TO-220 package.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM35	TO-CAN (3)	4.699 mm × 4.699 mm
	TO-92 (3)	4.30 mm × 4.30 mm
	SOIC (8)	4.90 mm × 3.91 mm
	TO-220 (3)	14.986 mm × 10.16 mm

(1) For all available packages, see the orderable addendum at the end of the datasheet.

Basic Centigrade Temperature Sensor (2°C to 150°C)

Full-Range Centigrade Temperature Sensor

Choose $R_1 = -V_S / 50\ \mu A$
V_{OUT} = 1500 mV at 150°C
V_{OUT} = 250 mV at 25°C
V_{OUT} = −550 mV at −55°C

An IMPORTANT NOTICE at the end of this data sheet addresses availability, warranty, changes, use in safety-critical applications, intellectual property matters and other important disclaimers. PRODUCTION DATA.

https://www.ti.com/lit/ds/symlink/lm35.pdf

Sensors: Data-sheets

8.2.1 Basic Centigrade Temperature Sensor

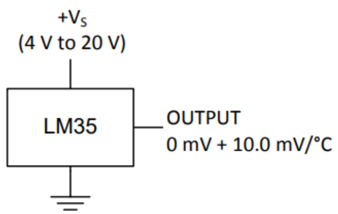


Figure 14. Basic Centigrade Temperature Sensor (2 °C to 150 °C)

8.2.1.1 Design Requirements

Table 1. Design Parameters

PARAMETER	VALUE
Accuracy at 25°C	±0.5°C
Accuracy from –55 °C to 150°C	±1°C
Temperature Slope	10 mV/°C

8.2.1.3 Application Curve

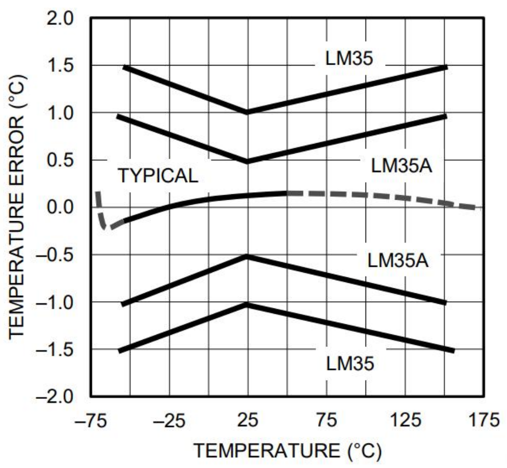


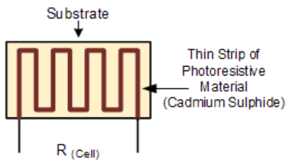
Figure 15. Accuracy vs Temperature (Ensured)

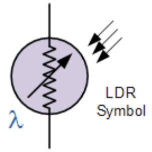
https://www.ti.com/lit/ds/symlink/lm35.pdf

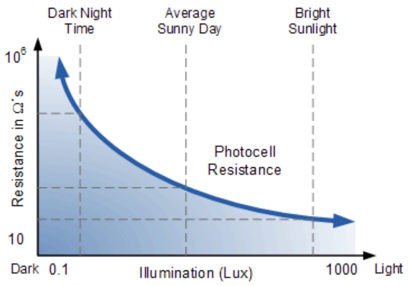
Sensors for you to design and explore

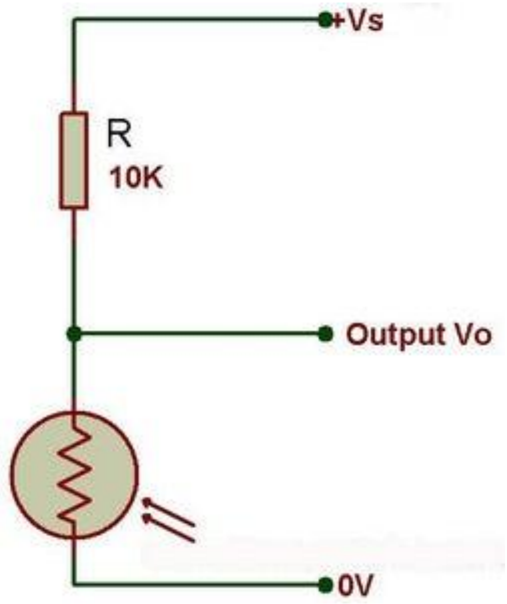
- Load Cell
- LDR Based color Sensors
- Photo-dioded based color Sensor
- Distance Sensor
- LDR (analog)
- Conductivity sensor for contact detection
- Switch

