# Physical Computing with the Raspberry Pi PICO

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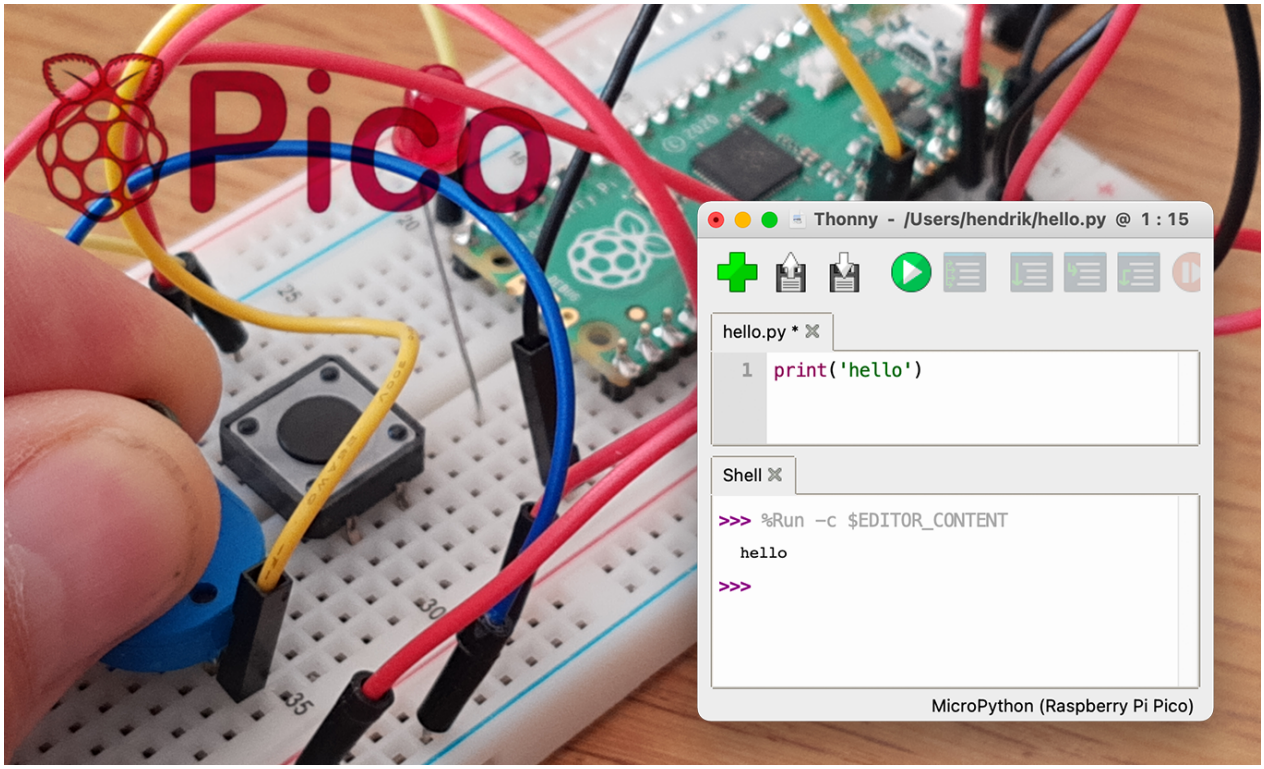
This tutorial is based on the official guide "Get Started with MicroPython on Raspberry Pi Pico". You you can download a PDF version for free.

👋🏼 Hi, welcome 👋🏼

You will learn the basics of physical computing [1] with this powerful microcontroller board. This includes learning to know and setting up the workflow, reading and reproducing circuits, program the Pico with MicroPython, …




▶ TOC 👈🏼 Click to expand

# 1. Introduction

You probably have lots of microcontrollers in your house already. There's a good chance your washing machine is controlled by a microcontroller, and maybe your watch is, and you might find one in your coffee machine or microwave. Of course, all these microcontrollers already have their programs and the manufacturers make it hard to change the software running on them. A Raspberry Pi Pico, on the other hand, can be easily reprogrammed over a USB connection.

Raspberry Pi Pico is a microcontroller development board, meaning simply that it's a printed circuit board housing a special type of processor designed for physical computing: the microcontroller. The RP Pico features the new RP2040 chip.

Raspberry Pi Pico - shortened to Pico - is designed for physical computing projects where it controls anything from LEDs and buttons to sensors, motors, and even other microcontrollers or software running on your computer or a webserver.

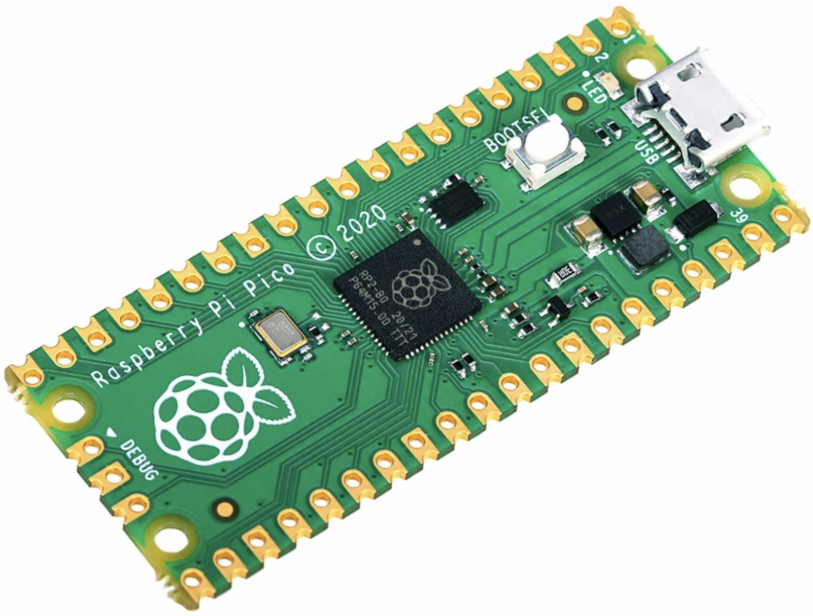
The Pico is programmable in C/C++ and MicroPython. In this tutorial we will focus on MicroPython as it is the fastest and more straightforward way to get started.

MicroPython is an implementation of the Python programming language. It offers the same friendly syntax, as Python, and allows full control over Pico's features. If you've programmed with Python before, you'll find MicroPython immediately familiar. If not, don't worry: it's a friendly language to learn!

See also this Quick MicroPython reference for the Raspberry Pi Pico.

# 2. the Raspberry Pi Pico Board

This is a Raspberry Pi Pico. Let's call it the Pico to keep it short.

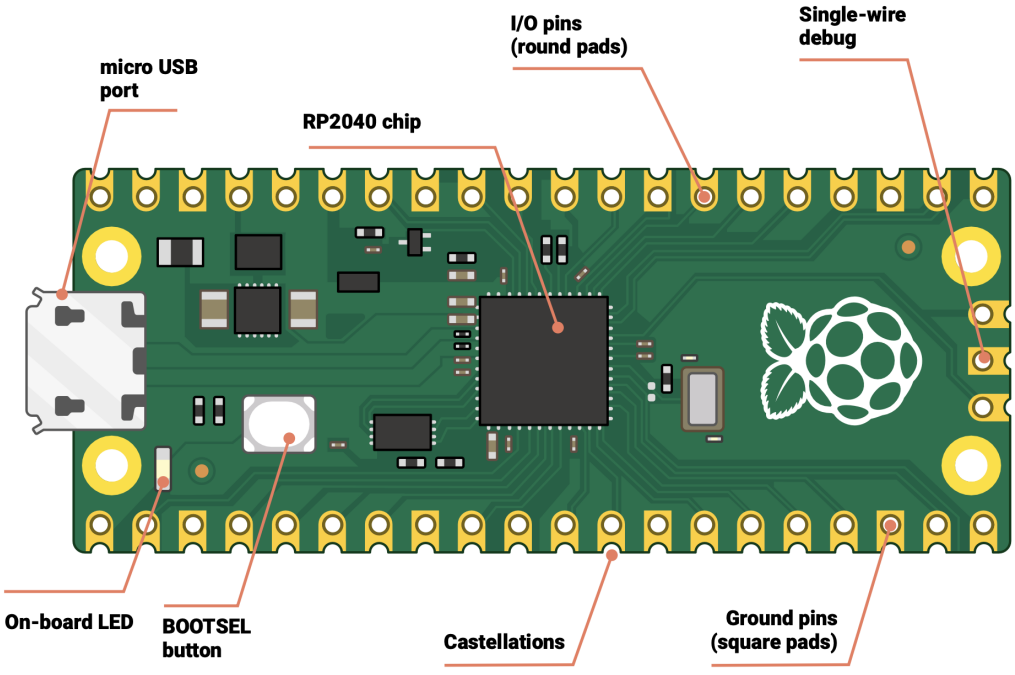



The gold-coloured sections at the outer edge of the board are **the pins** which provide the microcontroller with connections to the outside world – known as general purpose input/output (GPIO) Pins.

