Special Aspects of HCI: Prototyping with Arduino

Using the Arduino Open Hardware Platform to sketch and develop physical interactions and tangible user interfaces

Today:
crash course electrical engineering

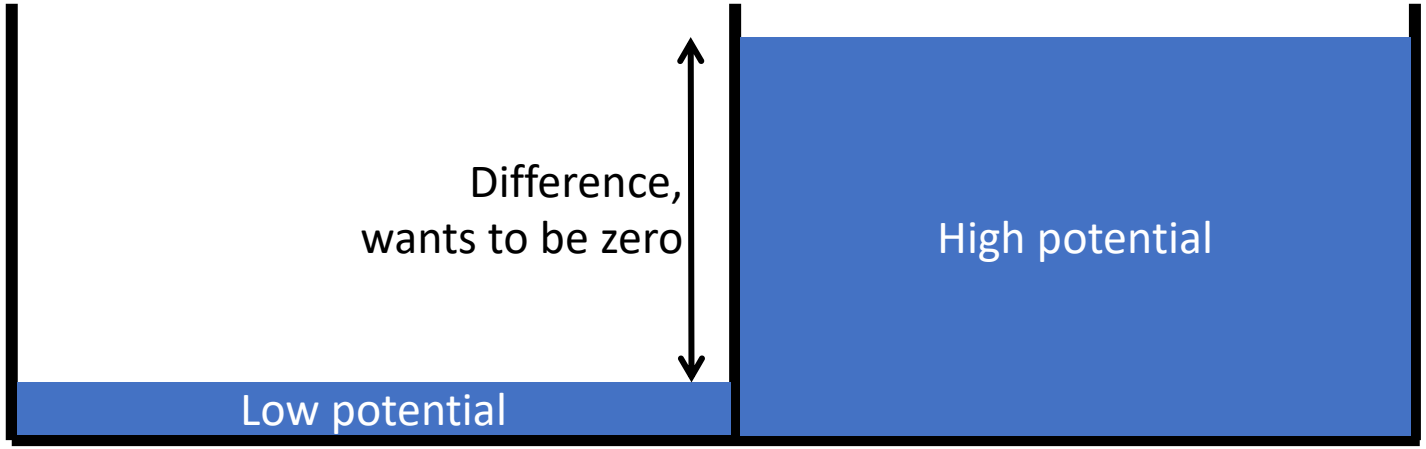
Refreshing the basics

- We keep it simple
- No scientific claim

- Some rules for us
  - Only use direct voltage and direct current
  - Keep Voltage below 30 Volt

Voltage

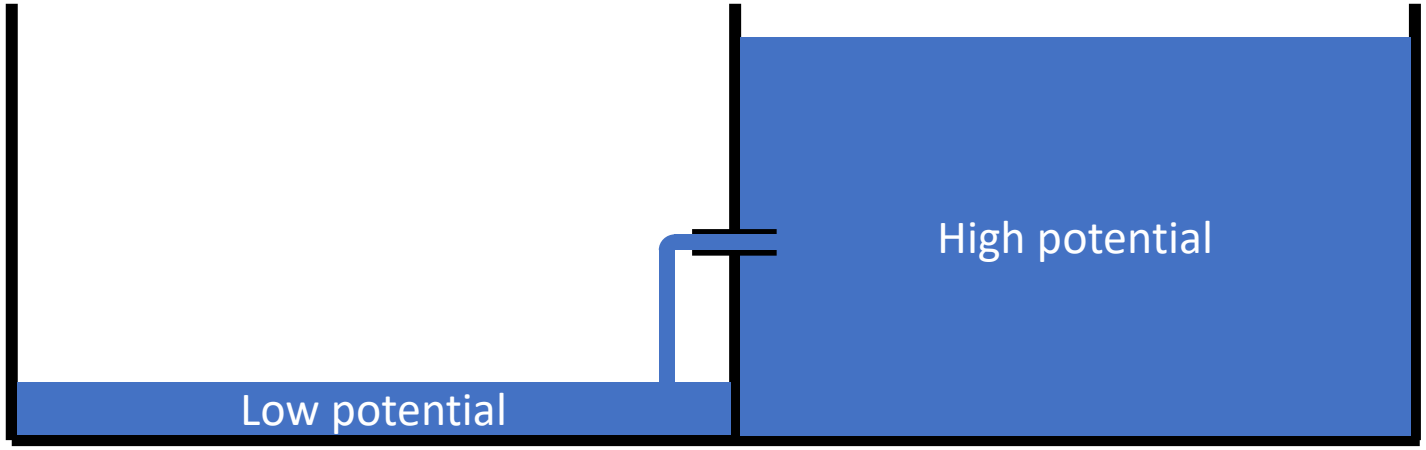
- Symbol: U
- Unit: V (Volt)
- is the difference in electric potential between two points
- High difference = high voltage