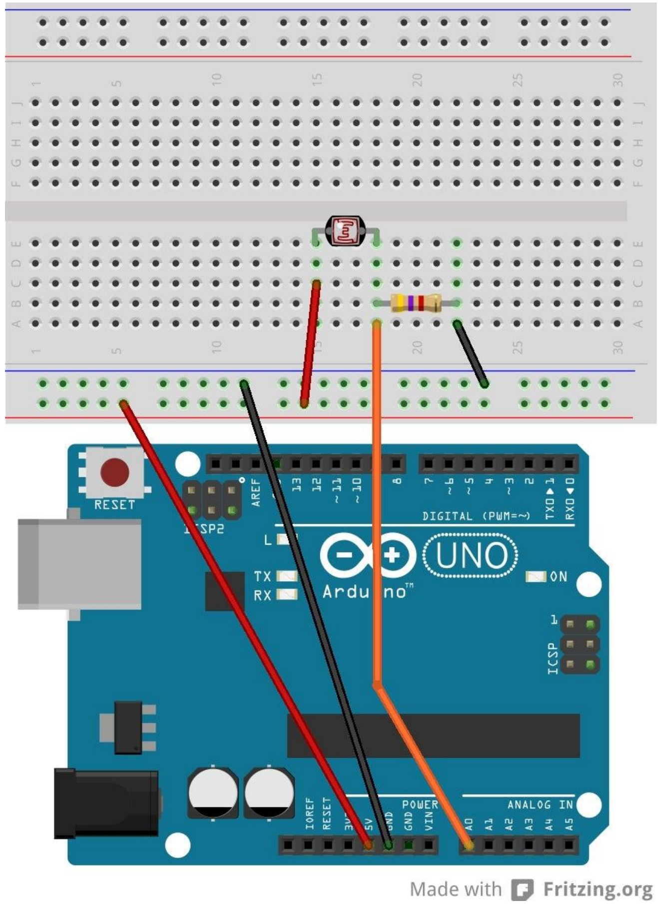
LDR: Light Dependent Resistor









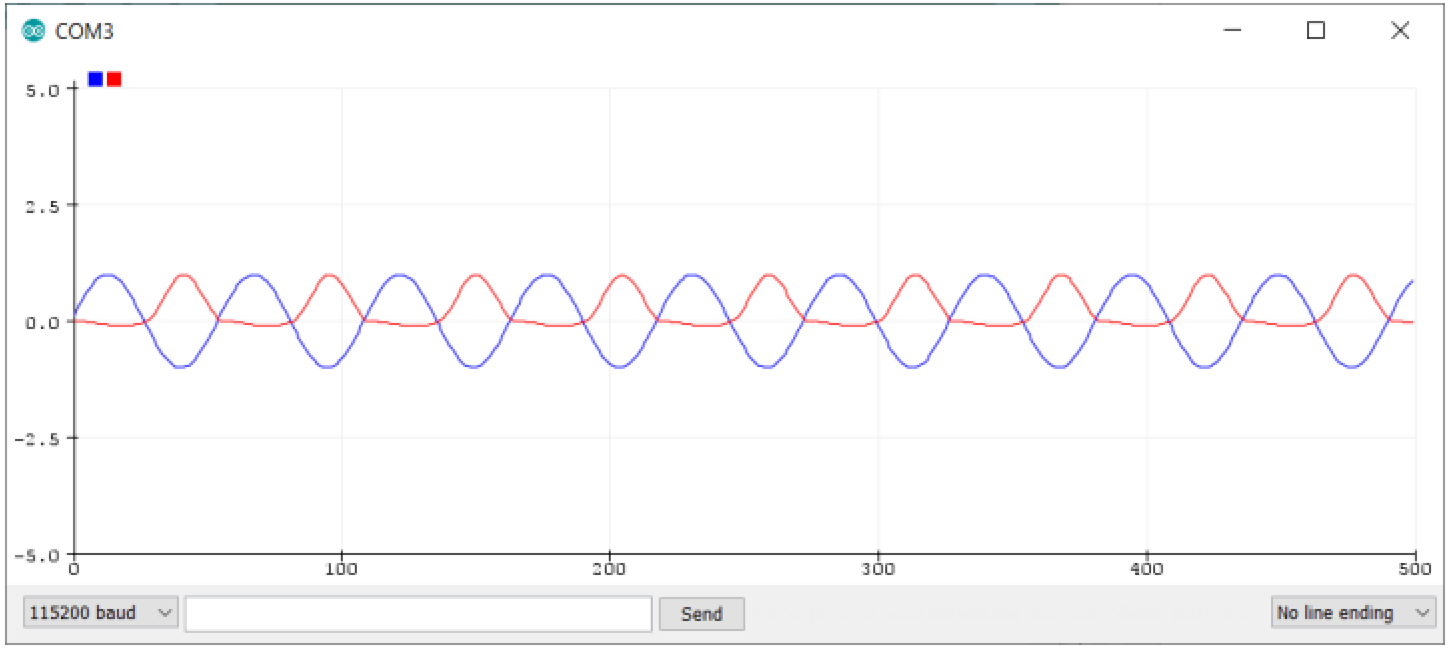


- What resistor value should I choose?

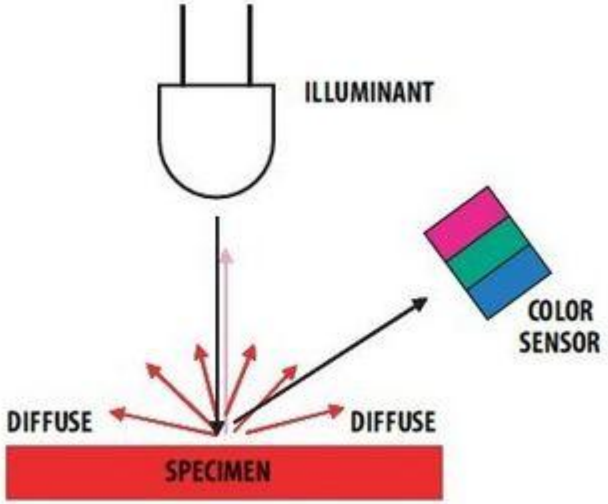
- What happens if you switch the LDR + base resistor around?

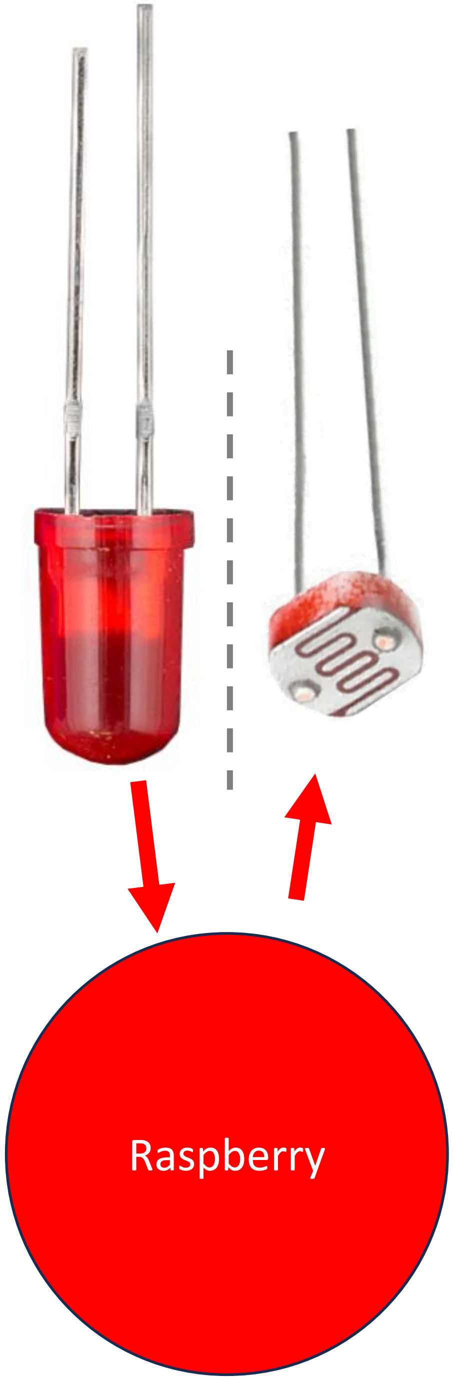
LDR: Light Dependent Resistor

```
int analogPin = A3; // potentiometer wiper (middle terminal) connected to analog pin 3
                    // outside leads to ground and +5V
int val = 0;  // variable to store the value read

void setup() {
  Serial.begin(9600);           //  setup serial
}

void loop() {
  val = analogRead(analogPin);  // read the input pin
  Serial.println(val);          // debug value
}
```