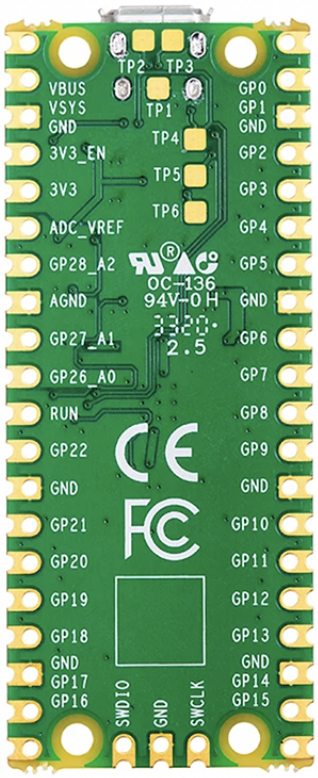
The chip at the centre of your Pico is a **the RP2040 IC**.

At the top of your Pico is a **micro USB port**. This provides power to make your Pico run, and also lets Pico talk to a computer via its USB
port – which is how you'll load your programs onto your Pico.

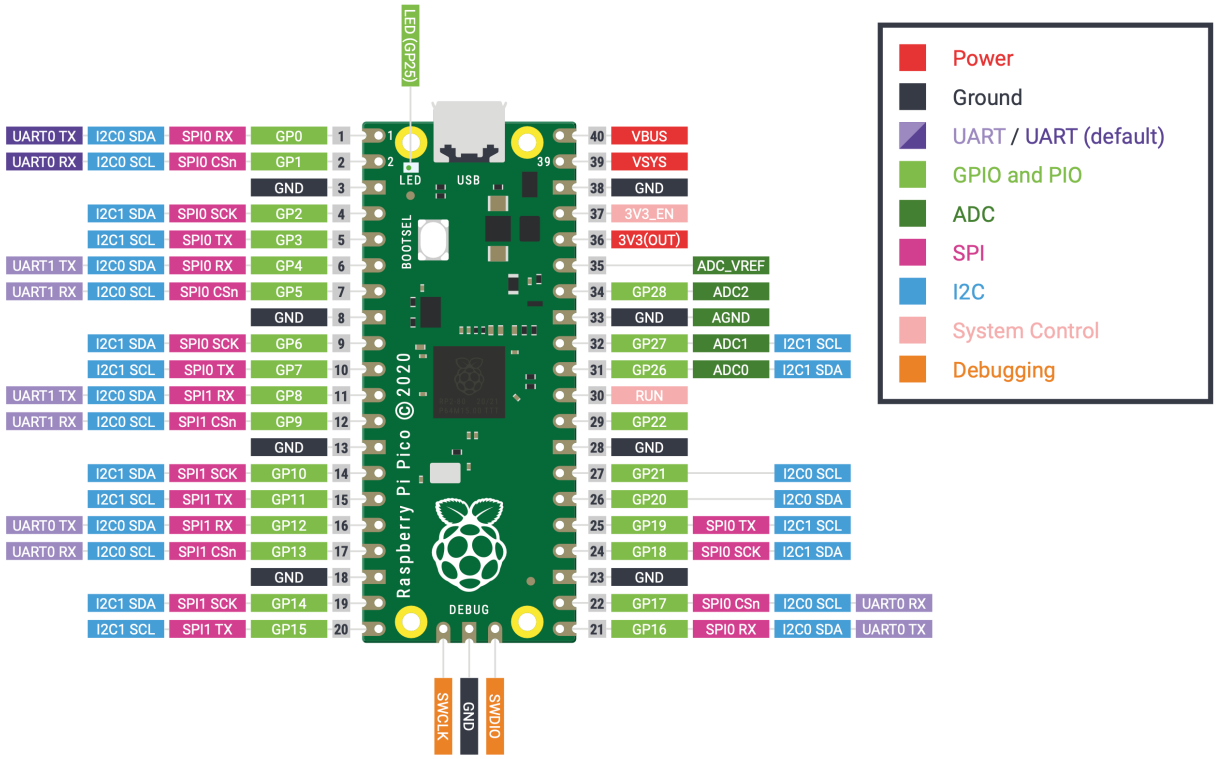
Just below the micro USB port is a **small button** marked '**BOOTSEL**', short for 'boot selection'. This switches your Pico between two start-up modes when it's first switched on. You'll use the boot selection button later, as you get your Pico ready for programming with MicroPython.




At the bottom of your Pico are three smaller gold pads with the word '**DEBUG**' above them. These are designed for debugging programs running on the Pico.




Now, turn your Pico over. You'll see the underside has writing on it. This is known as a silk-screen layer, and **labels** each of the pins with its core function. You'll see things like 'GP0' and 'GP1', 'GND', 'RUN', and '3V3'. If you ever forget which pin is which, these labels will tell you – but you won't be able to see them when the Pico is pushed into a breadboard. Therefore the following diagram might come in handy.




Wait. What is a breadboard? See here.

By soldering male pin headers in place pointing downwards, you can push your Pico into the breadboard to make connecting and disconnecting new hardware as easy as possible – great for experiments!

You can follow this guide to if you need to solder the pin headers. You'll need a soldering iron, some solder, a cleaning sponge, your Pico, and two 20-pin male header strips. If you already have a solderless breadboard, you can use it to make the soldering process easier.

## 3. the MicroPython Firmware

You can program your Pico by connecting it to a computer via USB, then dragging and dropping a file onto it.

1. Download the MicroPython UF2 file.
2. Push and hold the BOOTSEL button and plug your Pico into the USB port of your Raspberry Pi or other computer. Release the BOOTSEL button after your Pico is connected.
3. It will mount as a Mass Storage Device called RPI-RP2.
4. Drag and drop the MicroPython UF2 file onto the RPI-RP2 volume. Your Pico will reboot. You are now running MicroPython.

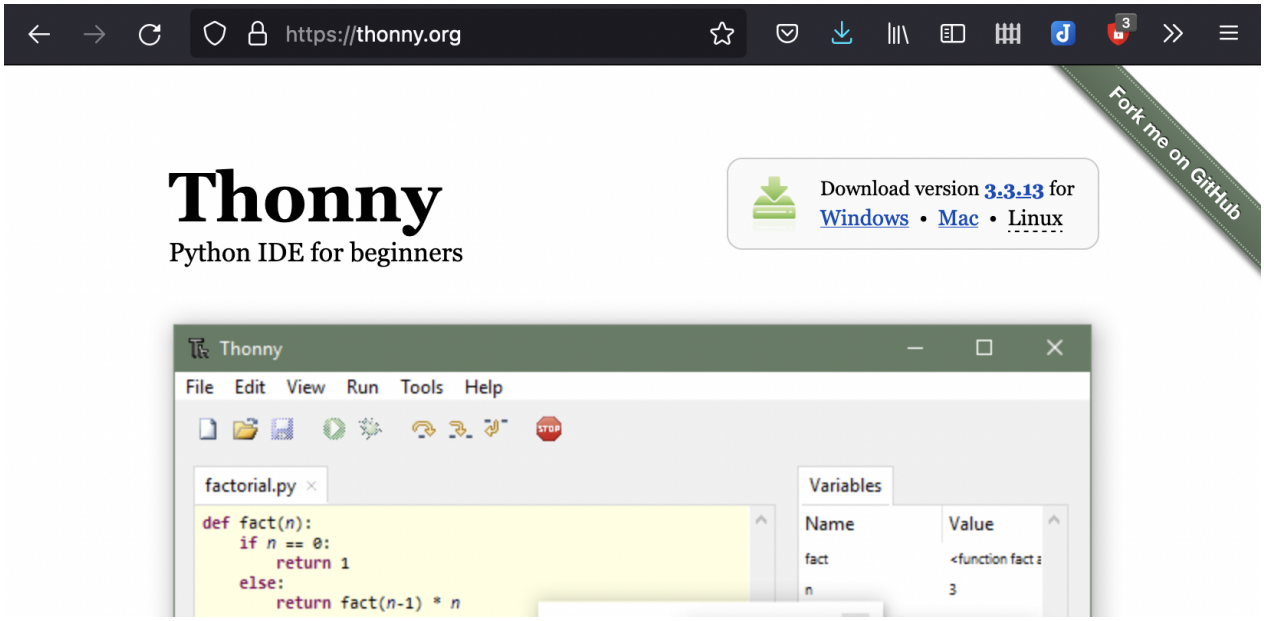
**Alternatively** you can get a copy of the MicroPython UF2 file from a webpage[2] linked from INDEX.HTM that is on RPI-RP2 flash memory and copy it to your RPI-RP2 drive. Or you could use the tool provided in Thonny > follow this guide.

