



# 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
<b>Total</b>	<i>You will need at least 4.5 points to pass the subject.</i>	<b>11p</b>



# 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

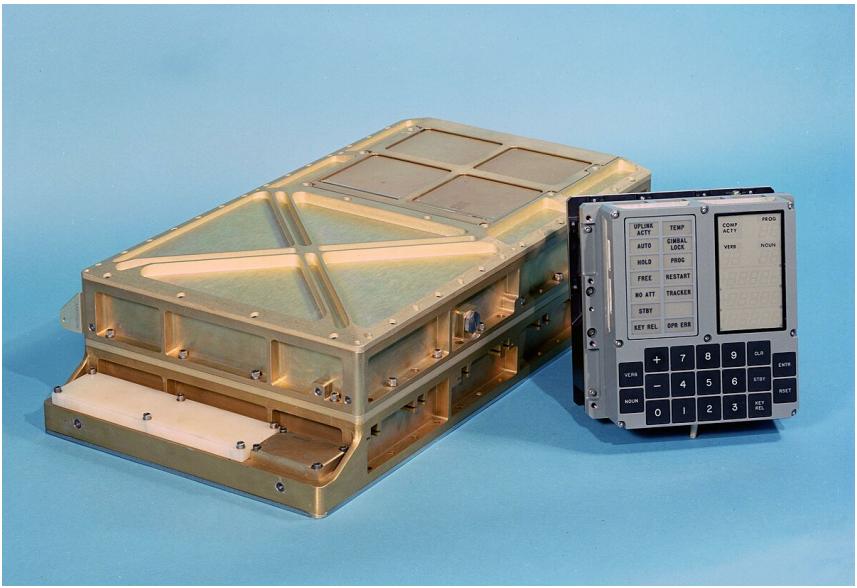
Frequency      2.048 MHz

Word Length    15 + 1 bit

RAM            4096 B

Storage        72 KB

Software API   AGC Assembly Language



This landed the *moon eagle*.



# DSKY

## Display and keyboard





# 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

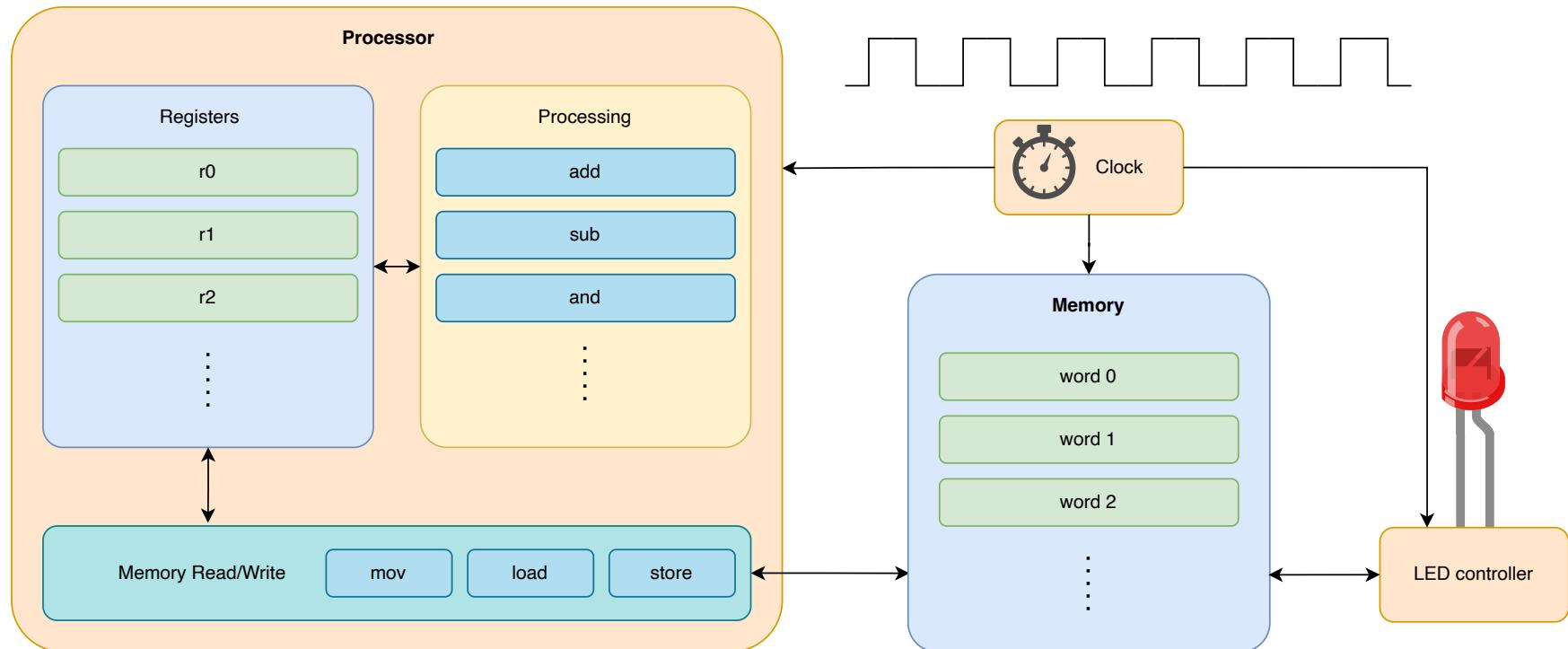
- high operating frequency (GHz)
- limited number of I/O ports
- usually requires an Operating System
- costs \$75 - \$500
- annual demand is tens of millions





