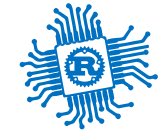
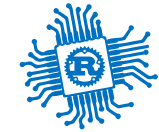


# Introduction

Lecture 1



# Welcome

to the *Microprocessor Architecture* engineering class

## You will learn

- how hardware works
- how to actually build your own hardware device
- the Rust programming Language

## We expect

- to come to class
- ask a lot of questions

# Team

# Our team

## Lectures

- Alexandru Radovici

## Labs

- Irina Niță
- Irina Bradu
- Teodor Dicu
- Andrei Zamfir
- Dănuț Aldea
- Teodora Miu

# Outline

## Lectures

- 12 lectures
- 1 Q&A lecture for the project

## Labs

- 12 labs

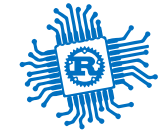
## Project

- Build a hardware device running software written in Rust
- The cost for the hardware is around 150 RON
- Presented at PM Fair during the last week of the semester

# Grading

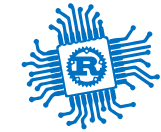
| Part | Description | Points |
|---|---|---|
| Lecture tests | You will have a test at every class with subjects from the previous class. | 2p |
| Lab | Your work at every lab will be graded. | 2p |
| Project | You will have to design and implement a hardware device. Grading will be done for the documentation, hardware design and software development. | 5p |
| Exam | You will have to take an exam during the session. | 2p |
| **Total** | *You will need at least 4.5 points to pass the subject.* | **11p** |

# Subjects



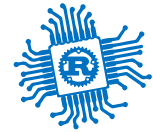
# Theory

- How a microprocessor works
- How the ARM Cortex-M processor works
- Using digital signals to control devices
- Using analog signals to read data from sensors
- How interrupts work
- How asynchronous programming works (async/await)
- How embedded operating systems work

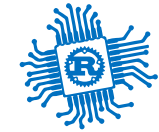


# Practical

- How to use the Raspberry Pi Pico
  - Affordable
  - Powerful processor
  - Good documentation
- How to program in Rust
  - Memory Safe
  - *Java-like features, without Java's penalties*
  - Defines an embedded standard interface *embedded-hal*



# Apollo Guidance Computer



# *We choose to go to the moon*

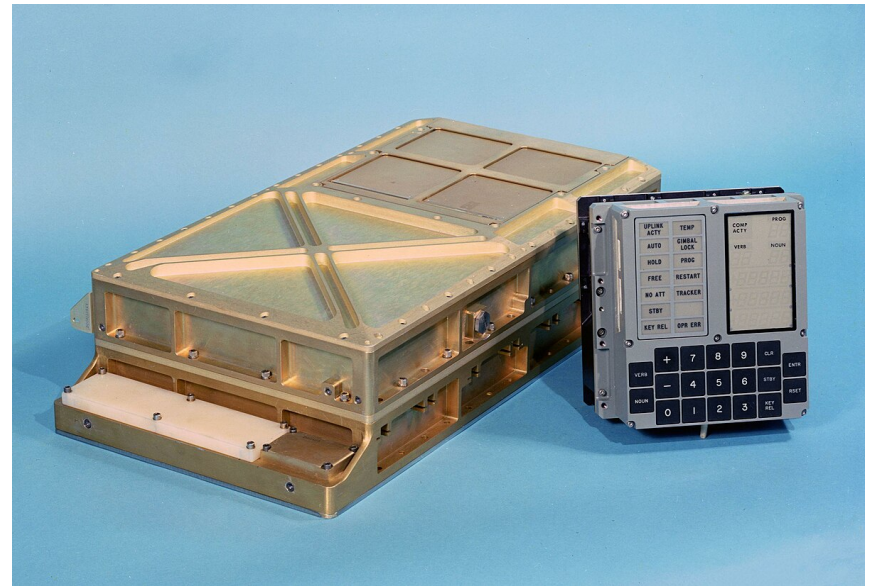
John F. Kennedy, Rice University, 1961

*in this decade and do the other things,* ***not because they are easy, but because they are hard****, because* ***that goal will serve to organize and measure the best of our energies and skills****, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too.*