See also this Quick MicroPython reference for the Raspberry Pi Pico.

## 4. the Software

### Bring Thonny in

An easy way to program in MicroPython on your Pico is with Thonny, a Python IDE (integrated development environment) for learning and teaching programming.

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Make sure you download and install the latest version of Thonny as the Raspberry Pi Pico interpreter is not available on older versions.

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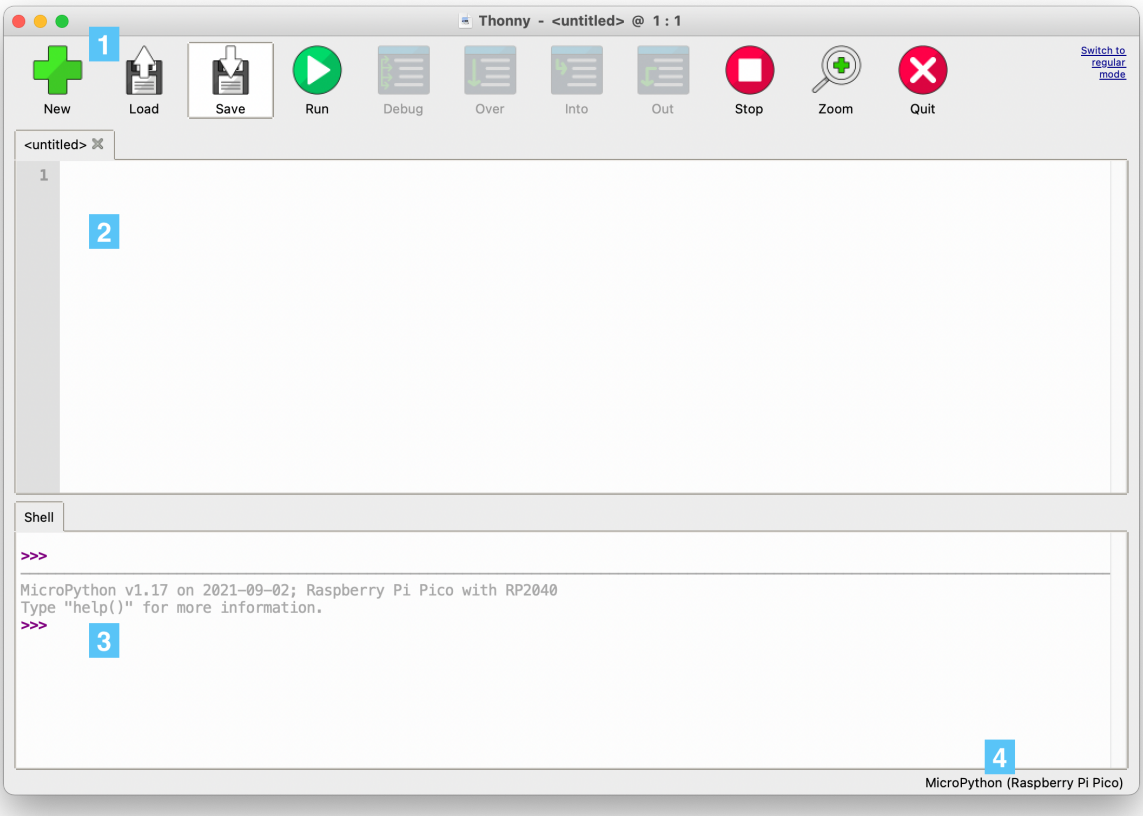
## a Walk through the Thonny UI




1. the *Toolbar** offers an icon-based quick-access system to commonly used program functions, like saving, loading, and running programs.

2. the **Script Area** is where your Python programs are written. It is split into a main area for your program and a small side margin for showing line numbers.

3. the **Python Shell** allows you to type individual instructions which are run as soon as you press the ENTER key, and also provides information about running programs. This is also known as **REPL**, for 'read, evaluate, print, and loop.'

4. the **Interpreter** at the bottom-right of the Thonny window. It shows, and lets you change, the current Python interpreter or the version of Python used to run your programs.

### 🚣 Linking Thonny to Pico

Thonny is normally used to write programs that run on the same computer you're using Thonny on. To switch to writing programs on your Raspberry Pi Pico, you'll need to choose a new Python interpreter. See point 4 above. Look at the bottom-right of the Thonny window for the word 'Python' followed by a version number: that's your current interpreter.

**Change it to 'MicroPython'**. It will tell you it's version and that it's running on 'Raspberry Pi Pico'.

👏 Congratulations: you're ready to start programming.

## 5. What the Shell! Conversing with (Micro)Python

Your first MicroPython program will be a classic Hello, World!

Click on the Python Shell Area (n°3) at the bottom of the Thonny window, just to the right of the interactive chevron >>> prompt and type the following instruction.

```
print("Hello, World!")
```

Then press the **ENTER** key.

Your program will run instantly. Python will respond, also in the Shell area, with the message 'Hello, World!'. Just as you asked. That's because the Shell is a direct line to the MicroPython interpreter running on your Pico, whose job it is to look at your instructions and interpret what they mean.

We are now in **interactive mode**. You can think of it like a face-to-face conversation with someone: as soon as you finish what you're saying, the other person will respond, then wait for whatever you say next.

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If your program doesn't run but instead prints a 'syntax error' message to the Shell area, there's a mistake somewhere in what you've written. All instructions needs to be written in a very specific way: miss a bracket or a quotation mark, spell 'print' wrong or give it a capital P, or add extra symbols somewhere and it won't run.
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## 6. Over to Script Mode

### 🚣 Switch that LED ON & OFF

The Shell is useful to make sure everything is working and try out quick commands. However, it's better to put longer programs in a file.

Thonny can save and run MicroPython programs directly on your Raspberry Pi Pico.

In this step, you will create a MicroPython program to switch the onboard LED on.

Type the following lines in the main script area (n°2).

```
from machine import Pin
led = Pin(25, Pin.OUT)
led.value(1)
```

Click the Run button to run your code.

Thonny will ask whether you want to save the file on This computer or the MicroPython device. Choose MicroPython device.

Enter blink.py (or something else) as the file name.
👉 You need to enter the .py file extension so that Thonny recognises the file as a Python file.

Thonny will save your program to your Raspberry Pi Pico and run it.

You should see the onboard LED switch on.
Try to switch it off again.

🔍 Okay, what is happening here?! A closer look at the code.

`from machine import Pin`
this tells MicroPython to import (or load) the 'Pin' function from the 'machine' library to the program. It is key to working with MicroPython on your Pico.
`import machine` would also work. It simply loads the whole library (= more memory consumption).

`led = Pin(25, Pin.OUT)`
We start by defining an object called 'led', or a name of your choice, that we will refer to later in the program.
The second part of the line calls the `Pin` function in the machine library. It is designed for handling the Pico's GPIO pins. At the moment, none of the GPIO pins – including GP25, the pin connected to the on-board LED – knows what they're supposed to be doing. The first argument, 25, is the number of the pin you're setting up. The second, Pin.OUT, tells Pico the pin should be used as an output rather than an input.

`led.value(1)`
This line takes the object and sets its value to 1 for 'on'. Obviously, if you set the value to 0 again, it goes 'off'.

Now, try the `led.toggle()` to alternate the output between 0 and 1 more easily.

```
from machine import Pin
led = Pin(25, Pin.OUT)
led.toggle()
```

`toggle()` simply inverts the state of an output on the Pico. So if the output is 1 (or HIGH) and we apply a toggle it goes to 0 (or LOW). This is an ideal function for a Blink program.

## 🏄 ON/OFF in Loop

Wouldn't it be easier if we didn't have to push the Run button all the time? Here comes an **infinite loop** function to the rescue.

To change our program from a definite loop to an infinite loop we need to add the line `while True:` before the `led.toggle()` function.

The colon symbol ( : ) tells MicroPython that the loop itself begins on the next line. To actually include a line of code in the loop, it has to be indented – moved in from the left-hand side of the script area. The next line starts with four blank spaces, which Thonny will have added automatically when you pressed ENTER after typing the colon symbol.

```
from machine import Pin
led = Pin(25, Pin.OUT)
while True:
    led.toggle()
```

If you run the code now, you will notice that the LED does not switch on and off but stays on. That is not quite the case. In fact, the code does exactly what we asked it to do, but the on and off switching is so fast that we don't notice it. That's because Pico works far more quickly than you can see with the naked eye.