Water analogy

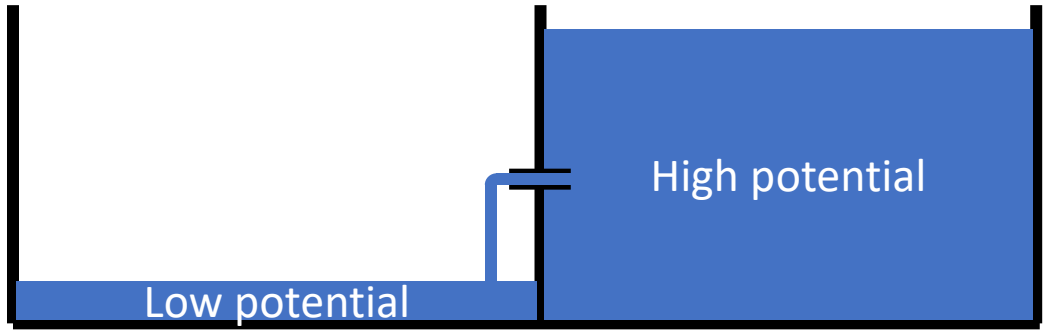
Electrical current

- Symbol: I
- Unit: A (Ampere)
- Is the process of leveling out different potentials
- Is basically the number of electron flowing through a conductor per time

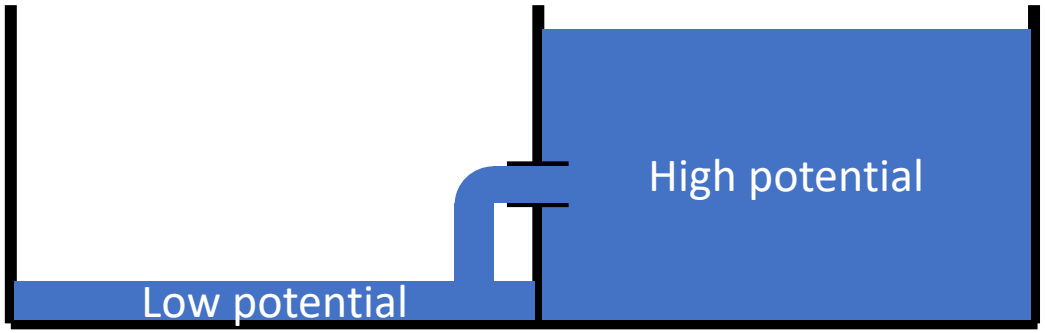


Electrical resistance

- Symbol: R
- Unit: Ω (Ohm)
- is the difficulty for the current to flow through a conductor
- Every conductor has a specific resistance
  - Conductors like copper or gold: low resistance
  - Isolators like plastic or glass: high resistance