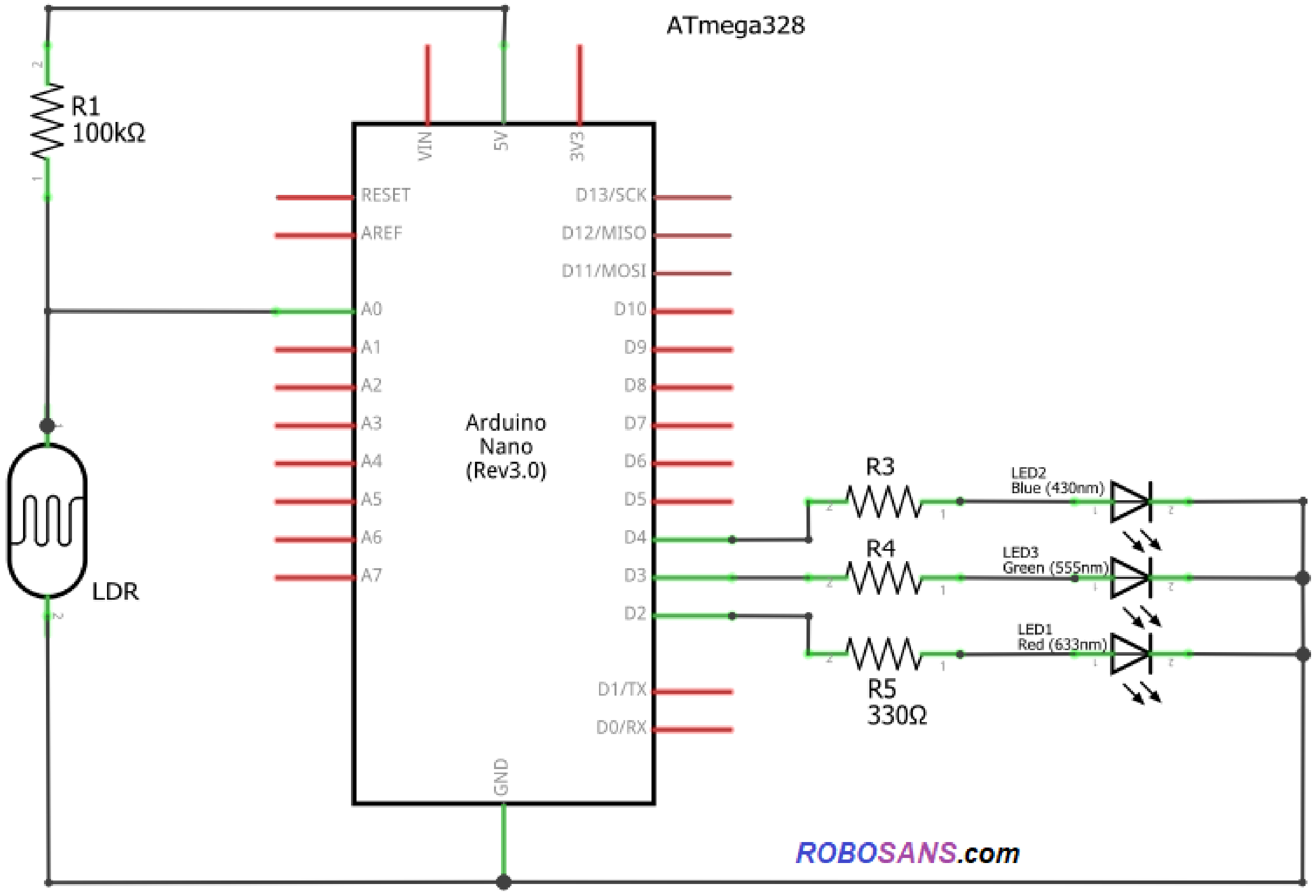


Color Sensor

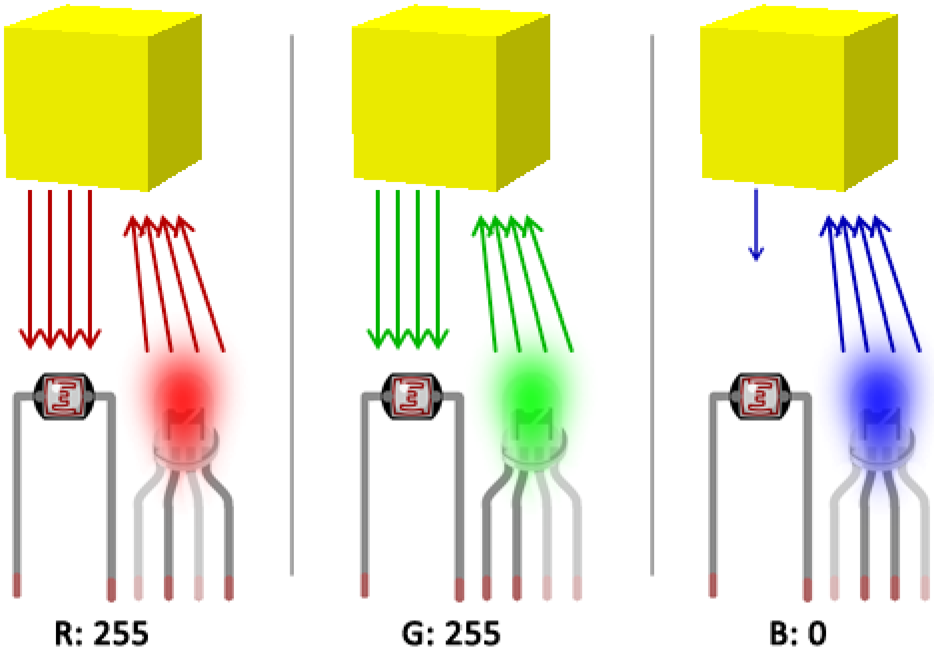




Color Sensor



Building your sensor…



- How to shield your LDR from Diode
- What color(s) to use
- What distance to have the sensor from the raspberry
- How to package and integrated this into your gripper.