To fix that, you need to slow your program down by introducing a delay by importing the time library at the start and adding a one-second sleep delay to the loop (you'll learn more about this library later). Your program should now look like this:

```
from machine import Pin
import time
led = Pin(25, Pin.OUT)
while True:
    led.toggle()
    time.sleep(1)
```

# 7. Let's Get Physical

Let's get on with some real physical computing and learn more about Pico's pins and electronic components we can connect and control.

## Your Pico's Pins

Most pins on the Picop work as a input/output (GPIO) pin. You can program them to act as an input or an output. Some pins have extra features and alternative modes for communicating with more complicated hardware, as analog in or PWM, but more in this later on. And other pins have a fixed purpose as providing connections for power.

We will generally refer to a pin by it's function and not the physical pin number.

Below the most important **pin-functions**.

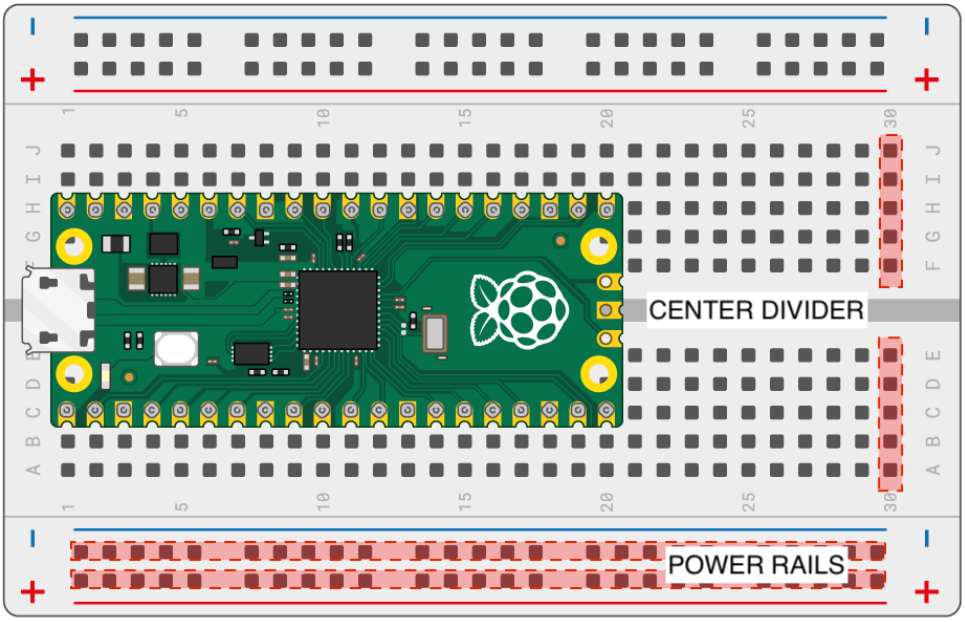
| | | |
|---|---|---|
| 3V3 | 3.3v power | your Pico runs at 3.3v internally |
| VSYS | ~2-5v power | pin directly connected to your Pico's internal power supply |
| VBUS | 5v power | 5v power taken from the Pico's micro USB port > used to power components that need more than 3.3v |
| GND | 0v ground | a ground connection, used to complete a circuit connected to a power source |
| GPxx | General Purpose Input/Output pin number 'xx' | GPIO pins labelled 'GP0' to 'GP28' |
| GPxx_ADCx | GPIO pin number 'xx', with analog input number 'x' | These can pins can also be used as an analog input |

## Common Components

The following a handful of common components that we will use in the following circuits.

## breadboard

A breadboard, also known as a solderless breadboard, is a small plastic board full of holes, each of which contains a spring-loaded contact (in metal). You can push a component's leg into one of the holes, and it will establish an electrical connection with all of the other holes in the same vertical column of holes. Many breadboards also include sections for power distribution, making it easier to build your circuits.




If you want some extra help check this: How to Use a Breadboard

## wires

The wire used to connect components. They come in a wide range of sizes and types. There are 2 main varieties; solid core or stranded. Solid core is stiffer, stranded wire is more flexible. We will use jumper wires, also known as jumper leads on our breadboard.

## switches

Switches pass or interrupt the flow of electricity. You can attach wires to 2 contacts and they are put in contact by activating the switch. Switches can be momentary and toggles switches. A toggle switch stays in it last position. A momentary switch (or pushbutton) spring back to their default position. We will use the latter.

## light-emitting diodes (LED)

LED's are the most common for of output from a microcontroller as they need very little power to be turned on. A LED is a diode that emits light. We need to understand how a diode operates.
A diode is like a one-way street: it only allows electricity to flow in one direction. In other words diodes are polarized. The 2 sides of a diode are called a cathode (-) and an anode (+).

## resistors

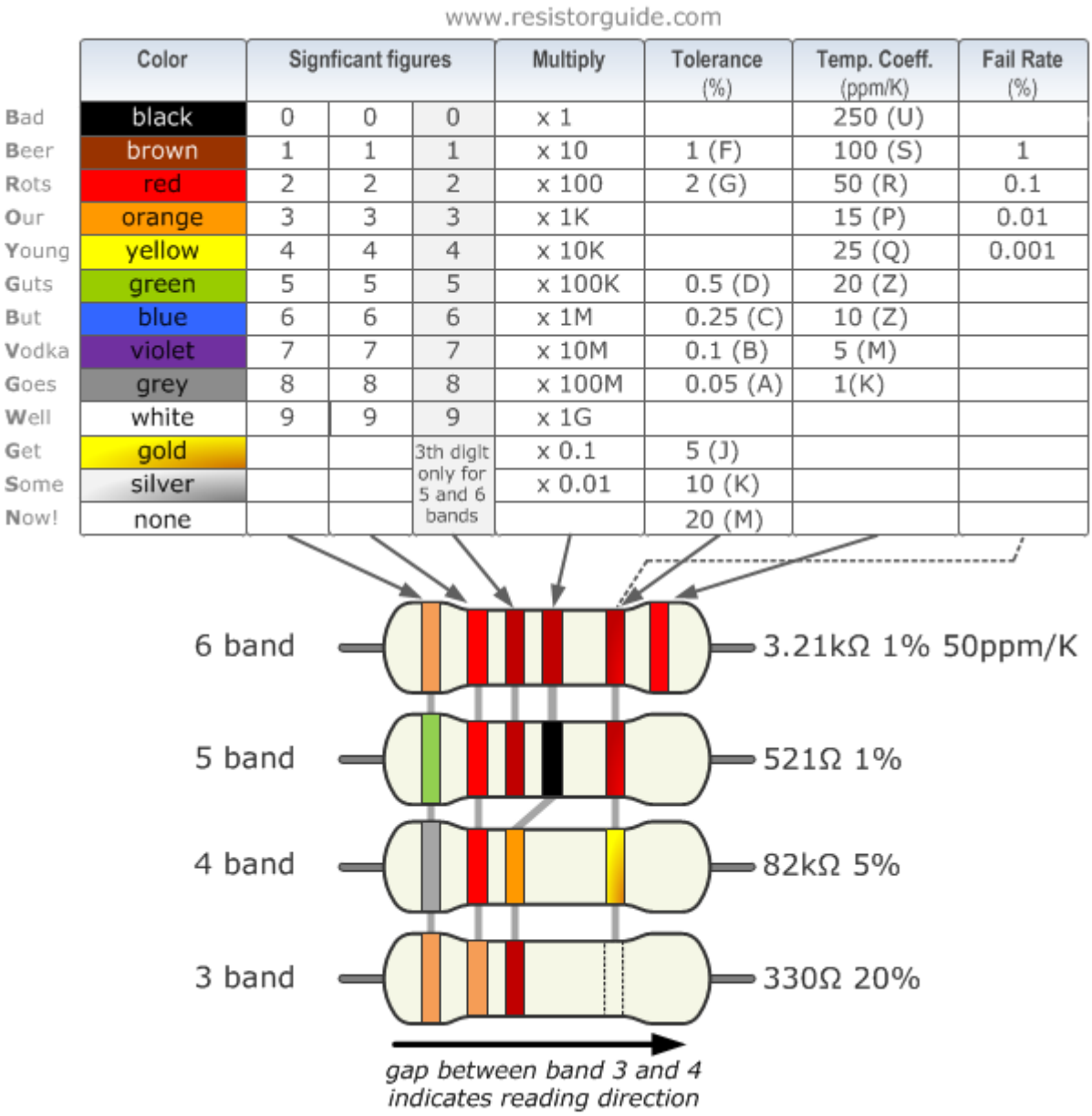
Resistors give electricity something to do: the convert electricity to heat. In this way, they prevent the infamous short circuit. Resistors have 2 leads and no polarity.
Resistors are rated in Ohms (Ω), indicating how much resistance they offer. Below you can learn to read the colour codes.

