

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 | <i>You will need at least 4.5 points to pass the subject.</i> | 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

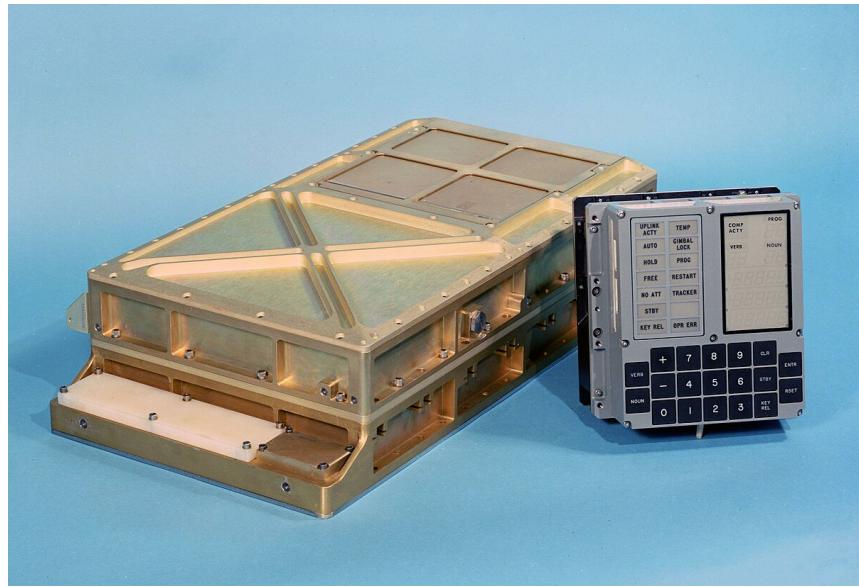
Frequency 2.048 MHz

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   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
22           POP B
23           POP A
24           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*

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

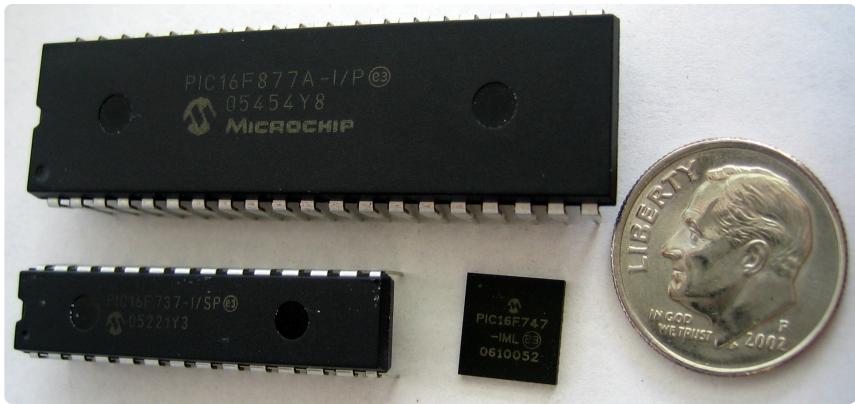
ISA PIC

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

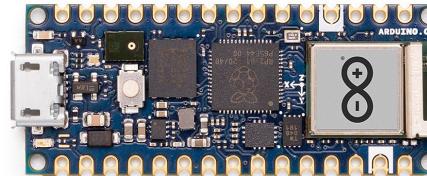
Boards

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



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