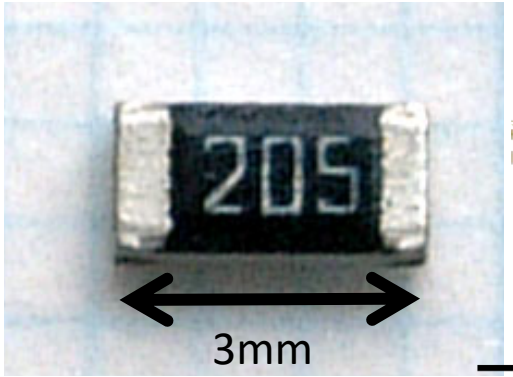


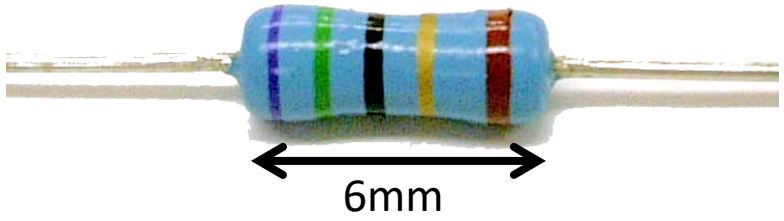
High resistance



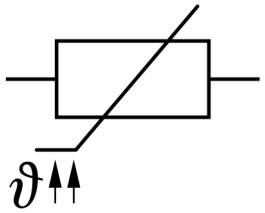
Low resistance

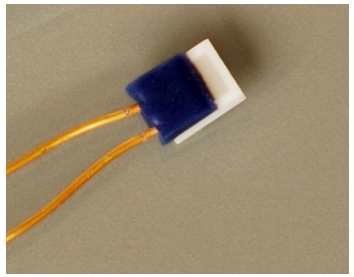
Resistor

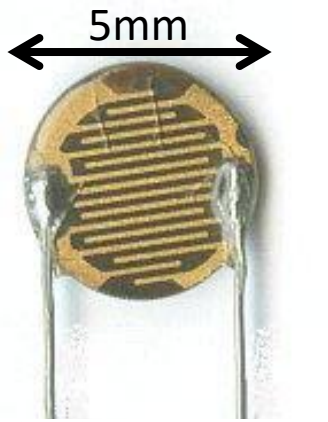


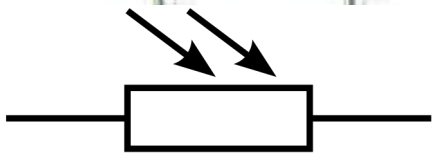


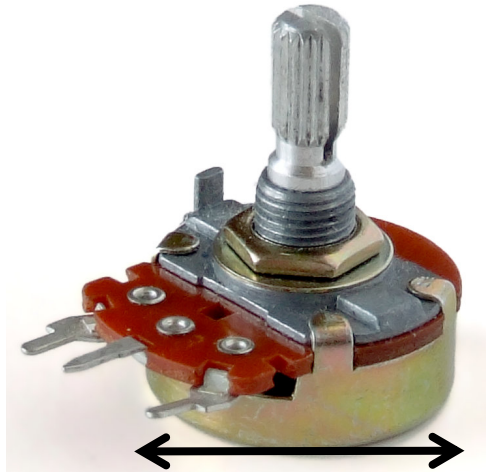
- Fixed resistance
- Manually changeable
- Resistance depends on other physical parameters (like light or temperature)

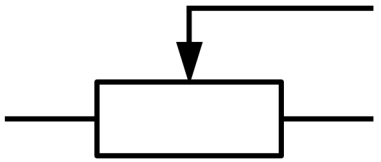












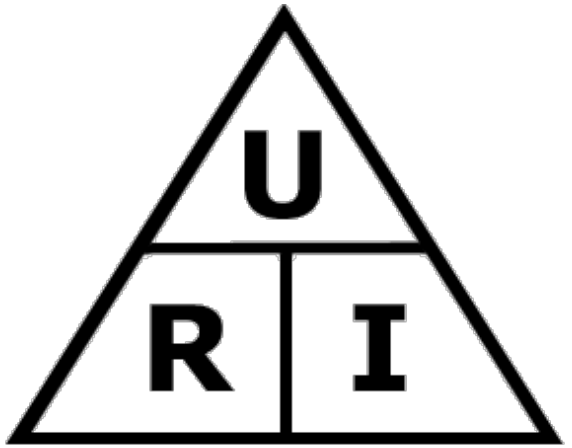
Ohm's law

- How voltage, current and resistance interact?

$$U = R \cdot I$$

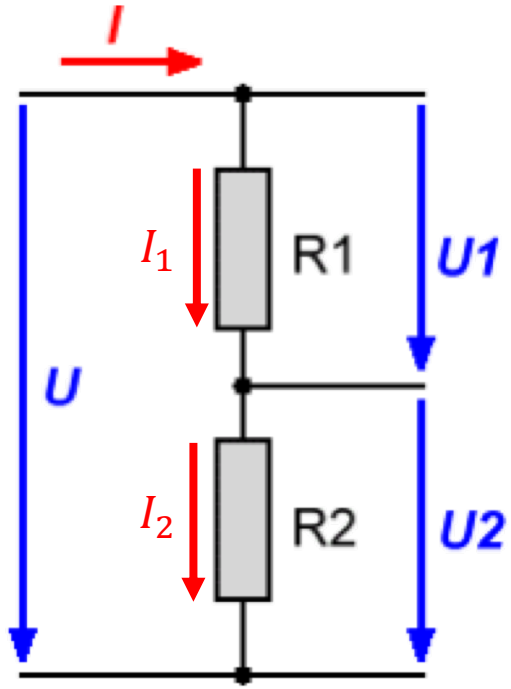
$$I = \frac{U}{R}$$

$$R = \frac{U}{I}$$



Series circuit and voltage divider

- The resistance adds up with a series circuit
  - $R_{total} = R_1 + R_2$
- The total voltage is divided in the ratio of resistances
  - $\frac{U_1}{U_2} = \frac{R_1}{R_2}$
- The current flow is the same in each part
  - $I = I_1 = I_2$



$$U = U_1 + U_2$$

$$\frac{U_1}{U_0} = \frac{R_1}{R_1 + R_2} \Rightarrow U_1 = U_0 \cdot \frac{R_1}{R_1 + R_2}$$