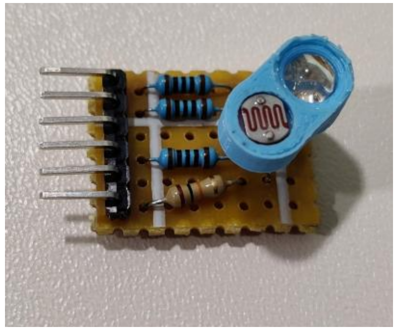
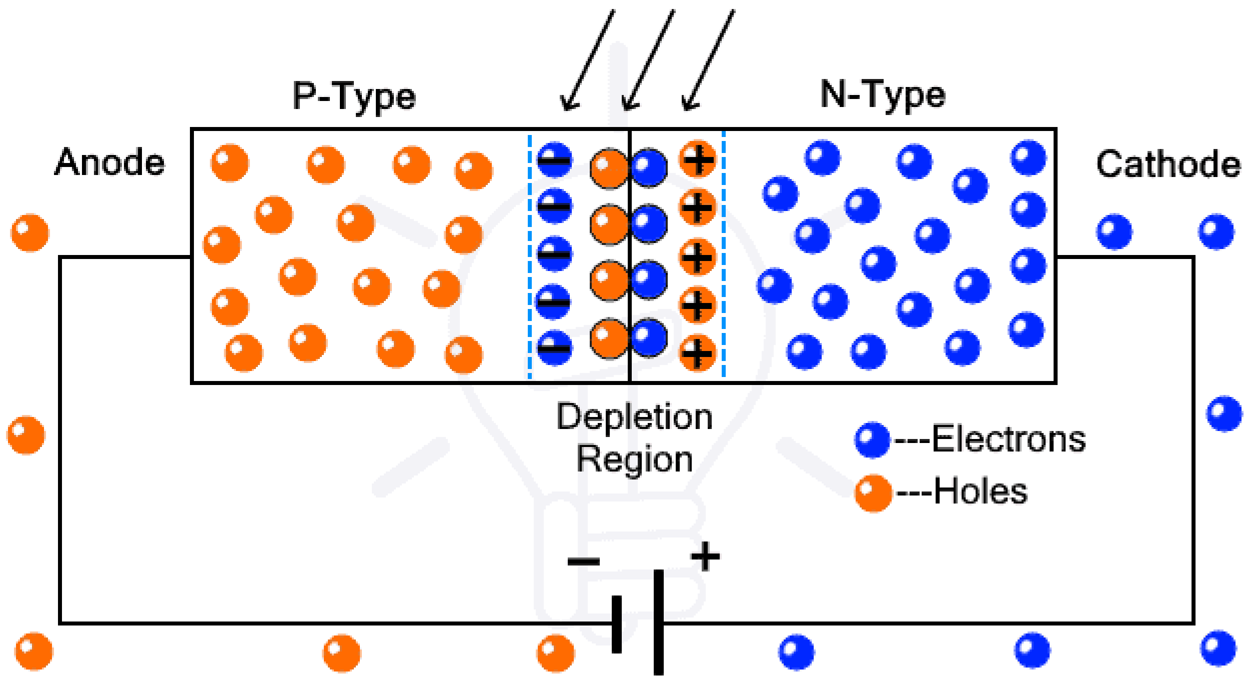
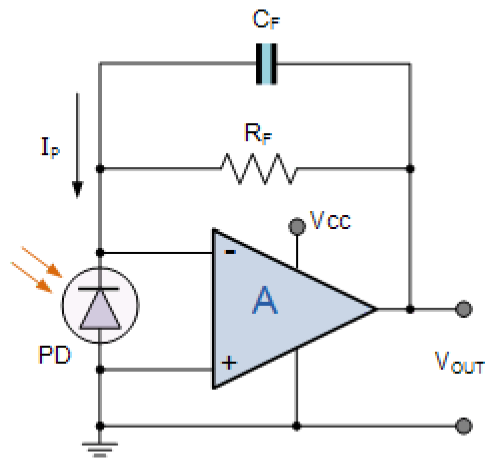
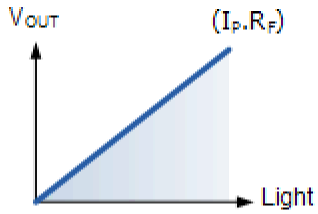


Photo-diode

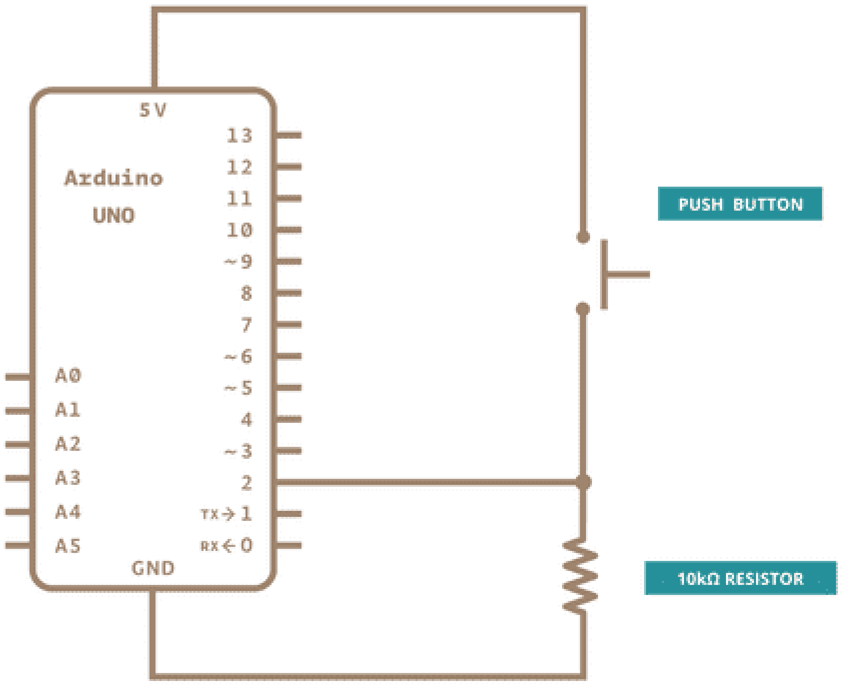


Photodiode Working



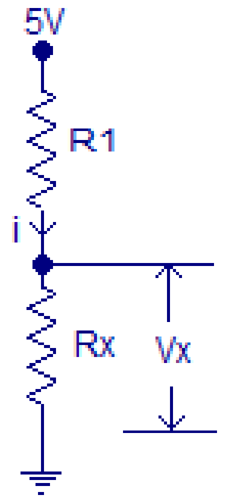


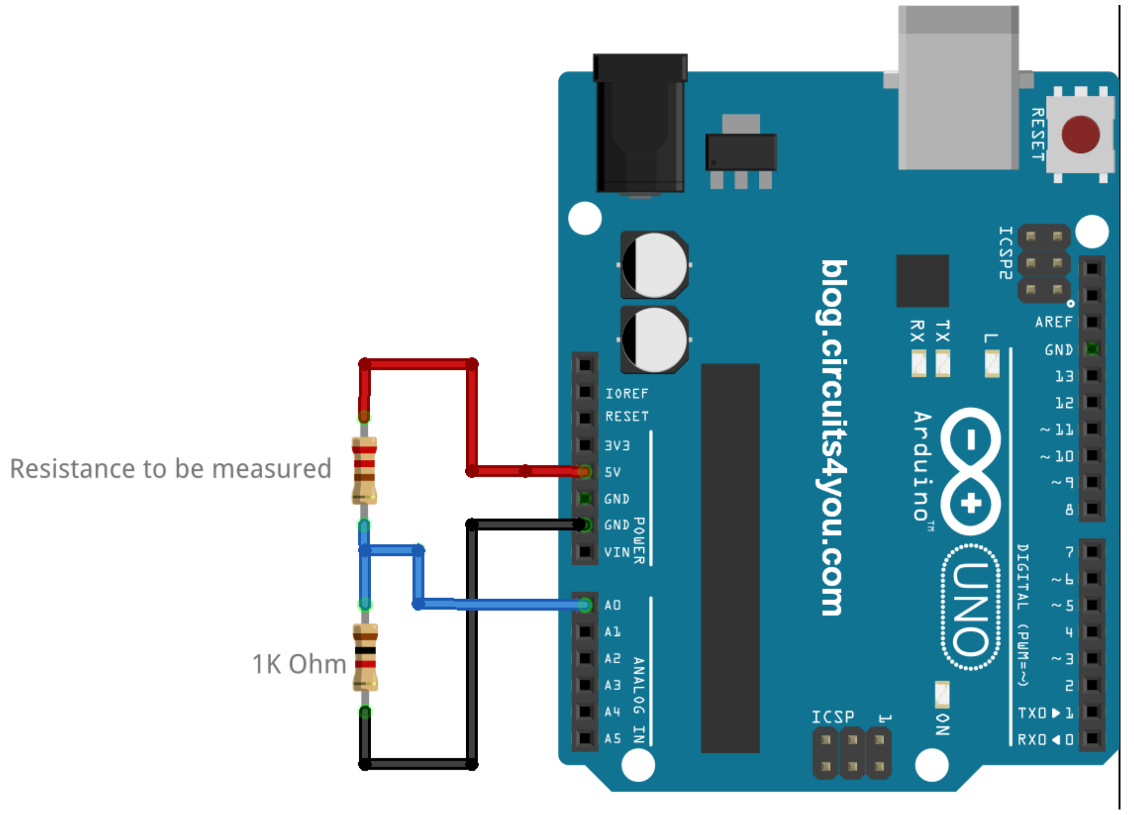
Switch (digital input)




```
const int DIN_PIN = 7;

void setup(){
    pinMode( DIN_PIN, INPUT );
    Serial.begin( 9600 );
}

void loop(){
    int value;

    value = digitalRead( DIN_PIN );
    Serial.println( value );

    delay( 1000 );
}
```