# AGC

August 1966

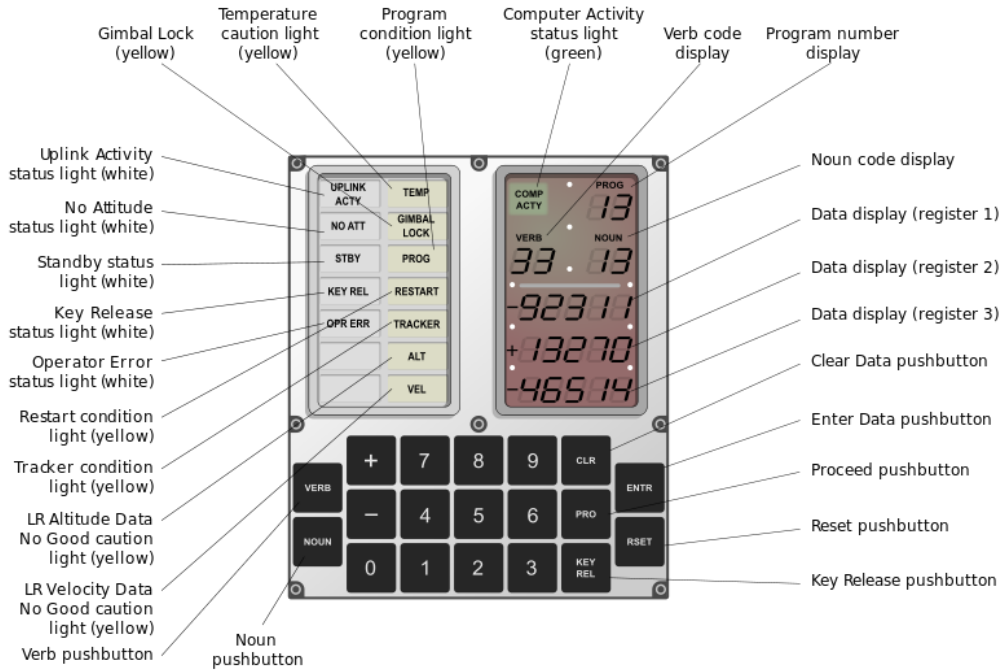
| | |
|---|---|
| Frequency | 2.048 MHz |
| World Length | 15 + 1 bit |
| RAM | 4096 B |
| Storage | 72 KB |
| Software API | AGC Assembly Language |




This landed the *moon eagle*.

# DSKY

## Display and keyboard



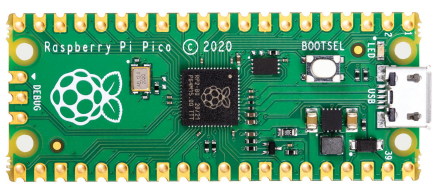

## Simulator

# What is a microprocessor?

# Microcontroller (MCU)

Integrated in embedded systems for certain tasks

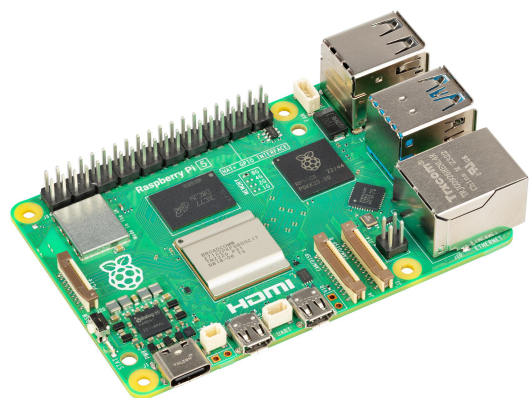
- low operating frequency (MHz)
- a lot of I/O ports
- controls hardware
- does not require an Operating System
- costs $0.1 - $25
- annual demand is billions