# How a microprocessor (MCU) works

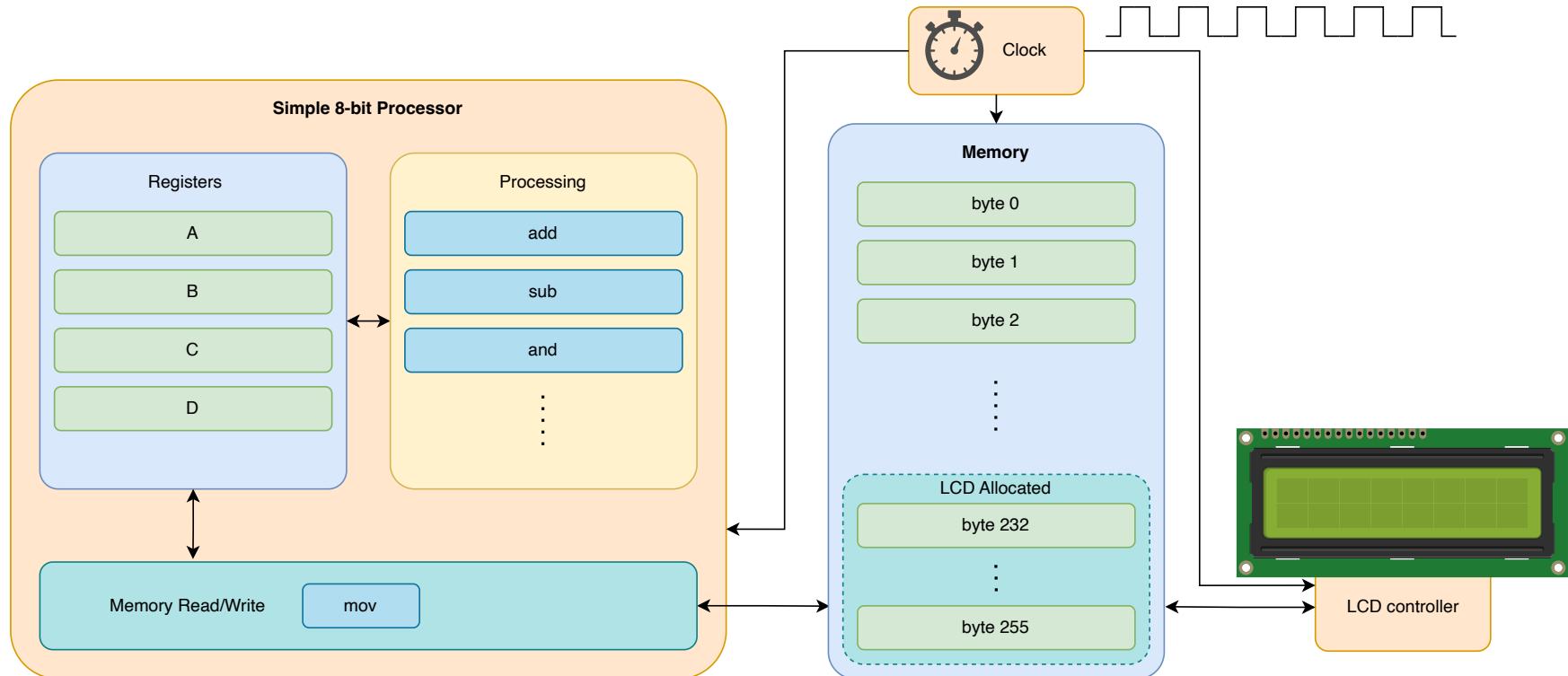
This is a simple processor





# 8 bit processor

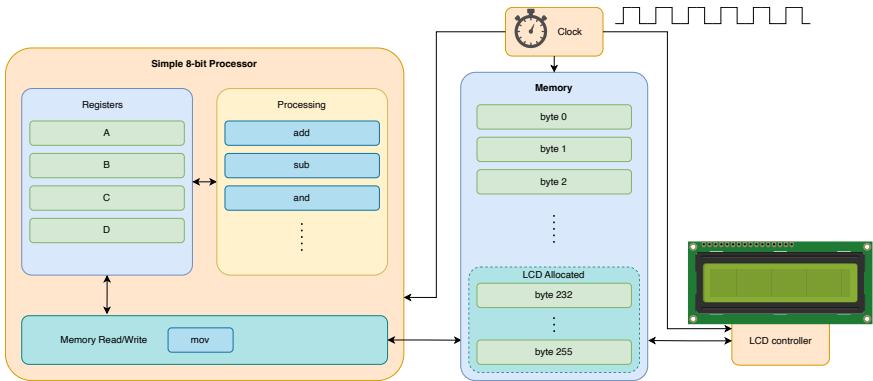
a simple 8 bit processor with a text display





# Programming

in Rust



```
1 use eight_bit_processor::print;
2
3 static hello: &str = "Hello World!";
4
5 #[start]
6 fn start() {
7     print(hello);
8 }
```