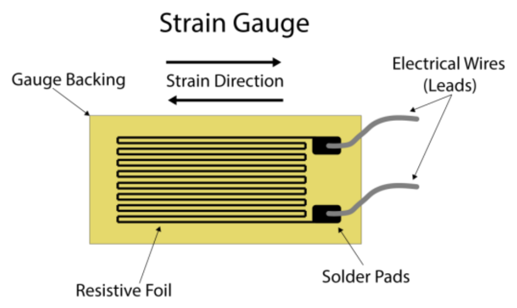
Conductivity Sensor





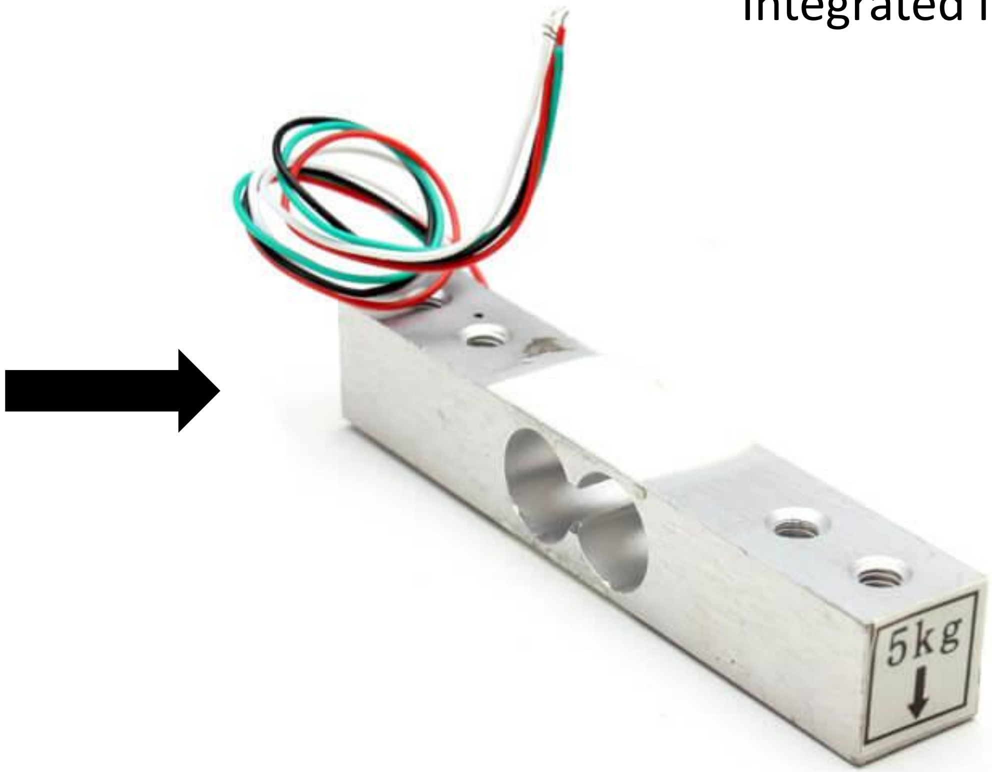
Load Cell

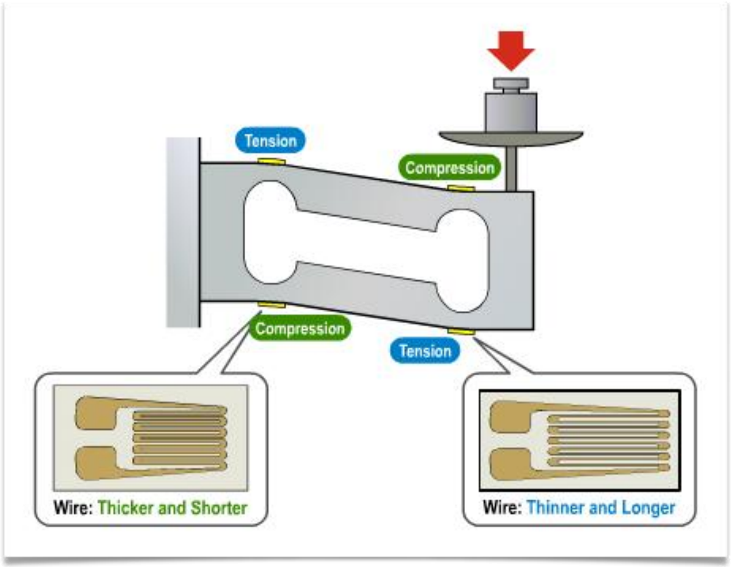
Strain gauge Sensors



→ Resistance changes with strain

Integrated into a Load Cell

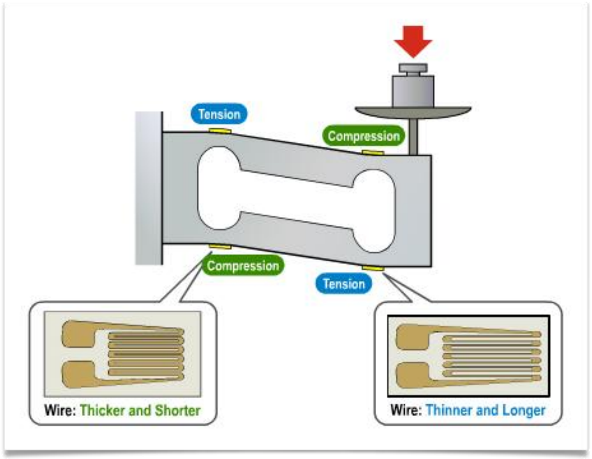




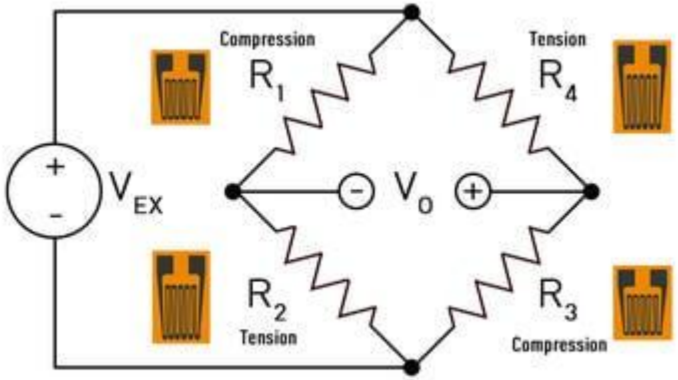
The placement amplifies the tension/compression measured