### potentiometers

Potentiometers, or pots for short, are variable resistors. Potentiometers have three legs. The power of a potentiometer is in the middle leg. It's resistance varies depends on the potentiometer's rotating (or sliding) contact (the wiper) position. It is best to use it as a voltage divider with our Pico. This means we have all 3 contacts connected: 1 to GND (or 3v3), 2 to ADC, 3 to 3V3 (or GND).
Other common variable resistors are photocells (LDR), termistors, force-sensitive (FSR) and bend-sensors. These are all two-legged (or "two-lead"). In order to make them work optimally on our Pico we need to add a 2nd resistor (later more).

See also https://makeabilitylab.github.io/physcomp/electronics/

## Reading Resistor Colour Codes



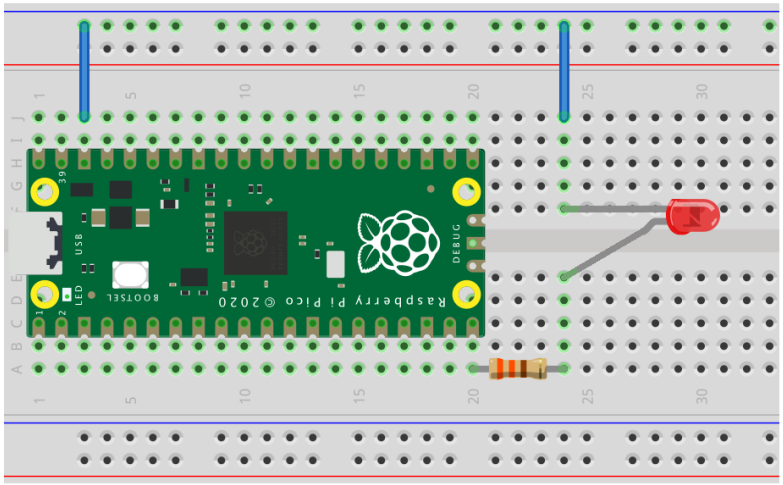

# 8. Wiring Diagrams & Schematics

Our next step is to wire an external LED to the board using a breadboard. I could explain you here in steps how to make the connections - *the anode (longest) leg of an LED is connected to GP 15 on the Pico with a 330Ω resistor (220Ω works fine too),*

*the negative or cathode (shortest) leg of the LED is then connected Ground* - but wouldn't it be much easier to draw you a schematic or drawing with the wires and components connected to the Pico plugged into the breadboard?!

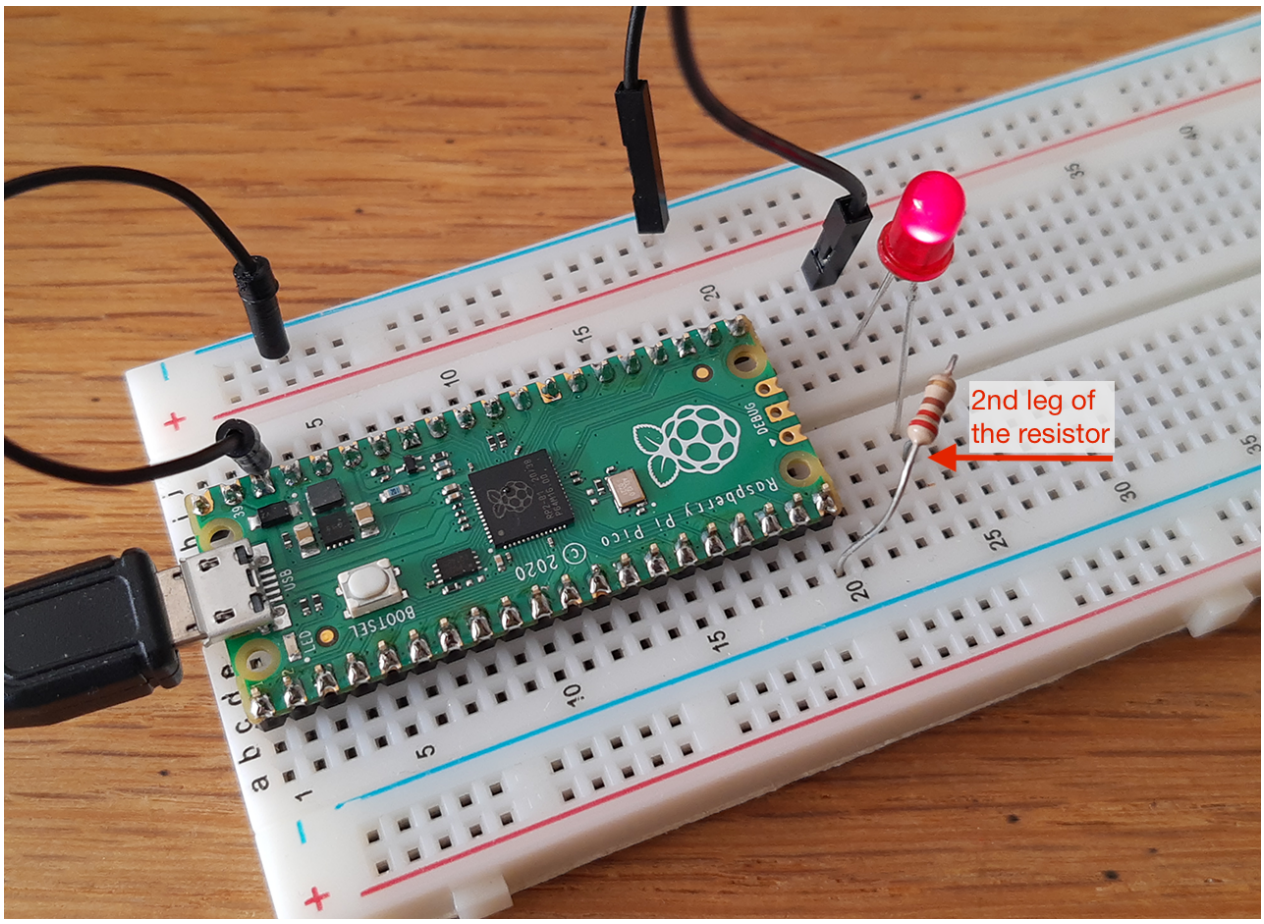
Being able to read these schematics and diagrams is a very important part of building circuits. Schematics are universal pictograms that allow people all over the world to understand and build electronics. Every electronic component has a very unique schematic symbol. These symbols are then assembled into circuits using a variety of programs. You could also draw them out by hand. If you want to dive deeper in the world of electronics and circuit building, learning to read schematics is a very important step in doing so.

Below is the schematics for the above circuit and, at the right, a much easier to read and wire diagram (made with Fritzing). We will mainly use this kind of wiring diagams in this tutorial.




Have a look at this more elaborate tutorial How to Read a Schematic.

So our after wiring pico and components on the breadboard according to the schematic (and wiring diagram) it will look more or less like this:




## 9. Next Level LED Blinking.

Controlling an external LED in MicroPython is no different to controlling your Pico's internal LED: only the pin number changes. Find the line:
`led_onboard = machine.Pin(25, machine.Pin.OUT)` and change 25 to 15.

```
from machine import Pin
import time
led = Pin(15, Pin.OUT)
while True:
    led.toggle()
    time.sleep(1)
```

Is it working? Great!
Some challenges: Can you modify the program to light up both the on-board and external LEDs at the same time? Can you write a program which lights up the on-board LED when the external LED is switched off, and vice versa?

## 10. a Pushbutton 👉 Digital Inputs

In prior examples, the LED was our actuator, and our Pico was controlling it. If we image an outside parameter to take control over this LED, our finger for example, we need **a sensor**. The simplest form of sensor available is …