# Assembly

```
1     JMP start
2     hello: DB "Hello World!" ; Variable
3             DB 0 ; String terminator
4
5 start:
6     MOV C, hello    ; Point to var
7     MOV D, 232    ; Point to output
8     CALL print
9     HLT           ; Stop execution
10
11 print:      ; print(C:*from, D:*to)
12     PUSH A
13     PUSH B
14     MOV B, 0
15
16 .loop:
17     MOV A, [C]    ; Get char from var
18     MOV [D], A    ; Write to output
19     INC C
20     INC D
21     CMP B, [C]    ; Check if end
22     JNZ .loop ; jump if not
23
24     POP B
25     POP A
26
27     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	<i>8048, 8051</i>





# AVR

probably *Alf and Vegard's RISC processor*

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Authors      Alf-Egil Bogen and Vegard Wollan

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Vendor      Microchip (*Atmel*)

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ISA          AVR

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Word        8 bit

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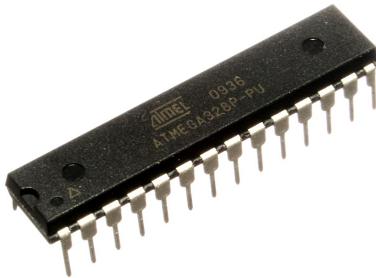
Frequency   1 - 20 MHz

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Storage     4 - 256 KB

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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	<i>TC2xx, TC3xx, TC4xx</i>





# ARM Cortex-M

Advanced RISC Machine

arm

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	<i>M0, M0+, M3, M4, M7, M33</i>



# RISC-V rv32i(a)mc

Fifth generation of RISC ISA

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Authors      University of California, Berkeley

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Vendor      Espressif System

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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)

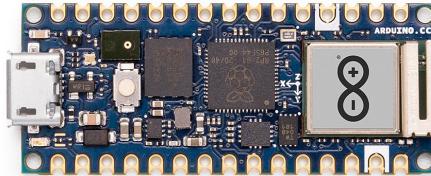
# Boards

that use RP2040

## Raspberry Pi Pico (W)



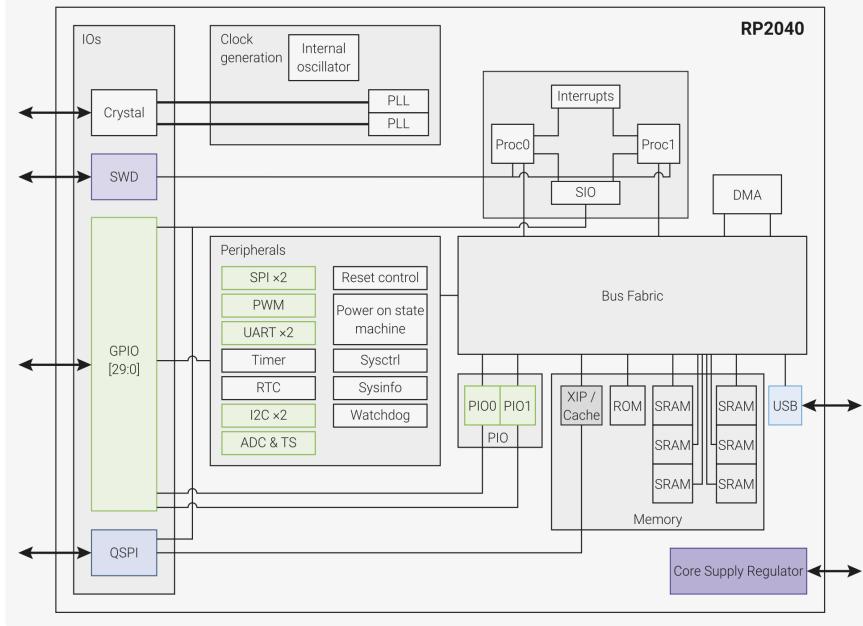