# Microprocessor (CPU)

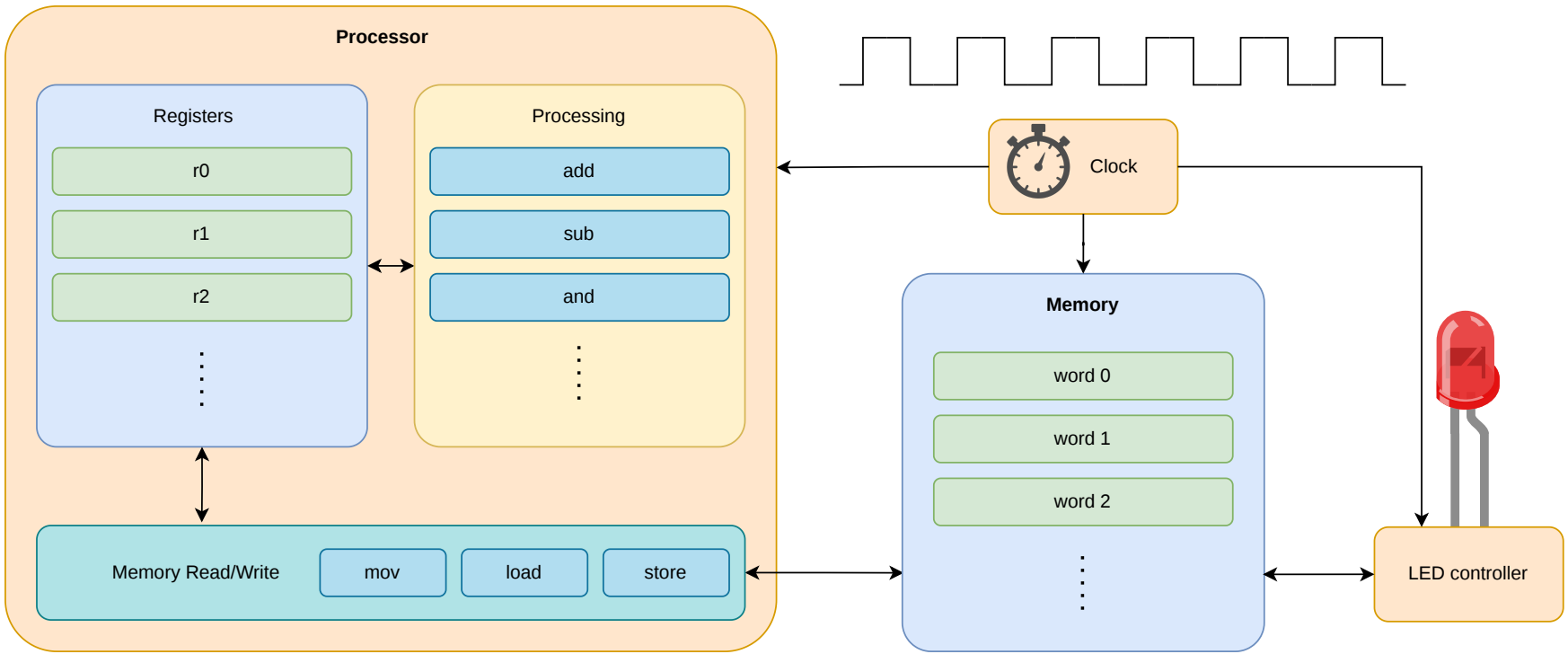
General purpose, for PC & workstations

- high operating frequency (GHz)
- limited number of I/O ports
- usually requires an Operating System
- costs $75 - $500
- annual demand is tens of millions