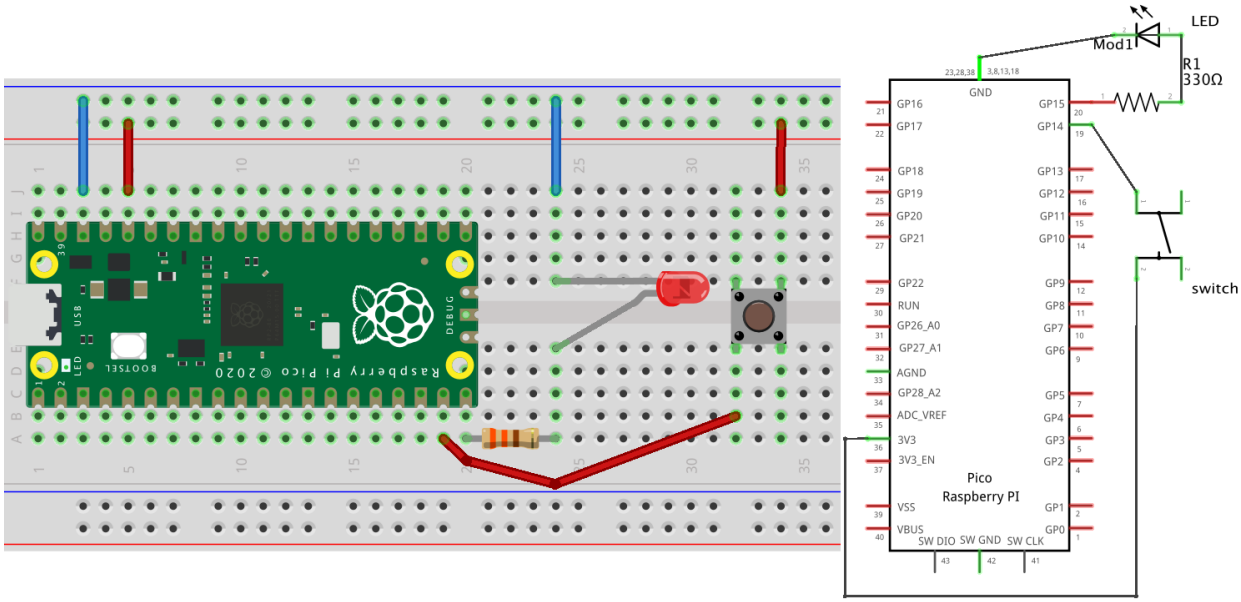
### 🏄 a Pushbutton

Let's make our wiring diagram first.

## Circuit

- LED anode (long leg) connected to pin 15 using a 330Ω (or 220Ω) resistor
- LED anode connected to ground (GND)
- one leg of the pushbutton connects to pin 14
- the other leg need to connect to the Pico's 3V3 pin (you can use the powerrail to do so)

If you're using a pushbutton with four legs, your circuit will only work if you use the correct pair of legs. So you need to either use the two legs on the same side or (as on the diagram below) diagonally opposite legs.




## Code

```
from machine import Pin
import time

led = Pin(15, Pin.OUT)
button = Pin(14, Pin.IN, Pin.PULL_DOWN)

while True:
    if button.value() == 1:
        print("you pressed the button")
        led.value(1)
        time.sleep(5)
    led.value(0)
```

Click the Run icon and save the program on your Pico. Nothing will happen until you push the button. The LED will light up. Let go of the button. After 5 seconds, the LED will go out again until you press the button again.

🔍 **A closer look at the code**
Now here is `if` instruction followed by an `==` in the while loop. That is very important in programming. It allows the computer to test a condition and make decisions accordingly.

Notice the difference between the `==` sign and the `=`. The former is used when two entities are compared, and returns TRUE or FALSE. The latter assigns a value to a variable.

There's also !=, which means not equal to – it's the exact opposite of ==. These symbols are technically known as comparison operators.

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Unlike an LED, a push-button switch doesn't need a currentlimiting resistor but it does still need a resistor, though. It needs what is known as **a pull-up or pull-down resistor**, depending on how your circuit works. Without a pull-up or pull-down resistor, an input is known as **floating**. This means it has a 'noisy' signal which can trigger even when you're not pushing the button.
The resistor in this circuit is hidden in your Pico. Just like it has an onboard LED, your Pico includes an on-board programmable resistor connected to each GPIO pin. These can be set in MicroPython to pull-down resistors or pull-up resistors as required by your circuit.

*What's the difference?* A **pull-down** resistor connects the pin to **ground**, meaning when the push-button is **not pressed**, the input will be **0**.
A **pull-up** resistor connects the pin to **3V3**, meaning when the push-button is **not pressed**, the input will be **1**.

We will use the programmable resistors in the pull-down mode.
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## 🏄 One Circuit Multiple Behaviours

Lets program **a second behaviour** that to make the on button "stick". The `.toggle` function is convenient for this application but we must also implement some form of 'memory', in the form of a software mechanism that will remember when we have pressed the button and will keep the light on even after we have released it.

```
from machine import Pin
import time

led = Pin(15, Pin.OUT)
button = Pin(14, Pin.IN, Pin.PULL_DOWN)

last_state = False
current_state = False

while True:
    current_state = button.value()

    if last_state == 0 and current_state == 1:
        led.toggle()

    last_state = current_state
```

What is happening here?

- First we declare 2 variables: `last_state = False` because the button is not pressed when we start the program and also `current_state = False` for that same reason.
  In the loop we:
- read the current state of the button
- then we check if the following condition is met: current state equals (use **==** and not =) 1 (meaning the button is pressed) but also the last state equals 0 (meaning the button was not pressed before)
- then we toggle the LED ON or OFF.
- Finally, we write the value of the current state variable in the past state variable.

Now the LED switches ON/OFF the Rising edge, meaning when we push the button. You can change the behaviour to switch the LED on the Falling edge or when you release the button with this line `if last_state == 1 and current_state == 0:`

## 🔶 a Pushbutton with Interrupt (optional)

An **Interrupt** is pretty much like it sounds like, an event that *interrupts* the normal flow of a program. In our case we are dealing with external hardware interrupts, meaning that a signal or change of state has occurred that needs to be addressed before the program can continue.

On the Pico we create an Interrupt as follows:

- We define a pin as being *the interrupt input*, and we define what change of state on that point is considered to be an interrupt. On the Pico, we can use any GPIO pin for this, and we can define multiple.
- Then we create an *interrupt handler* function, something we want to run when an interrupt is detected.
- We pair that *interrupt handler* with the *interrupt input*.

Now every time that interrupt input condition occurs the Pico will stop whatever it is doing and will execute the “interrupt handler”. It will then resume where it left off.

```
# import the required libraries
from machine import Pin
import time

# counter for loop
counter = 0

# declare the pin objects
redPin = Pin(15, Pin.OUT)
buttonPin = Pin(14, Pin.IN, Pin.PULL_DOWN)

# interrupt handler function
def alert(pin):
    global counter
    counter += 1
    print("counter = ",counter)
    print("Inside the interrupt handler function")

# attach the interrupt to the buttonPin
buttonPin.irq(trigger = Pin.IRQ_RISING, handler = alert)

while True:
    # turn on green led on
    redPin.value(1) # active low , common anode type led
    time.sleep(0.1)
    redPin.low()
    time.sleep(0.1)
```

### 🎏 Other On/Off Sensors

Now that you’ve learned how to use a pushbutton, you should know that there are other basic sensors that work according to the same *on/off* principle, as:

- **Switches** are just like a pushbutton, but doesn’t automatically change state when released.
- **Thermostats** is a switch that opens when the temperature reaches a set value.
- **Magnetic switches** (or “reed relays”)
  have two contacts that come together when they are near a magnet.
- **Carpet switches** are small mats that you can place under a carpet or a doormat to detect the presence of a human being (or heavy cat).
- **PIR** or Passive InfraRed sensor. This small device triggers when a human being (or other living being) moves within its proximity.
- **Tilt switches** are electronic components that contains two contacts and a little metal ball.
  You can try some!
- …

## 11. Sensors 👉🏻 Analog Inputs

A digital input is either on or off, a binary state. Your Pico can accept another type of input signal with **analog input**. The analog signal can be anything from completely off to completely on – a range of possible values. It works through a piece of hardware

known as an analog-to-digital converter (ADC).
An ADC has two key features:

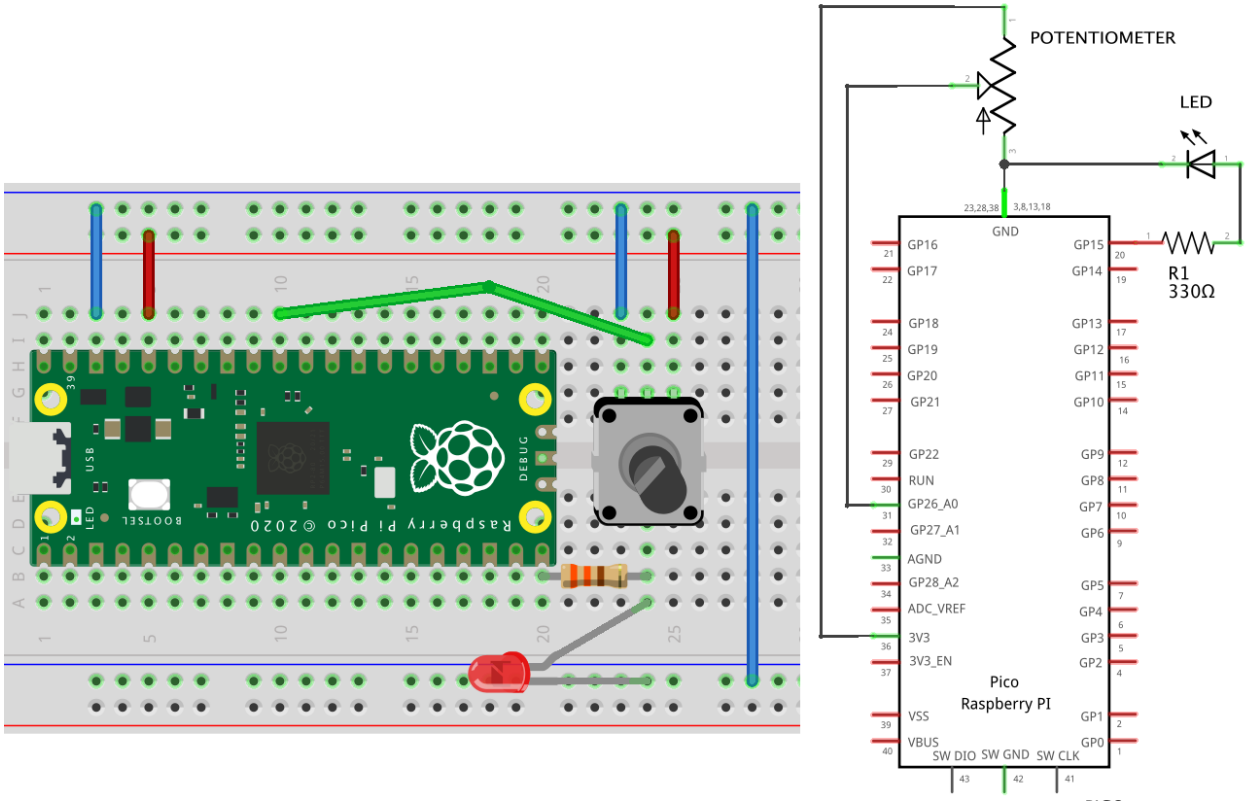
- its resolution, measured in digital bits &
- its channels, or how many analog signals it can accept and convert at once.
  The ADC in your Pico has a resolution of 12 bits, meaning that it can transform an analog signal into a digital signal as a number ranging from 0 to 4095. But - and this is a bit odd - it is transformed to a 16-bit number ranging from **0 to 65.535**, so that it behaves similar as other MicroPython microcontrollers.
  The Pico **3 channels** brought out to the GPIO pins: GP26, GP27, and GP28, which are also known as GP26_ADC0, GP27_ADC1, and GP28_ADC2 for analog channels 0, 1, and 2. There's also a fourth ADC channel, which is connected to a temperature sensor built into RP2040.

## Let's Read the Value of a Potentiometer

The next program & electronics diagram demonstrates analog input by reading an analog sensor, as a potentiometer (or trimpot), on our 1st analog channel (0).

### Circuit

- Wire the middle pin to pin GP26_ADC0 on your Pico, that is pin 10 on top.
- Wire one of the outer pins to GND and the other one to 3V3. *These are interchangeable and determine the functionality of the wiper, e.g. turn to the left to reduce or increase the value.*




We will use the LED in the 2nd experiment.

### Code

```
from machine import Pin, ADC
import time

potentiometer = ADC(Pin(26))
```

```
while True:
    print(potentiometer.read_u16())
    time.sleep(0.05)
    # is similar to time.sleep_ms(50)
```

Reading an analog input is similar identical to reading a digital input but we use the function `read_u16()` and not `value()`. The `_u16` warns that rather than receiving a binary 0 or 1 result, you'll receive a whole number between 0 and 65.535 (called an unsigned 16-bit integer).

You will also notice that we loaded the ADC function from the machine library. Without this function our code will not work. Loading different function in one go needs a comma to separate them.

Notice the comment: `time.sleep(0.05)` is similar to `time.sleep_ms(50)` as 0.05 seconds is equal to 50 milliseconds.

Tip: Thonny has also a built in data plotter window. It visualises numbers and series of numbers printed to the shell.

## 🚀 Controlling the Speed of our Blinking LED with a Potentiometer.

In this 2nd program the value of our potentiometer will now determine the interval of the blinking LED. That speed will actually correspond to the actual voltage that passes through the variable resistor.

### Circuit

as above

### Code

```
from machine import Pin, ADC
import time

potentiometer = ADC(Pin(26))
led = Pin(15, Pin.OUT)
conversion_factor = 3.3 / 65535

while True:
    voltage = (potentiometer.read_u16()) * conversion_factor
    print(voltage)
    led.toggle()
    time.sleep(voltage)
```

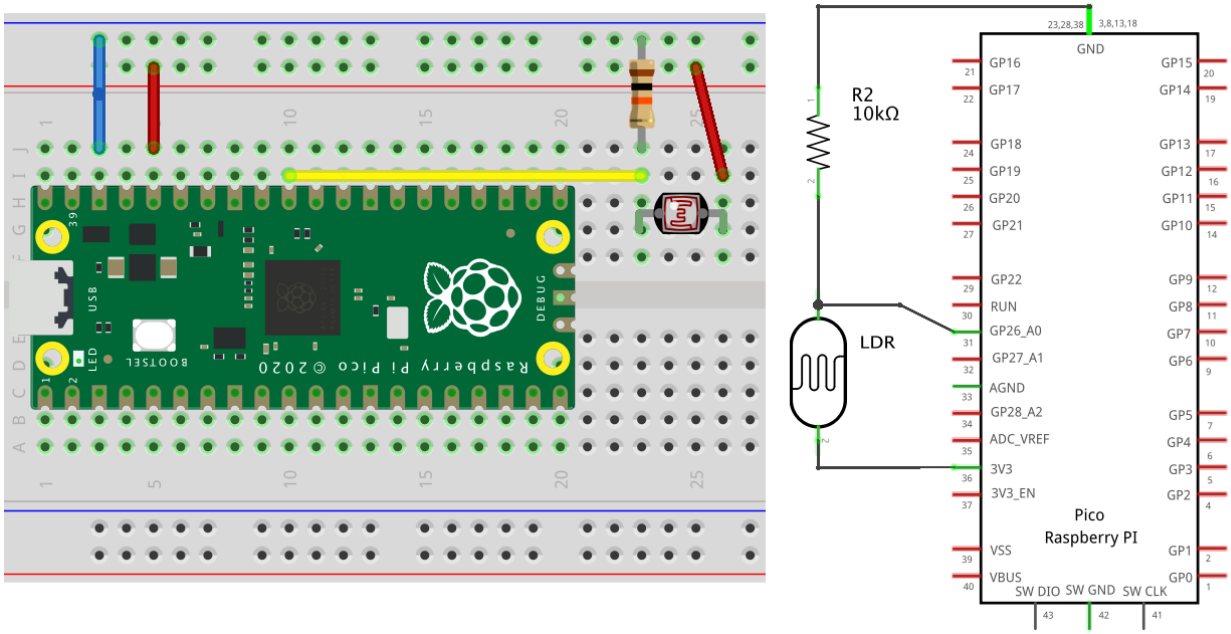
The range of from 0 to 65.535 it's not always handy and user-friendy. With a simple mathematical equation we can fix this adding `conversion_factor = 3.3 / 65535` to our code.
This way the number that the ADC gives is recalculated into an approximation of the actual voltage it represents. 3.3 (or the maximum possible voltage that the pin can expect) divided by 65.535 (or the maximum value the analog input reading can be). If you need a range from 0 to 10 you should use this `10 / 65535` formula.

## 🚀 Other analog sensors

So, analog sensors are basically variable resistors. But only a potentiometer (and other prepared sensor-boards) have 3 legs and function in their own as a voltage divider circuit giving us their full power.

In order to make a voltage divider circuit with a 2-legged analog sensor we need to add an extra resistor (in the range of our variable resistor). In this way the variable and the fixed resistor divide the voltage in two parts. The variable resistor feeds the varying voltage to our ADC-pin and the fixed provides a path to GND.

See the circuit below for an example with a photocell.




Other possible analog sensors are accelerometers, pressure or force sensors, light sensors, sound sensors, temperature sensors, …
There are also many digital sensors nowadays. In digital sensors, the signal measured is directly converted into a digital signal output and transmitted through a digital (serial) protocol.