## Arduino Nano RP2040 Connect





# The Chip

# Peripherals



**GPIO:** General Purpose Input/Output

**SWD:** Debug Protocol

**DMA:** Direct Memory Access

**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

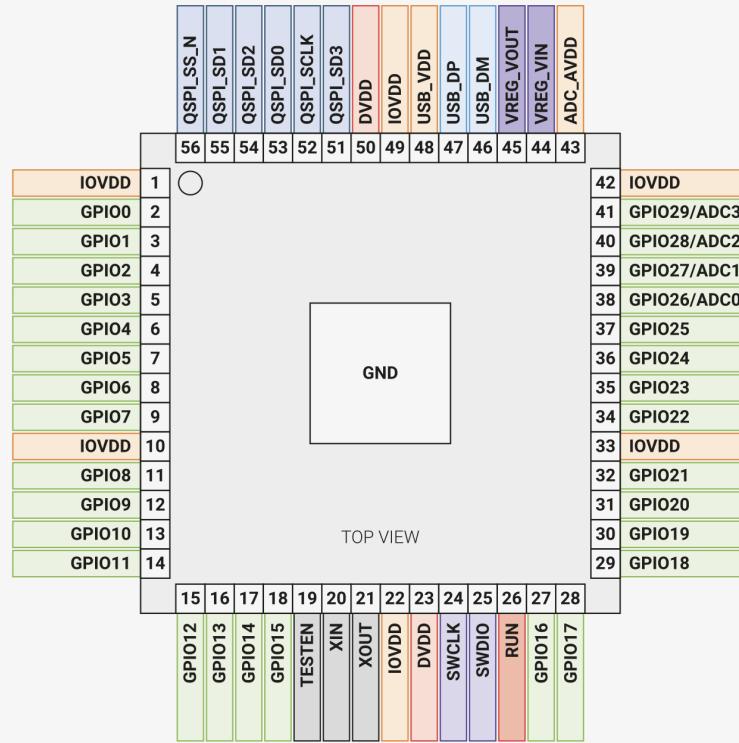
**PIO** Programmable Input/Output



# Pins

have multiple functions

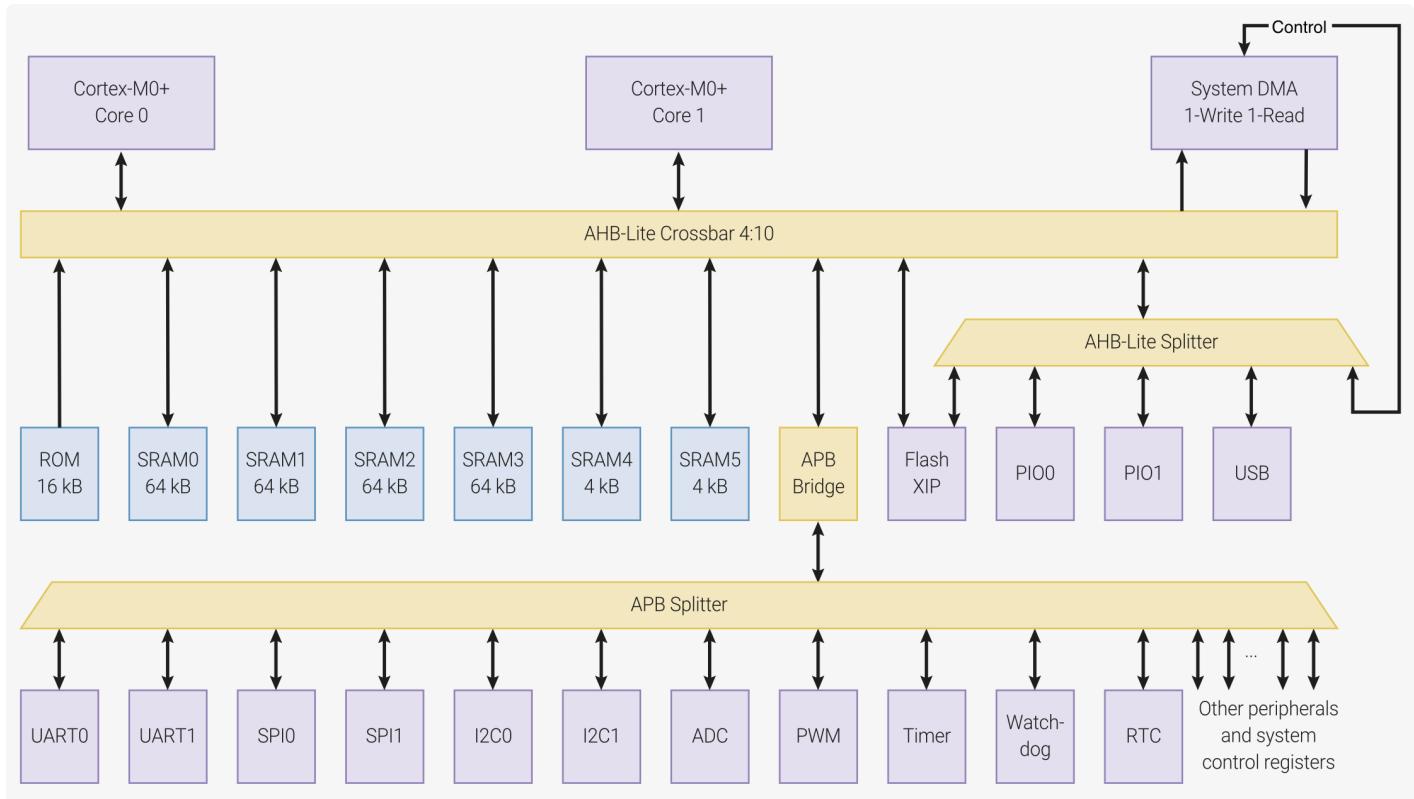
GPIO	Function									
	F1	F2	F3	F4	F5	F6	F7	F8	F9	
0	SPI0 RX	UART0 TX	I2C0 SDA	PWM0 A	SIO	PIO0	PIO1			USB OVCUR DET
1	SPI0 CSn	UART0 RX	I2C0 SCL	PWM0 B	SIO	PIO0	PIO1			USB VBUS DET
2	SPI0 SCK	UART0 CTS	I2C1 SDA	PWM1 A	SIO	PIO0	PIO1			USB VBUS EN
3	SPI0 TX	UART0 RTS	I2C1 SCL	PWM1 B	SIO	PIO0	PIO1			USB 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
20	SPI0 RX	UART1 TX	I2C0 SDA	PWM2 A	SIO	PIO0	PIO1	CLOCK_SPLICE		USB VBUS EN





# The Bus

that interconnects the cores with the peripherals





# Conclusion

we talked about

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