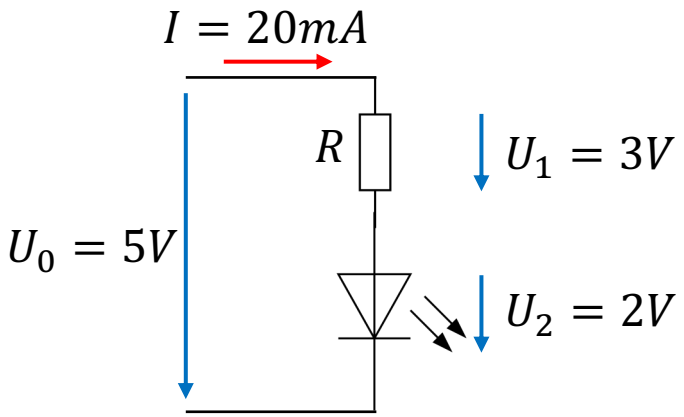
$$\frac{U_0}{U_2} = \frac{R_1 + R_2}{R_2} \Rightarrow U_2 = U_0 \cdot \frac{R_2}{R_1 + R_2}$$

Voltage divider for output

- Some components just can handle a specific amount of voltage
  - Popular example: light emitting diode (LED)
- Use a resistor to lower the voltage

How to calculate the resistor

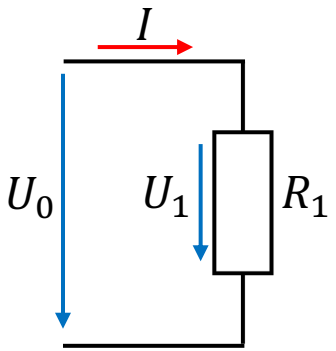
- Example:
  - LED can handle 2 – 2.5V (depending on type, see datasheet)
  - LED need around 20mA to light up (depending on type, see datasheet)
  - Arduino supplies 5V
  - 2.5 – 3V too much, needs to be compensated by resistor



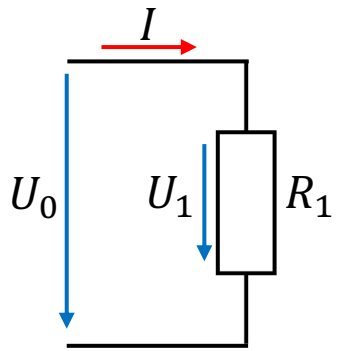
$$R = \frac{U_1}{I} = \frac{3V}{20 \cdot 10^{-3} A} = 150\ \Omega$$

Voltage divider for input

- What is the difference between this circuits?



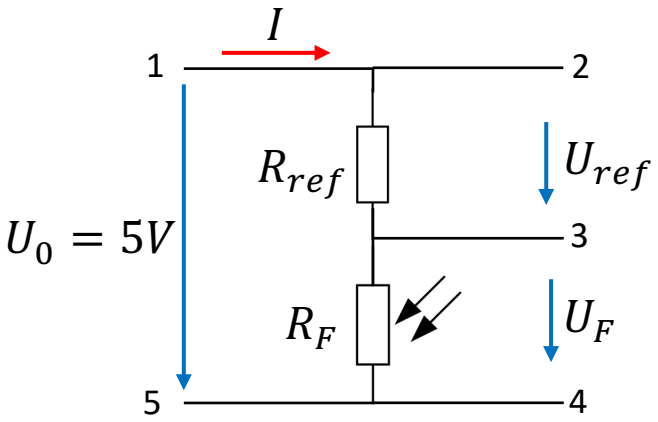
$U_0 = 5V$
$R_1 = 100\Omega$
$U_1 = ?$
$I = ?$



$U_0 = 5V$
$R_1 = 200\Omega$
$U_1 = ?$
$I = ?$

- An Arduino cant measure current directly, only voltage

Voltage divider for photoresistor (analog input)



$$R_{ref} = \sqrt{R_{min} \cdot R_{max}}$$

$$R_{ref} = 4{,}7k\Omega$$

$$R_F = 2 \ldots 11k\Omega$$

$2k\Omega$ at brightness

$11k\Omega$ at darkness

$$U_{F\,R_{min}} = U_0 \cdot \frac{R_F}{R_{ref} + R_F} = 5V \cdot \frac{2k\Omega}{4{,}7k\Omega + 2k\Omega} = 1{,}49V$$

$$U_{F\,R_{max}} = U_0 \cdot \frac{R_F}{R_{ref} + R_F} = 5V \cdot \frac{11k\Omega}{4{,}7k\Omega + 11k\Omega} = 3{,}5V$$