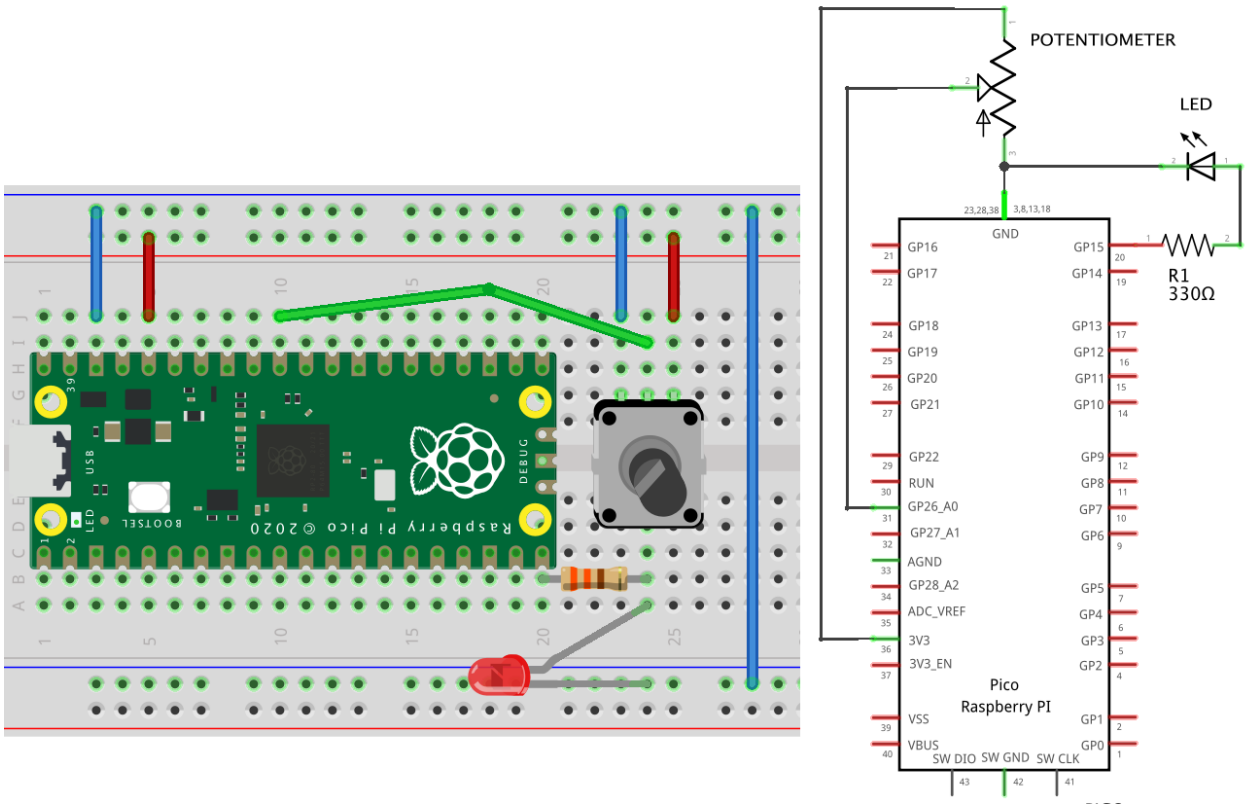
## 12. PWM 👉🏻 Analog Outputs

PWM, short for **Pulse Width Modulation**, is a technique used to encode analog signal level into a digital one.

A microcontroller's digital output can only be on or off, 0 or 1. Turning a digital output on and off is known as a pulse and by altering how quickly the pin turns on and off you can change, or modulate, the width of these pulses – hence 'pulse-width modulation'.
We use it to control dimming of RGB LEDs or to control the direction of a servo motor, sound synthesis, etc.

Every GPIO pin on your Pico is capable of pulse-width modulation, but the microcontroller's pulse-width modulation block is made up of eight slices, each with two outputs.That makes 16 PWM channels in total which can be clocked from 7Hz to 125Mhz.

### 🏄‍♂️ Fading an LED with the Potentiometer & PWM




This is the same circuit as the potentiometer circuit above.

```
from machine import Pin, ADC, PWM
import time

potentiometer = ADC(Pin(26))
led = PWM(Pin(15))

led.freq(1000)

while True:
  led.duty_u16(potentiometer.read_u16())
```

This creates an LED object on pin GP15, but with a difference: it activates the pulse-width modulation output on the pin, channel B[7] – the second output of the eighth slice, counting from zero.

The frequency (led.freq) tells Raspberry Pi Pico how often to switch the power between on and off for the LED.

Click the Run icon and try turning the potentiometer all the way one way, then all the way the other. Watch the LED: this time, unless you're using a logarithmic potentiometer, you'll see the LED's brightness change smoothly from completely off at one end of the potentiometer knob's limit to fully lit at the other.

## Fading an LED IN & OUT with PWM

In this program we remove the potentiometer and set the Pico to fade the led in and out autonomously.

```
from machine import Pin, PWM
import time

led = PWM(Pin(15))

led.freq(1000)
```

```
while True:
    # fade in loop
    for duty in range(65025):
        led.duty_u16(duty)
        time.sleep(0.0001)
    # fade out loop
    for duty in range(65025, 0, -1):
        led.duty_u16(duty)
        time.sleep(0.0001)
```

We welcome a new programming function, **the for loop**. This a definite loop, it will repeat one or more instructions until a end condition is reached.

we decode the fade in loop:

- A variable named *duty*, is assigned to the loop.
- the range instruction with only 1 argument functions as this: `range(max_value)`. It will start at the number 0 and work upwards towards, but never reaching, the number 65025. Each loop or iteration the variable duty will increase; 0, 1, 2, 3, 4, etc
- then the colon symbol ( : ) tells MicroPython that the loop itself begins on the next line.
- in the line `led.duty_u16(duty)` the variable number assigned to the PWM Pin.

The fade out loop is very similar. We need to iterate over a decreasing sequence. We use an extended form of range() with three arguments `range(start_value, end_value, step)`.
So in `for duty in range(65025, 0, -1):`
counting will start at 65025 to 0 decreasing with 1 each loop.

⚡ ⚡ ⚡
But wait why is it only 65025 and not 65535 (or the biggest 16bit number) as seen before. I frankly don't know.
I found this. The duty is 0 to 65025 or 0% to 100%. 65025 is 255*255 (255 times 255) which is probably where that comes from.
¯_(ツ)_/¯
⚡ ⚡ ⚡

### 🚤 Other PWM-controlled Actuators

🚧 🚧 🚧

We can replace the LED with:

- more LEDs, eg. RGB led (and use arrays to define and controls the pins),
  see https://makersportal.com/blog/raspberry-pi-pico-tests-with-micropython
- a servomotor (needs 5v, thus pin 40) see https://circuitdigest.com/microcontroller-projects/control-a-servo-motor-with-raspberry-pi-pico-using-pwm-in-micropython
- a transistor to drive a dc motor (speed), high power LED (brightness), solenoid (push / pull power), …
  see https://learn.adafruit.com/use-dc-stepper-servo-motor-solenoid-rp2040-pico/ (circuitPython ≠ microPython)
- an H-bridge to drive a dc motor driver (speed & direction)
- a stepper driver (basically some transistors) to control a stepper motor.
- …

## 13. Data logger

Turn Raspberry Pi Pico into a temperature data-logging device and untether it from the computer to make it fully portable.

See guide "Get Started with MicroPython on Raspberry Pi Pico" page 104

```
from machine import Pin, ADC
import time
```

```
sensor_temp = ADC(ADC.CORE_TEMP)

conversion_factor = 3.3 / 65535
file = open("temps.txt", "w")

while True:
    reading = sensor_temp.read_u16() * conversion_factor
    temperature = 27 - (reading - 0.706)/0.001721
    file.write(str(temperature) + "\n")
    file.flush()
    time.sleep(10)
```

## File storage

Your Pico has 2MB of flash memory available to store files. This memory is shared between the program it's running (the firmware) and any file storage used by MicroPython (your program files). If you write code that saves a file, as the log-file above, it is also takes up room. How long it takes to fill the storage will depend on how many other files you have and how often your data logger saves a reading.

## Running without a Host Computer

If you want to run your Raspberry Pi Pico without it being attached to a computer, you need to use a USB power supply or through the Pico VSYS power input. It operates safely if voltages are between 1.8V and 5.5V.

To automatically run a MicroPython program, simply save it to the device with the name main.py.

When the Pico boots up it looks for a program titled main.py. If it finds it, then it will load it and run it on startup.

So if you want your program to run unattended you'll need to save it as main.py (all in lowercase). Later on, you can change main.py to another program if you wish, or delete it.

After saving the program "main.py", unplug your Pico from your computer and power into a suitable power source. You should see it spring to life and run the *main* program.

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1. What Is Physical Computing?
All computing is physical. We work with computational systems by taking action with our bodies, on devices. The construction of computing devices, and their use, consumes raw materials and energy as well. In short, the virtual always has physical consequences.
Physical Computing here refers especially to creating or using devices that interact with the world around them. A computer senses its environment (as touch, movement, temperature, …), processes that information, and then performs some action (with lights, motors, …).

2. This webpage also includes a wealth of additional resources. Click on the tabs and scroll to access guides, projects, and the data book collection – a bookshelf of detailed technical documentation covering everything from the inner workings of the RP2040 microcontroller which powers your Pico to programming in both the Python and C/C++ languages.

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