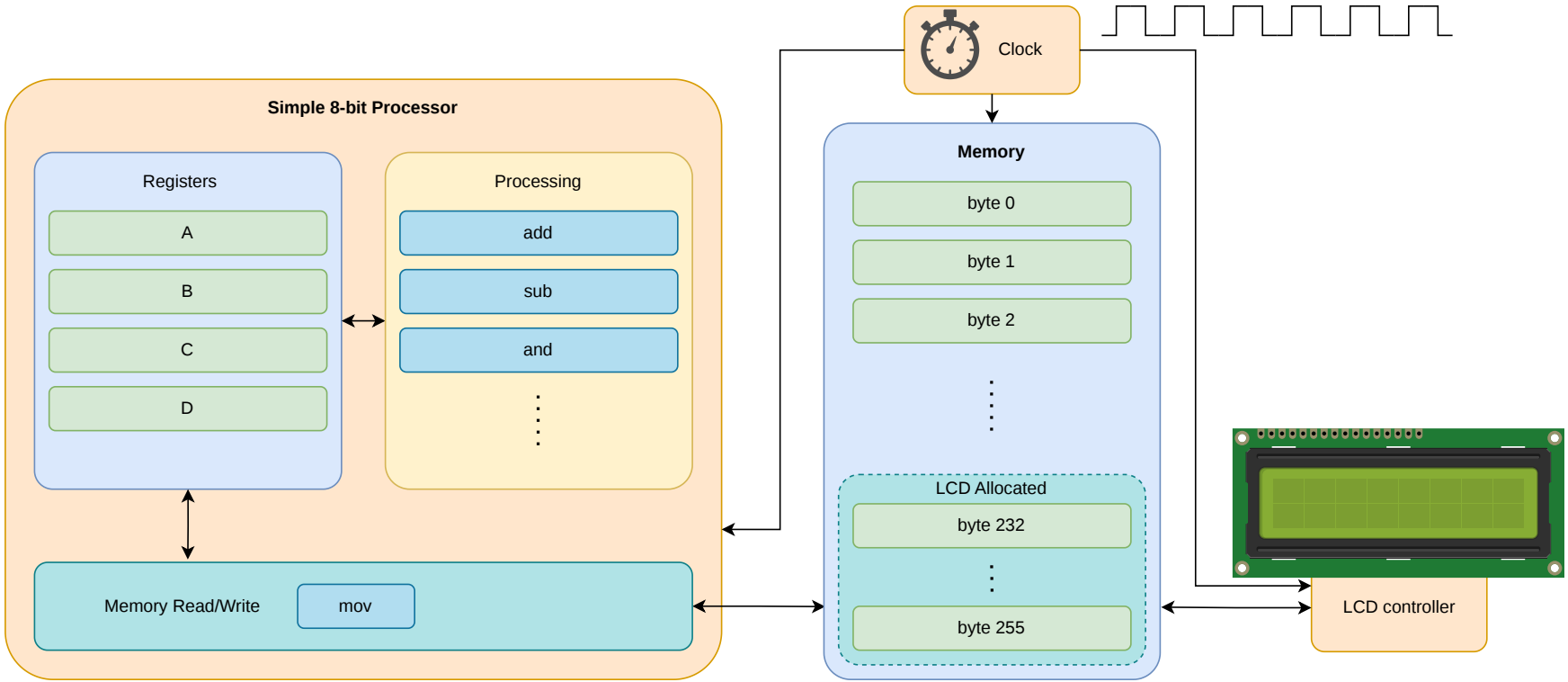
# How a microprocessor (MCU) works

This is a simple processor



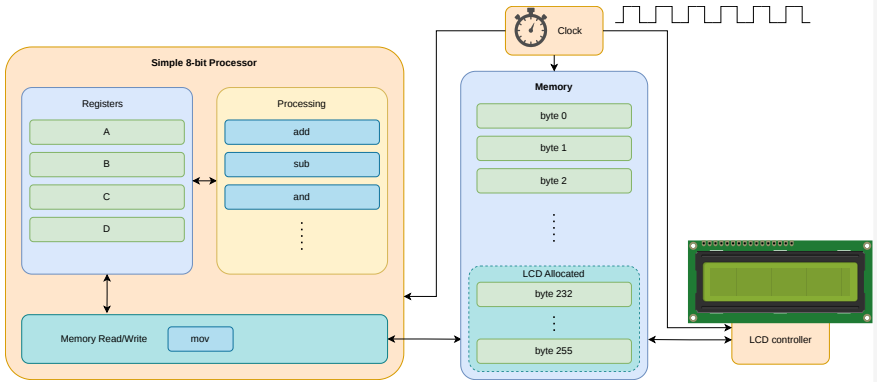
# 8 bit processor

a simple 8 bit processor with a text display



# Programming

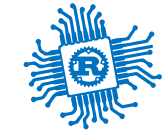
in Rust




```rust
use eight_bit_processor::print;

static hello: &str = "Hello World!";

#[start]
fn start() {
    print(hello);
}
```

# Assembly

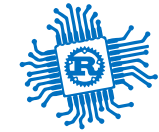
```
   JMP start
hello: DB "Hello World!" ; Variable
       DB 0 ; String terminator
start:
   MOV C, hello    ; Point to var
   MOV D, 232  ; Point to output
   CALL print
        HLT             ; Stop execution
print:      ; print(C:*from, D:*to)
   PUSH A
   PUSH B
   MOV B, 0
.loop:
   MOV A, [C]  ; Get char from var
   MOV [D], A  ; Write to output
   INC C
   INC D
   CMP B, [C]  ; Check if end
   JNZ .loop ; jump if not

   POP B
   POP A
   RET
```