$$U_{ref\,R_{min}} = U_0 - U_{F\,R_{min}} = 3{,}51V$$

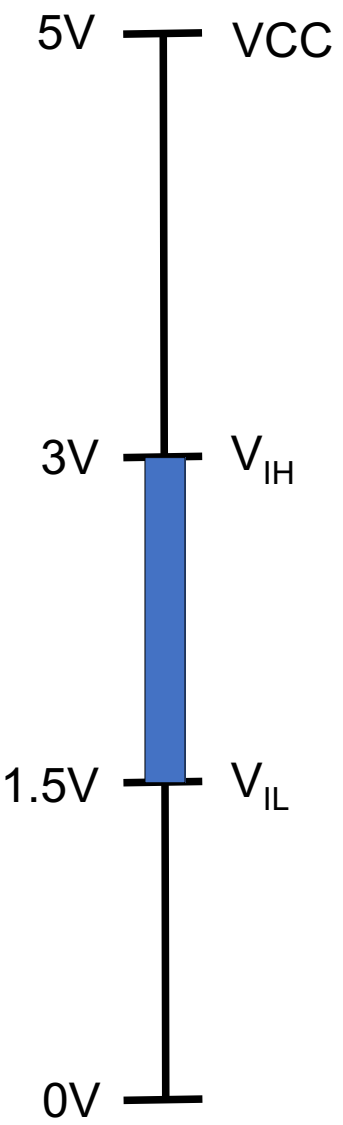
$$U_{ref\,R_{max}} = U_0 - U_{F\,R_{max}} = 1{,}5V$$

To which pin of the Arduino you need to connect point 1 and 5?

Which point (2, 3 or 4) should you connect to the Arduino to measuring the level of brightness? And which Arduino pin do you use?

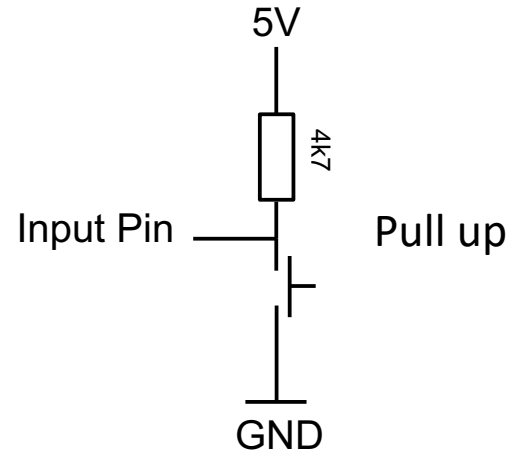
Digital inputs

- A digital pin can have two states: LOW or HIGH
- The voltage have to be greater than 3V to set the pin HIGH
- The voltage have to be lower than 1.5V to set the pin LOW
- The range 1.5V and 3V is undefined
- If the pin isn’t connected to anything is somewhere between LOW and High
  - EMF and induction can cause weird errors
  - While using buttons/switches use pull up or pull down resistor to set the input on a defined level when the circuit is open

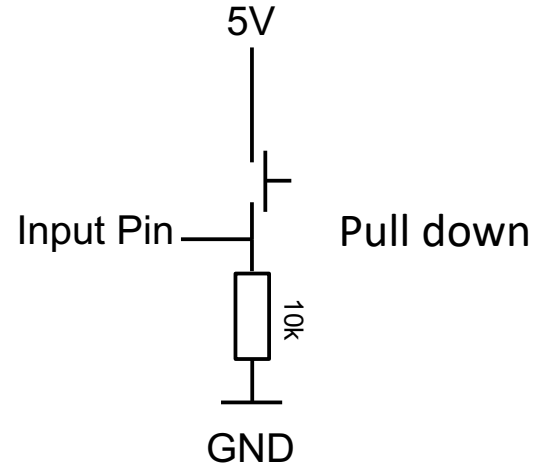


Pull up / pull down resistor

- Pull up
  - Between VCC and Input
  - In open state => the resistor pulls up the input to 5V
  - In closed state => the button pulls the input down to ground



- Pull down
  - Between Input and ground
  - In open state => the resistor pulls down the input to ground
  - In closed state => the button pulls the input up to 5V