Load Cell

Load Cell



Wheatstone Bridge → Subtract differences

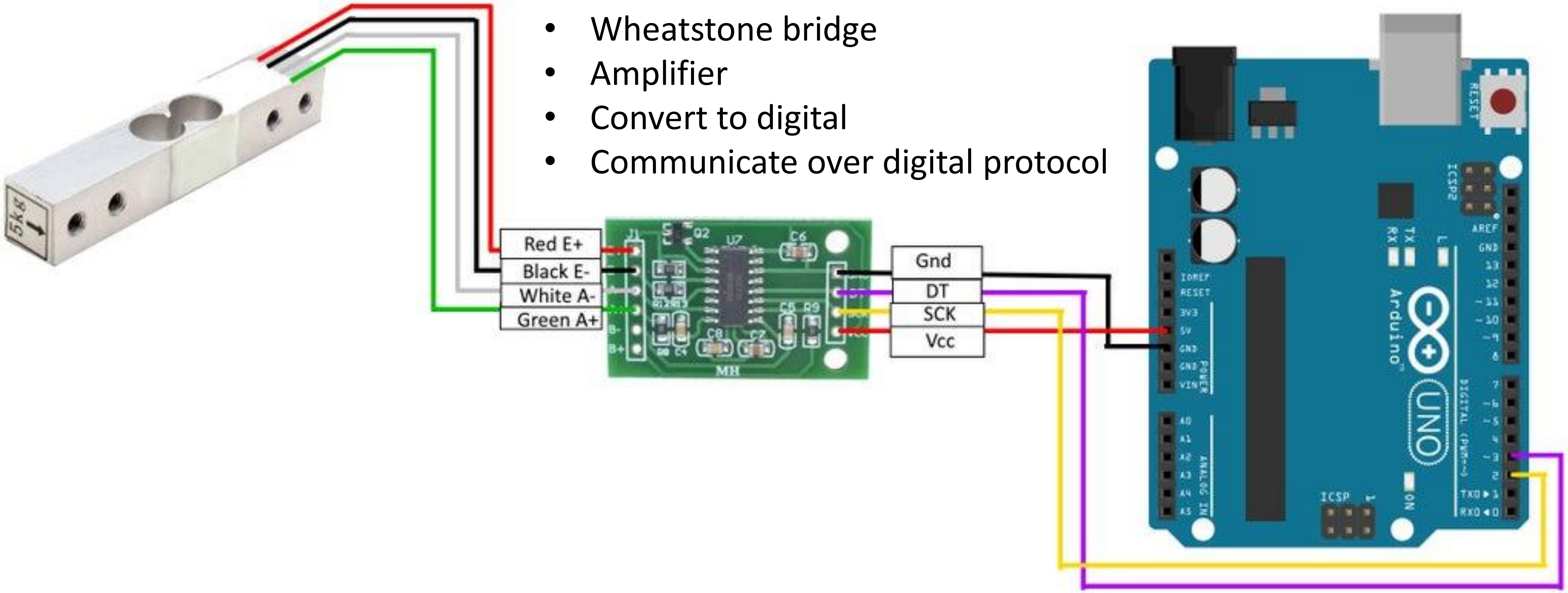


Amplify differences

Load Cell Amplifier HX711

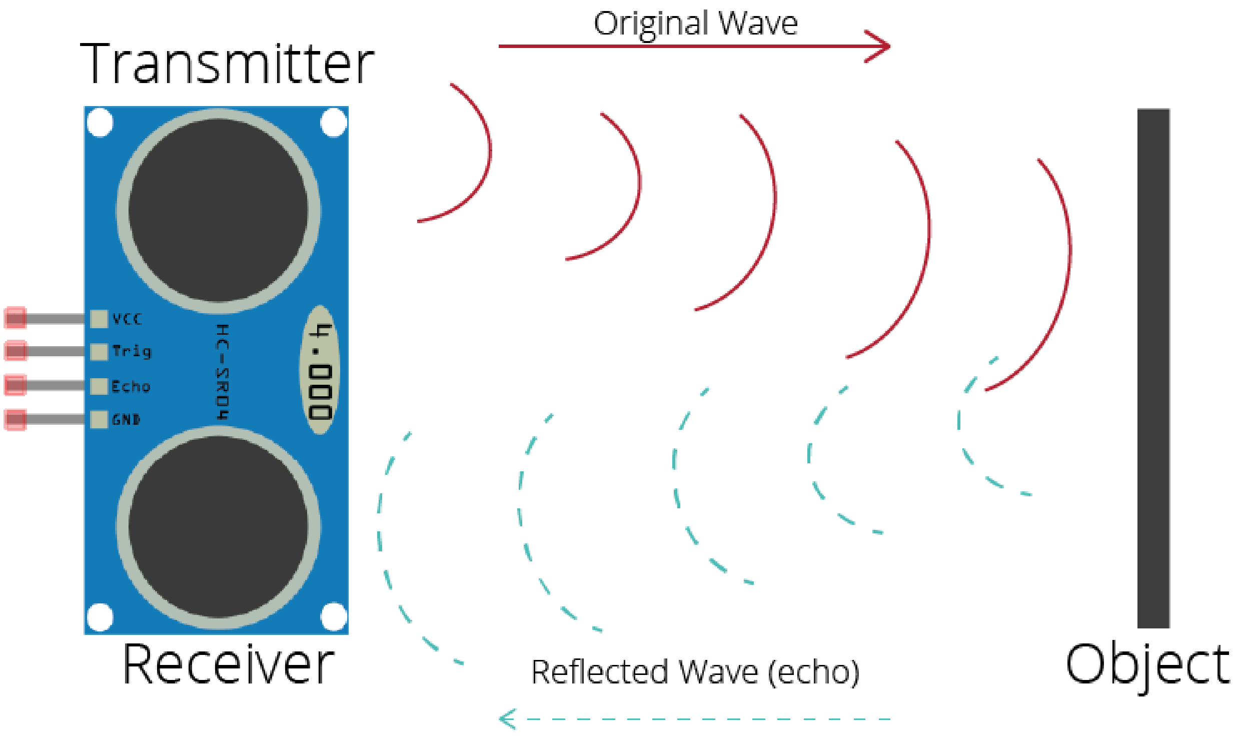
Load Cell

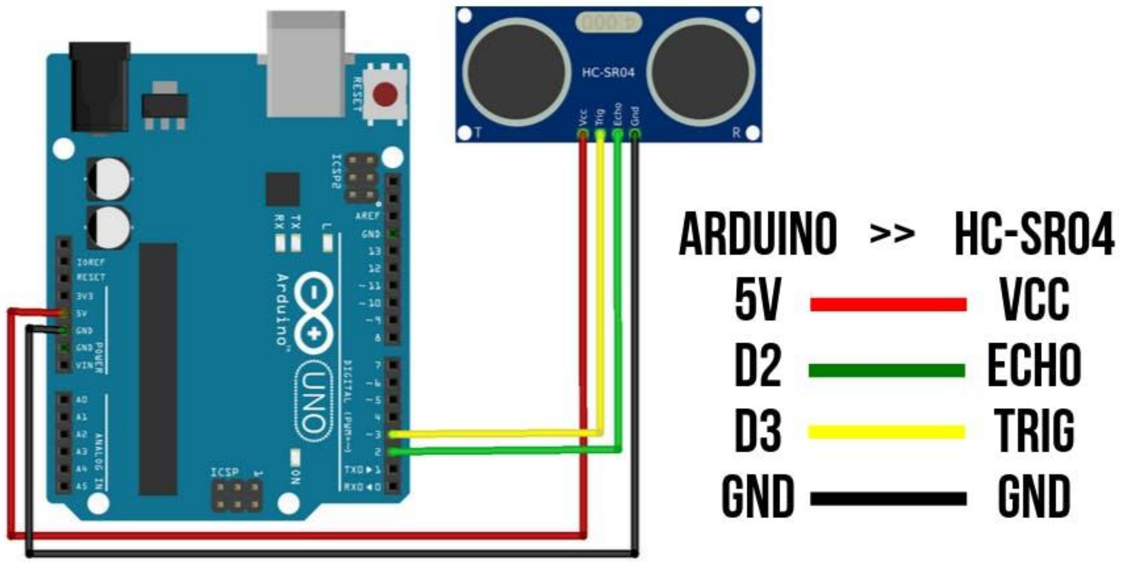
- Wheatstone bridge
- Amplifier
- Convert to digital
- Communicate over digital protocol



Use the Arduino HX111 library – provides the communication
Good tutorial:
https://learn.sparkfun.com/tutorials/load-cell-amplifier-hx711-breakout-hookup-guide

Distance Sensor



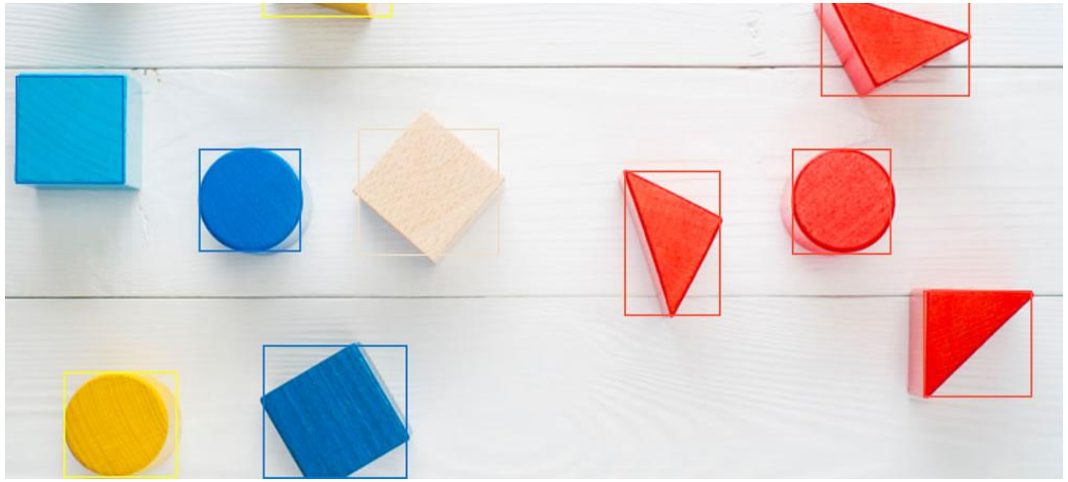


Webcams

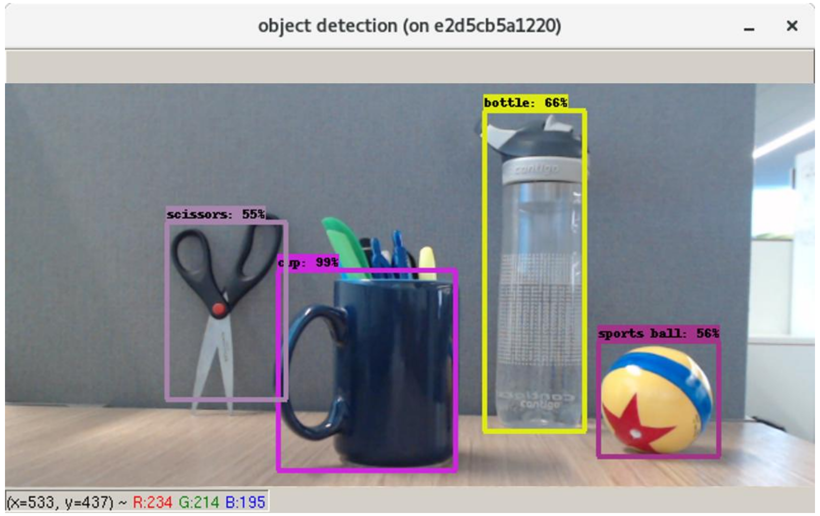
- Very powerful (high information content)
- Low cost, high useage
- Can be used ‘classically’ e.g. detect color/shape
- Can be used with learning based approaches. Many NN are particularly suited for image data

Webcams

Threshold/identify colors/shapes



Learning based object detection & classification



e.g. YoLo,

Although visual data is very useful for humans, it is challenging for machines
- Many different object orientations
- Variability in background light/conditions

→ Either need large training data-sets
→ Or need robust classifiers decision making algorithms