# Demo

## a working example for the previous code

Start



# Real Word Microcontrollers

Intel / AVR / PIC / TriCore / ARM Cortex-M / RISC-V rv32i(a)mc

# Bibliography

for this section

**Joseph Yiu**, *The Definitive Guide to ARM® Cortex®-M0 and Cortex-M0+ Processors, 2nd Edition*

- Chapter 1 - *Introduction*
- Chapter 2 - *Technical Overview*

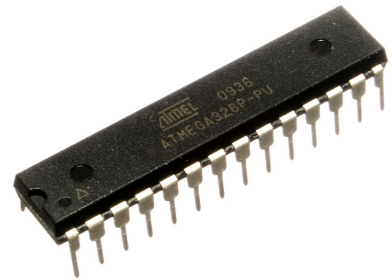
# Intel

| | |
|---|---|
| Vendor | Intel |
| ISA | 8051, 8051 |
| Word | 8 bit |
| Frequency | a few MHz |
| Storage | ? |
| Variants | *8048*, *8051* |

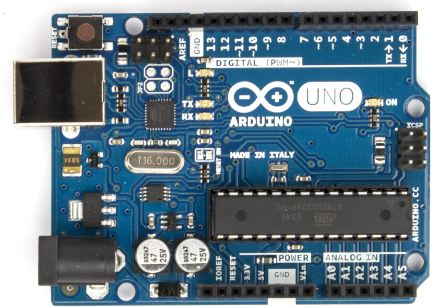
# AVR

probably *Alf and Vegard's RISC processor*

| | |
|---|---|
| Authors | Alf-Egil Bogen and Vegard Wollan |
| Vendor | Microchip (*Atmel*) |
| ISA | AVR |
| Word | 8 bit |
| Frequency | 1 - 20 MHz |
| Storage | 4 - 256 KB |
| Variants | *ATmega*, *ATtiny* |



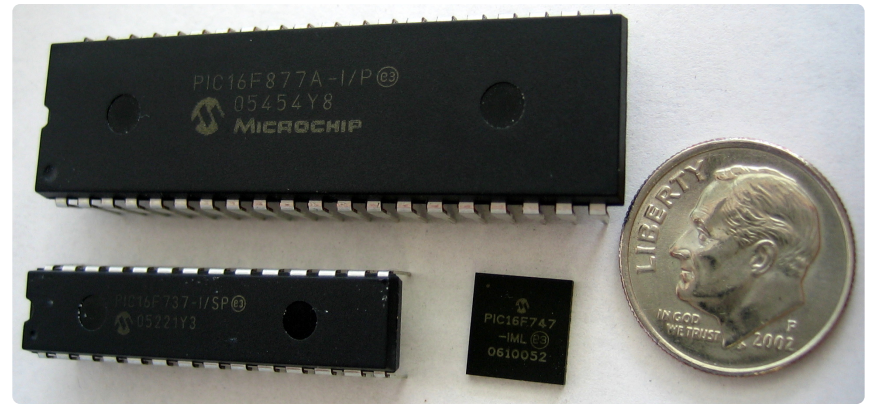

Board



# PIC

Peripheral Interface Controller / Programmable Intelligent Computer

| | |
|---|---|
| Vendor | Microchip |
| ISA | PIC |
| Word | 8 - 32 |
| Frequency | 1 - 20 MHz |
| Storage | 256 B - 64 KB |
| Variants | *PIC10*, *PIC12*, *PIC16*, *PIC18*, *PIC24*, *PIC32* |



# TriCore

| | |
|---|---|
| Vendor | Infineon |
| ISA | AURIX32 |
| Word | 32 bit |
| Frequency | hundreds of MHz |
| Storage | a few MB |
| Variants | *TC2xx*, *TC3xx*, *TC4xx* |

# ARM Cortex-M

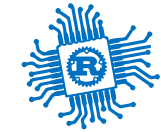
Advanced RISC Machine

| | |
|---|---|
| Vendor | Qualcomm, NXP, Nordic Semiconductor, Broadcom, Raspberry Pi |
| ISA | ARMv6-M (Thumb and some Thumb-2) ARMv7-M (Thumb and Thumb-2) |
| Word | 32 |
| Frequency | 1 - 900 MHz |
| Storage | up to a few MB |
| Variants | *M0*, *M0+*, *M3*, *M4*, *M7*, *M33* |

# RISC-V rv32i(a)mc

Fifth generation of RISC ISA

| | |
|---|---|
| Authors | University of California, Berkeley |
| Vendor | Espressif System |
| ISA | rv32i(a)mc |
| Word | 32 bit |
| Frequency | 1 - 200 MHz |
| Storage | 4 - 256 KB |
| Variants | *rv32imc*, *rv32iamc* |