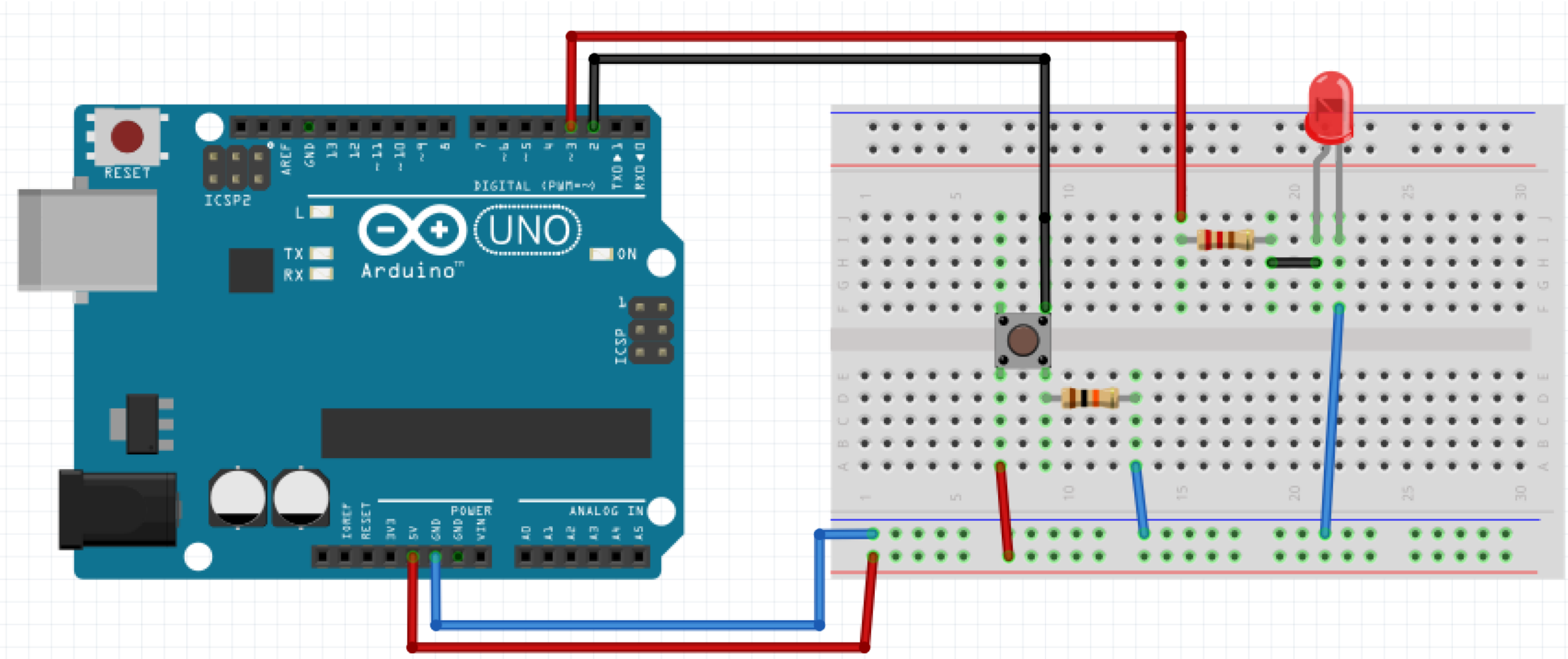
- Arduinos have a built in pull up
  - The built in pull up can be used by configuring a digital pin with pinMode(pin_number, INPUT_PULLUP)

Hands on!

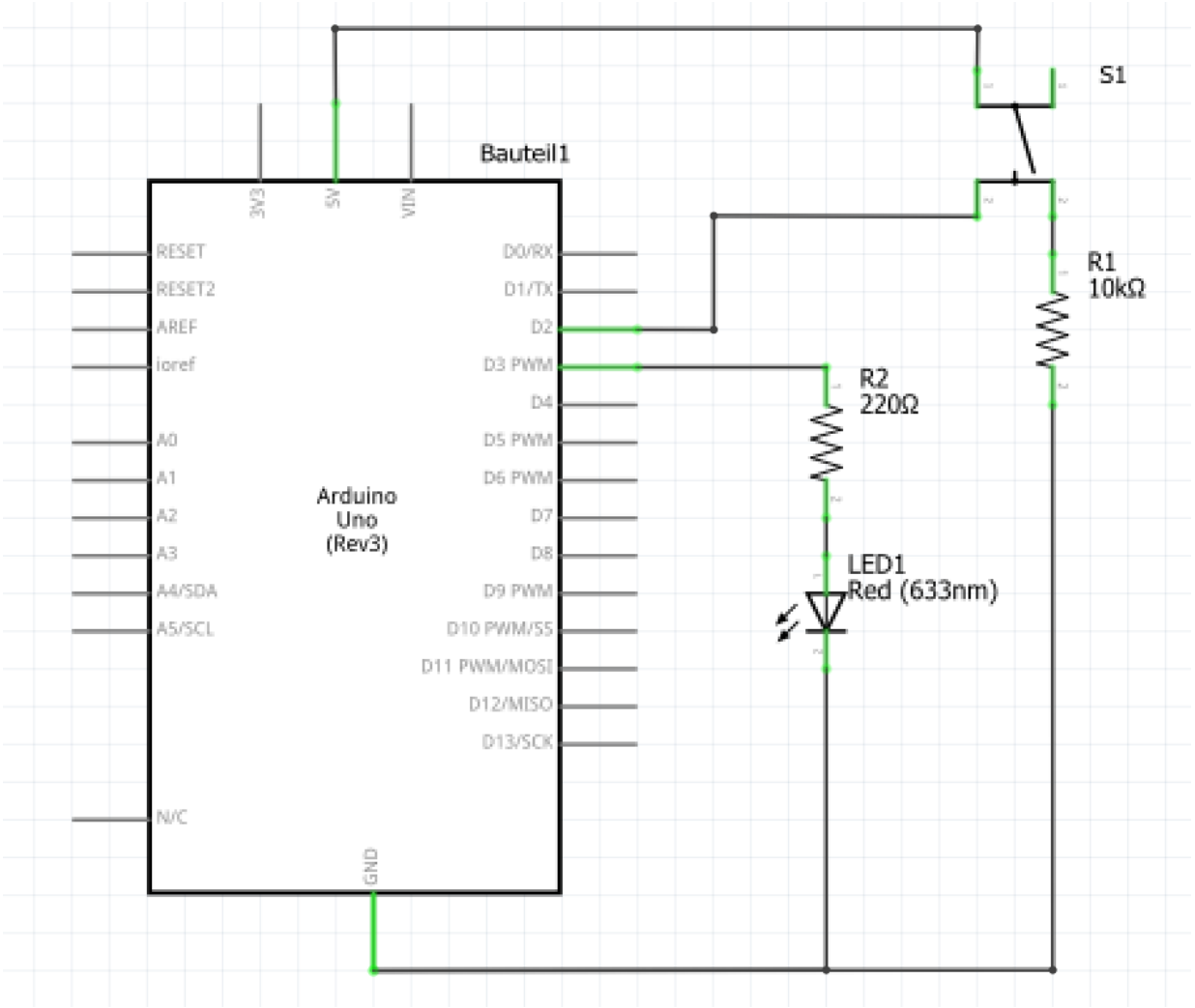
- Goal: control a LED with a button
  1. LED is on when the button is pressed
  2. LED is 5 seconds on after the button is pressed, doesn't matter how long it is pressed
  3. LED toggles each time you press the button, not on release

