

# 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

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Frequency      2.048 MHz

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Word Length    15 + 1 bit

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RAM            4096 B

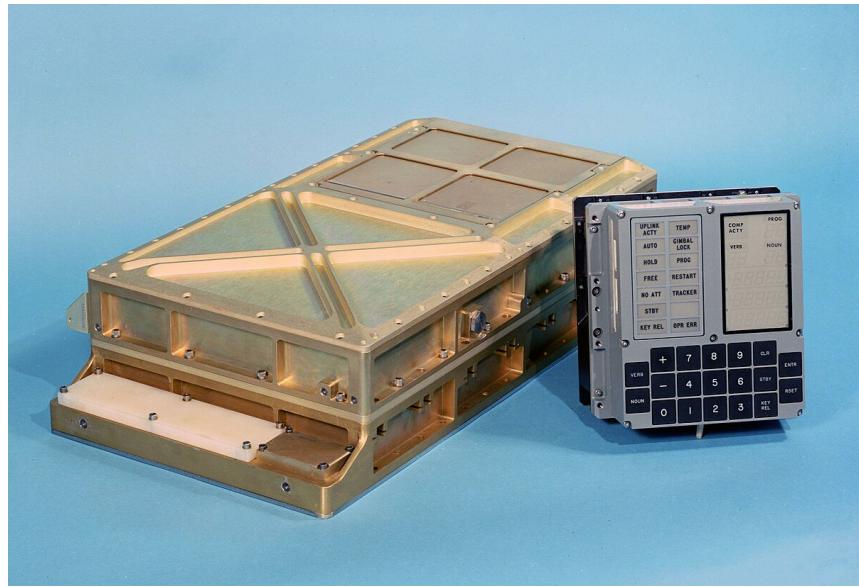
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Storage        72 KB

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Software API   AGC Assembly Language

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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)

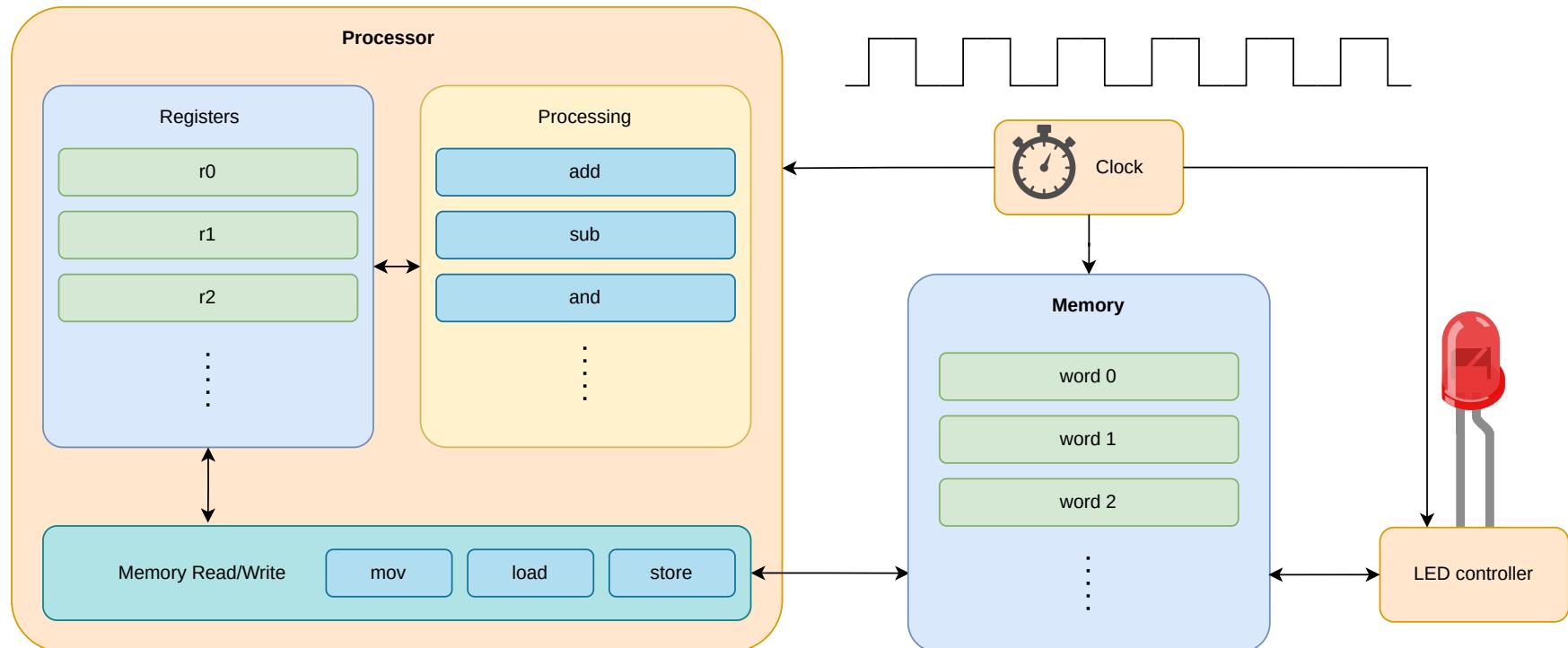
General purpose, for PC & workstations

- 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 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    print:      ; print(C:*from, D:*to)
11        PUSH A
12        PUSH B
13        MOV B, 0
14        .loop:
15            MOV A, [C]   ; Get char from var
16            MOV [D], A   ; Write to output
17            INC C
18            INC D
19            CMP B, [C]   ; Check if end
20            JNZ .loop ; jump if not
21            POP B
22            POP A
23            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

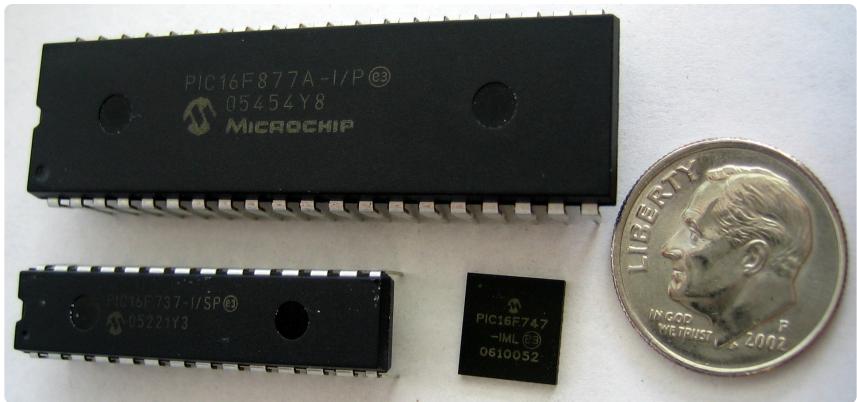
ISA PIC

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 *TC2xx, TC3xx, TC4xx*



# ARM Cortex-M

Advanced RISC Machine



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Vendor      Qualcomm, NXP, Nordic  
                Semiconductor, Broadcom, Raspberry  
                Pi

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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*

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# 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

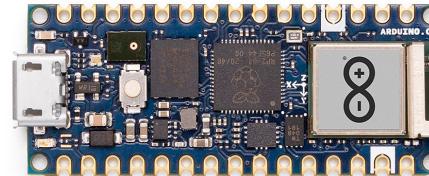
# Boards

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 I/O (implements GPIO)

**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



# 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