# RP2040

ARM Cortex-M0+, built by Raspberry Pi

# Bibliography

for this section

**Raspberry Pi Ltd**, *RP2040 Datasheet*

- Chapter 1 - *Introduction*
- Chapter 2 - *System Description*
  - Section 2.1 - *Bus Fabric*

# RP2040

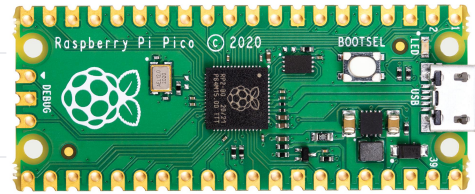
the MCU

| | |
|---|---|
| Vendor | Raspberry PI |
| Variant | ARM Cortex-M0+ |
| ISA | ARMv6-M (Thumb and some Thumb-2) |
| Cores | 2 |
| Word | 32 bit |
| Frequency | up to 133 MHz |
| RAM | 264 KB |
| Storage | N/A (external only) |

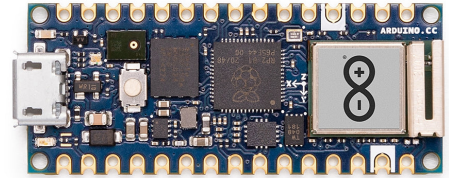
# Boards

that use RP2040

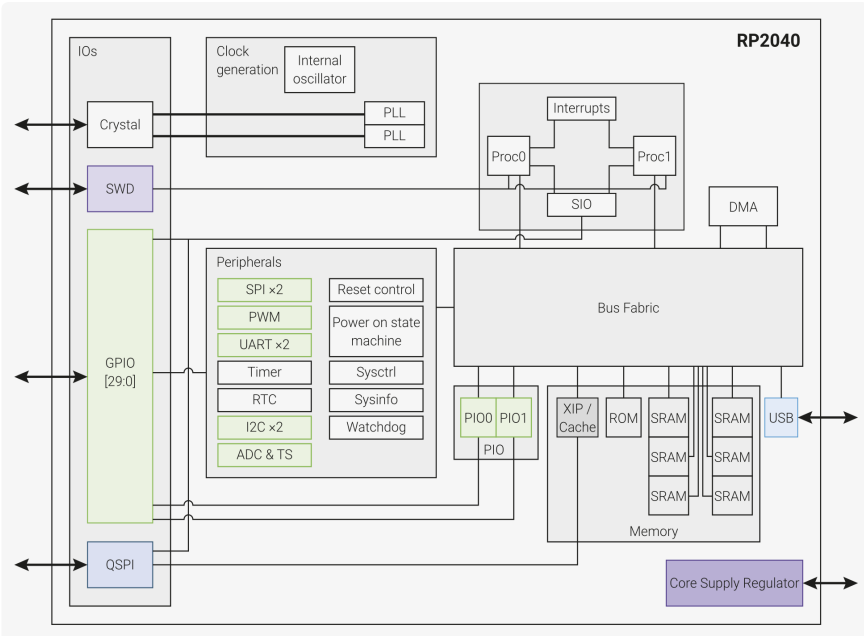
## Raspberry Pi Pico (W)




## Arduino Nano RP2040 Connect



# The Chip




*GPIO*: General Purpose Input/Output
*SWD*: Debug Protocol
*DMA*: Direct Memory Access