- Steps:
  - Create an electronic circuit
  - Connect electronic circuit with Arduino board
  - Write code to control the LED with the button
  - Upload code to the Arduino board

Wiring the circuit



Schematic


Bauteil1
3V3
5V
VIN
RESET
RESET2
AREF
ioref
A0
A1
A2
A3
A4/SDA
A5/SCL
N/C
GND
D0/RX
D1/TX
D2
D3 PWM
D4
D5 PWM
D6 PWM
D7
D8
D9 PWM
D10 PWM/SS
D11 PWM/MOSI
D12/MISO
D13/SCK
Arduino
Uno
(Rev3)
S1
R1
10kΩ
R2
220Ω
LED1
Red (633nm)

Methods to get the job done

- void setup() and void loop()
- void pinMode(pin, mode);
  - pin: the pin number
  - mode: INPUT, OUTPUT, or INPUT_PULLUP
- void digitalWrite(pin, value);
  - pin: the pin number
  - value: HIGH or LOW
- int digitalRead(pin);
  - pin: the pin number
  - Returns: LOW or HIGH
- void delay(time);
  - time: time in milliseconds

- One possible solution (1)

```
int ledPin = 3;          // choose the pin for the LED
int inputPin = 2;        // choose the input pin (for a pushbutton)
int buttonValue = 0; // variable for reading the pin status, HIGH=pressed, LOW=released

void setup()
{
  pinMode(ledPin, OUTPUT);          // declare LED as output
  pinMode(inputPin, INPUT);         // declare pushbutton as input
}

void loop()
{
  buttonValue = digitalRead(inputPin);          // read input value
  digitalWrite(ledPin, buttonValue);
}
```

- One possible solution (2)

```
int ledPin = 3;                 // choose the pin for the LED
int inputPin = 2;               // choose the input pin (for a pushbutton)
int buttonValue = 0;            // variable for reading the pin status, HIGH=pressed, LOW=released
int previousButtonValue = 0;
int timeLEDon = 5000;           // in ms

void setup()
{
  pinMode(ledPin, OUTPUT);  // declare LED as output
  pinMode(inputPin, INPUT);  // declare pushbutton as input
}

void loop()
{
  buttonValue = digitalRead(inputPin);     // read input value
  if(previousButtonValue == LOW && buttonValue == HIGH)
  {
    digitalWrite(ledPin, HIGH);
    delay(timeLEDon):
    digitalWrite(ledPin, LOW);
  }
  previousButtonValue = buttonValue;
}
```