Webcams: Classical Computer Vision Approaches

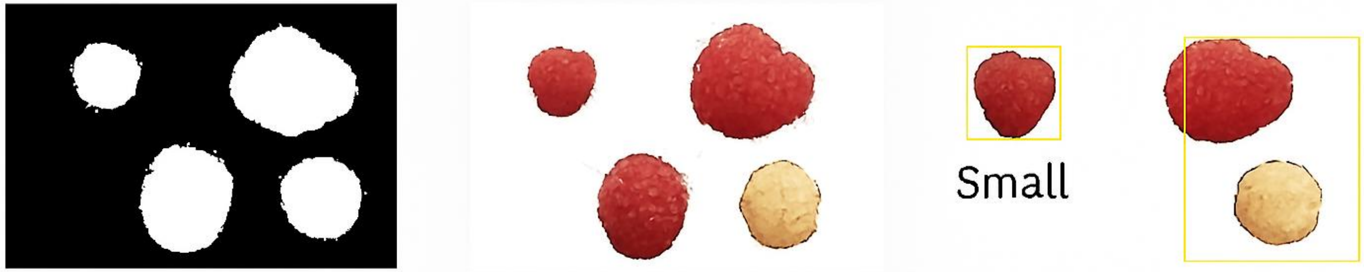
OpenCV

python™

Matlab Computer
Vision Toolbox

Webcams: Classical Computer Vision Approaches

- Convert to HSV colorspace
- Apply masking → find contours

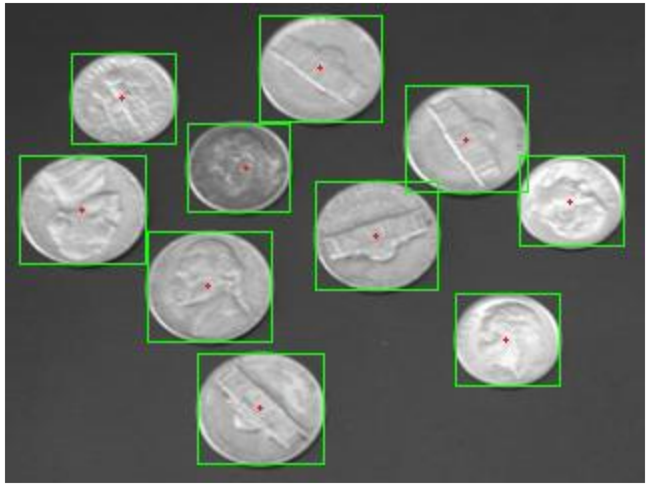


HSV Mask
Analogous Colors

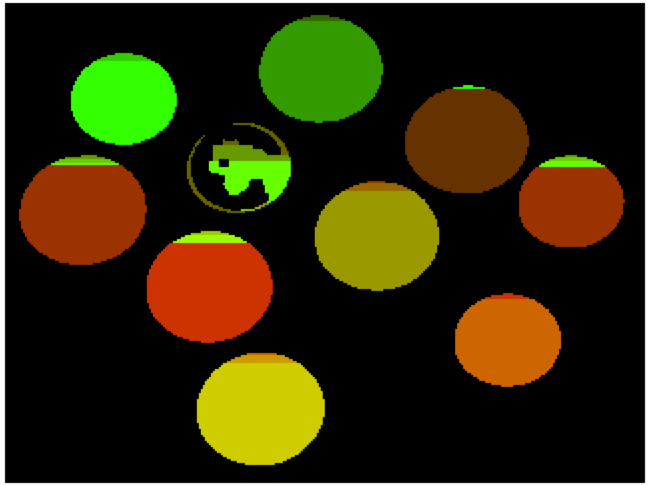
Contours of
Raspberries

Bounding Box
Small Large

Webcams: Classical Computer Vision Approaches



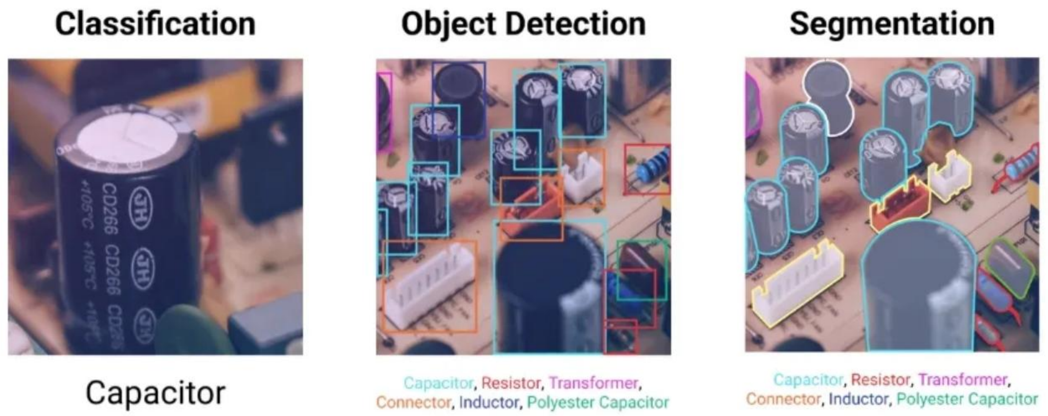
Blob detection

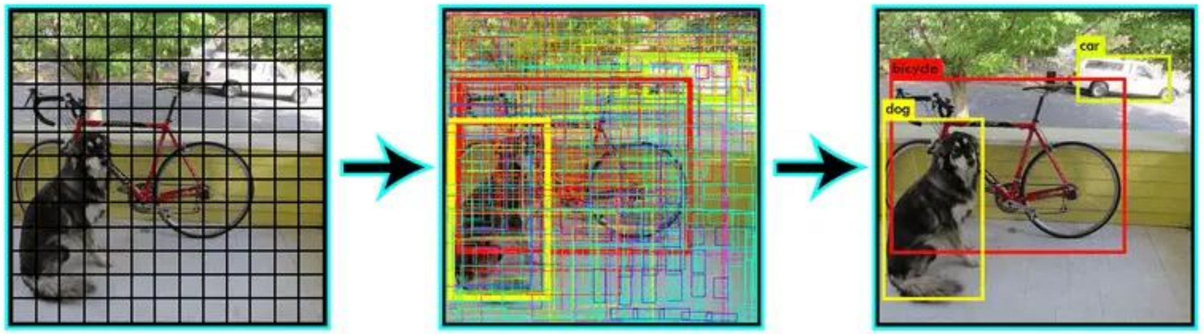


Segment pixels
→ Get color and size

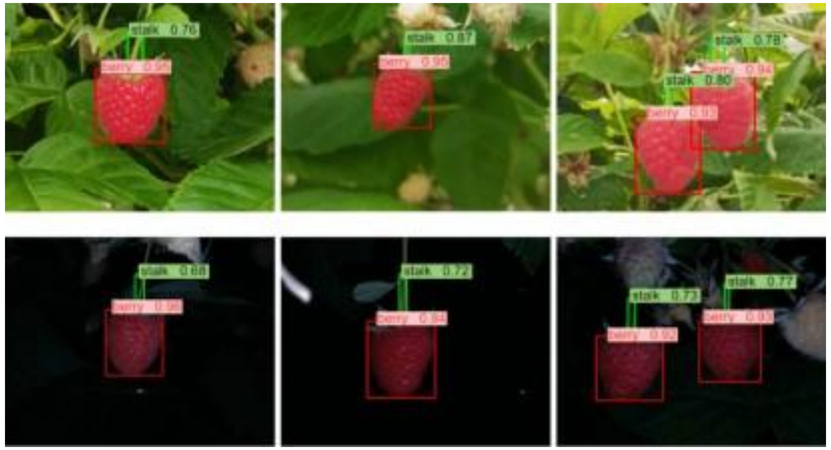
Webcams: ML Based Approaches

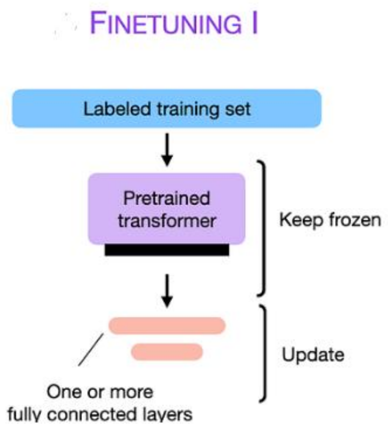
Segmentation & Classification (YoLo): You only look once





Pre-trained networks (YoLos)





Have a great Holiday Week and see you in 2 weeks!

Reminder: Drop in sessions Monday and Friday
(but not next week)

Send me an email with any questions/problems.