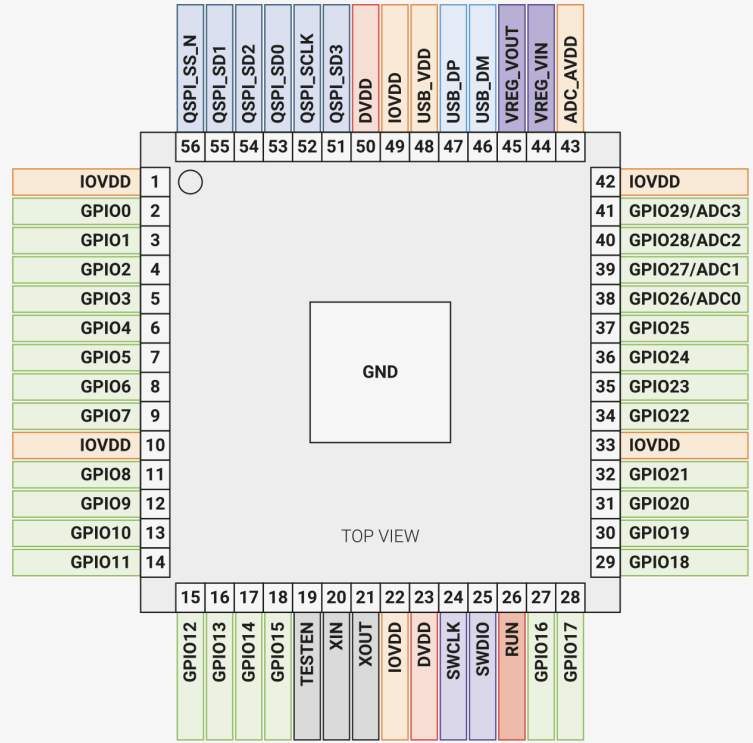
# Peripherals

| | |
|---|---|
| SIO | Single Cycle Input/Output |
| PWM | Pulse With Modulation |
| ADC | Analog to Digital Converter |
| (Q)SPI | (Quad) Serial Peripheral Interface |
| UART | Universal Async. Receiver/Transmitter |
| RTC | Real Time Clock |
| I2C | Inter-Integrated Circuit |
| PIO | Programmable Input/Output |