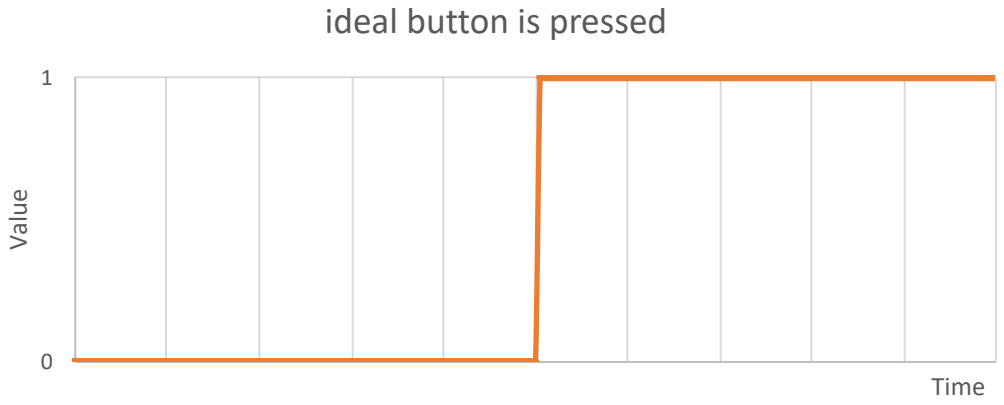
- Why is this solution bad?
- What is happening if the button is pressed a second time in this 5 seconds?
- What would happen if there would be two LEDs with one button each and the same behavior?

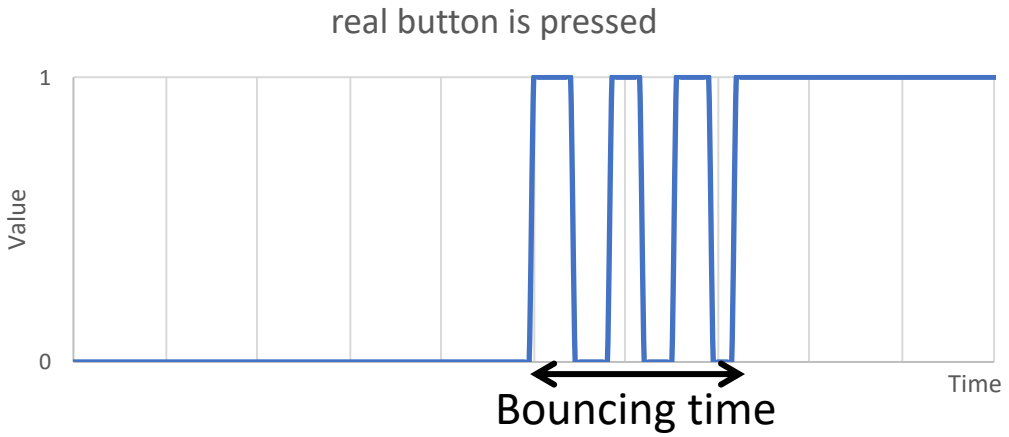
- One possible solution (3)

```
int ledPin = 3;           // choose the pin for the LED
int inputPin = 2;         // choose the input pin (for a pushbutton)
int buttonValue = 0;   // variable for reading the pin status, HIGH=pressed, LOW=released
int previousButtonValue = 0;
int ledState = 0;         // variable for storing the LED state

void setup()
{
  pinMode(ledPin, OUTPUT);  // declare LED as output
  pinMode(inputPin, INPUT);   // declare pushbutton as input
}

void loop()
{
  buttonValue = digitalRead(inputPin);     // read input value
  if(previousButtonValue == LOW && buttonValue == HIGH)
  {
   ledState = !ledState;                        // toggle ledState
    digitalWrite(ledPin, ledState);
  }
  previousButtonState = buttonState;
}
```

Did everything work?

- Maybe not
- One reason could be the bouncing of buttons
- Mechanical buttons physically vibrate - bounce - when they are first pressed or released.
- This creates spurious state changes that need to be filtered or "de-bounced".
- Bouncing time depends on the button, mostly under 20 ms, can be higher





Hands on!

- Goal: include some kind of debouncing

- Steps:
  - Use previous circuit
  - Do it manually
    - Detect a signal edge and wait for a couple of milliseconds
    - After that, process the input as usually
  - Or use Bounce library or Button library
    - Bounce library: https://playground.arduino.cc/Code/Bounce
    - Button library: https://playground.arduino.cc/Code/Button

Simple manually debounce

```
int debouncingTime = 20; // in ms
int buttonValue = 0;    // variable for reading the pin status, HIGH=pressed, LOW=released
int previousButtonValue = 0;

void setup() {
  pinMode(inputPin, INPUT);              // declare pushbutton as input
}

void loop(){
  if(millis() - startDebounceTime > debouncingTime){
    buttonValue = digitalRead(inputPin);    // read input value
    if(buttonValue != previousButtonValue){
      startDebounceTime = millis();
     }
     previousButtonValue = buttonValue;
   }
}
```