# Pins

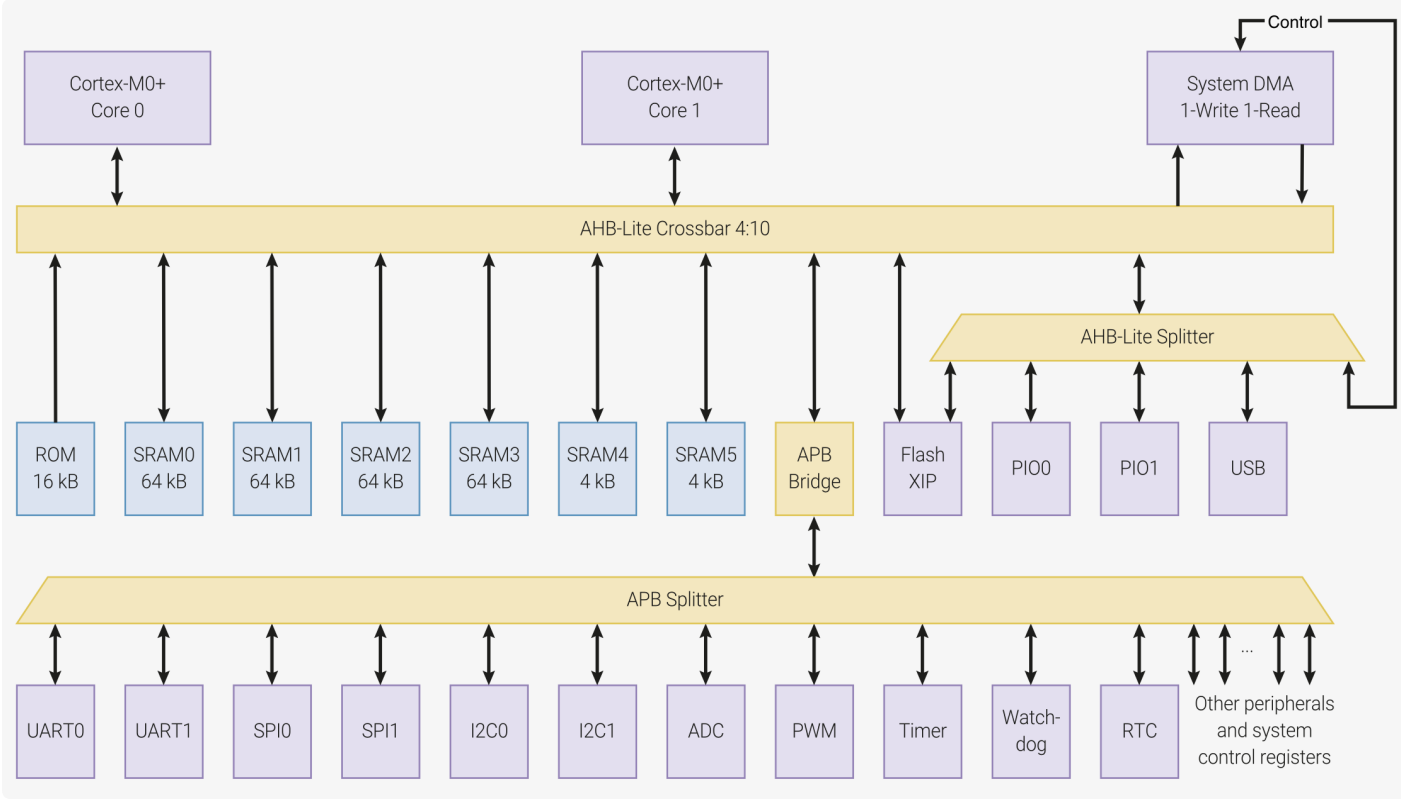
## have multiple functions

| | Function | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| GPIO | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 |
| 0 | SPI0 RX | UART0 TX | I2C0 SDA | PWM0 A | SIO | PIO0 | PIO1 | | USB OVCUR DET |
| 1 | SPI0 CSn | UART0 RX | I2C0 SCL | PWM0 B | SIO | PIO0 | PIO1 | | USB VBUS DET |
| 2 | SPI0 SCK | UART0 CTS | I2C1 SDA | PWM1 A | SIO | PIO0 | PIO1 | | USB VBUS EN |
| 3 | SPI0 TX | UART0 RTS | I2C1 SCL | PWM1 B | SIO | PIO0 | PIO1 | | USB OVCUR DET |
| 4 | SPI0 RX | UART1 TX | I2C0 SDA | PWM2 A | SIO | PIO0 | PIO1 | | USB VBUS DET |
| 5 | SPI0 CSn | UART1 RX | I2C0 SCL | PWM2 B | SIO | PIO0 | PIO1 | | USB VBUS EN |
| 6 | SPI0 SCK | UART1 CTS | I2C1 SDA | PWM3 A | SIO | PIO0 | PIO1 | | USB OVCUR DET |
| 7 | SPI0 TX | UART1 RTS | I2C1 SCL | PWM3 B | SIO | PIO0 | PIO1 | | USB VBUS DET |
| 8 | SPI1 RX | UART1 TX | I2C0 SDA | PWM4 A | SIO | PIO0 | PIO1 | | USB VBUS EN |
| 9 | SPI1 CSn | UART1 RX | I2C0 SCL | PWM4 B | SIO | PIO0 | PIO1 | | USB OVCUR DET |
| 10 | SPI1 SCK | UART1 CTS | I2C1 SDA | PWM5 A | SIO | PIO0 | PIO1 | | USB VBUS DET |
| 11 | SPI1 TX | UART1 RTS | I2C1 SCL | PWM5 B | SIO | PIO0 | PIO1 | | USB VBUS EN |
| 12 | SPI1 RX | UART0 TX | I2C0 SDA | PWM6 A | SIO | PIO0 | PIO1 | | USB OVCUR DET |
| 13 | SPI1 CSn | UART0 RX | I2C0 SCL | PWM6 B | SIO | PIO0 | PIO1 | | USB VBUS DET |
| 14 | SPI1 SCK | UART0 CTS | I2C1 SDA | PWM7 A | SIO | PIO0 | PIO1 | | USB VBUS EN |
| 15 | SPI1 TX | UART0 RTS | I2C1 SCL | PWM7 B | SIO | PIO0 | PIO1 | | USB OVCUR DET |
| 16 | SPI0 RX | UART0 TX | I2C0 SDA | PWM0 A | SIO | PIO0 | PIO1 | | USB VBUS DET |
| 17 | SPI0 CSn | UART0 RX | I2C0 SCL | PWM0 B | SIO | PIO0 | PIO1 | | USB VBUS EN |
| 18 | SPI0 SCK | UART0 CTS | I2C1 SDA | PWM1 A | SIO | PIO0 | PIO1 | | USB OVCUR DET |
| 19 | SPI0 TX | UART0 RTS | I2C1 SCL | PWM1 B | SIO | PIO0 | PIO1 | | USB VBUS DET |



# The Bus

that interconnects the cores with the peripherals



# Conclusion

we discussed about

- How a processor functions
- Microcontrollers (MCU) / Microprocessors (CPU)
- Microcontroller architectures
- ARM Cortex-M
- RP2040