# Industrial processors

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UNIMORE
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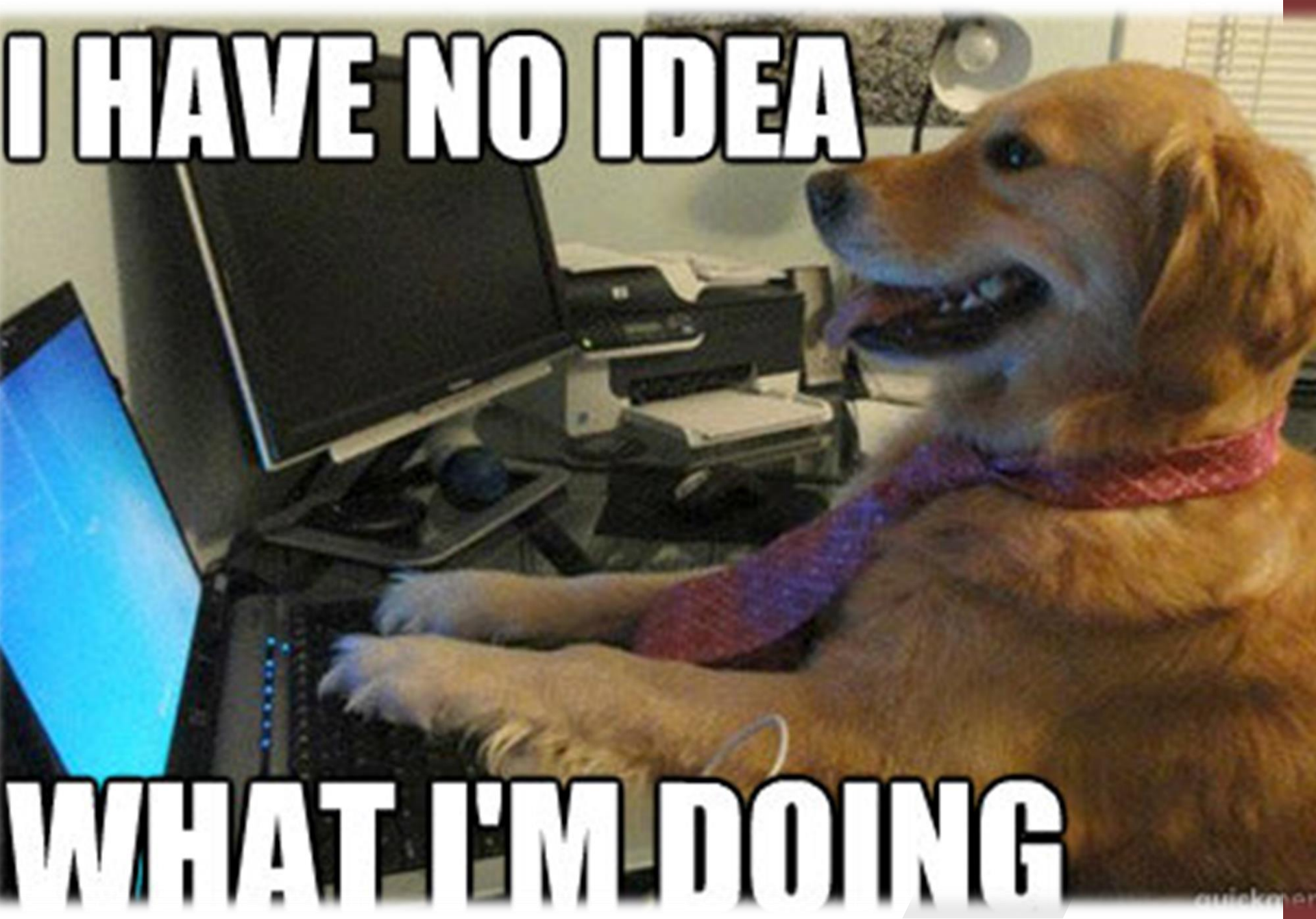
High Performance
Real Time Lab


I HAVE NO IDEA
WHAT I'M DOING

# Industrial computing continuum

A modern design: in the past might have been different!

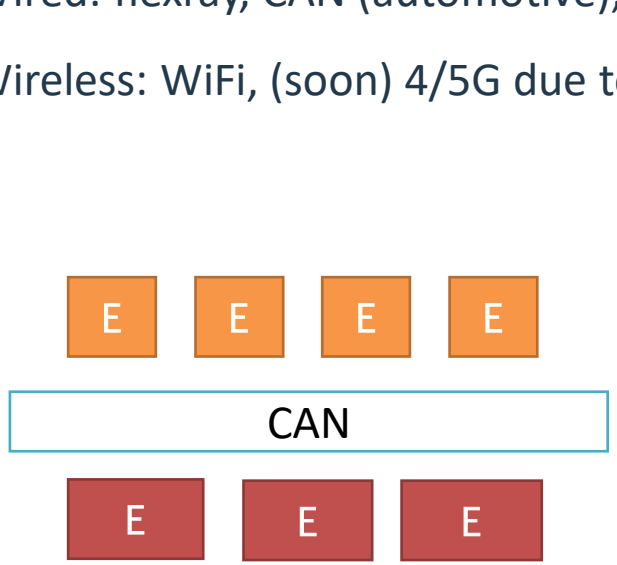
› Embedded (*edge*) devices for plant control

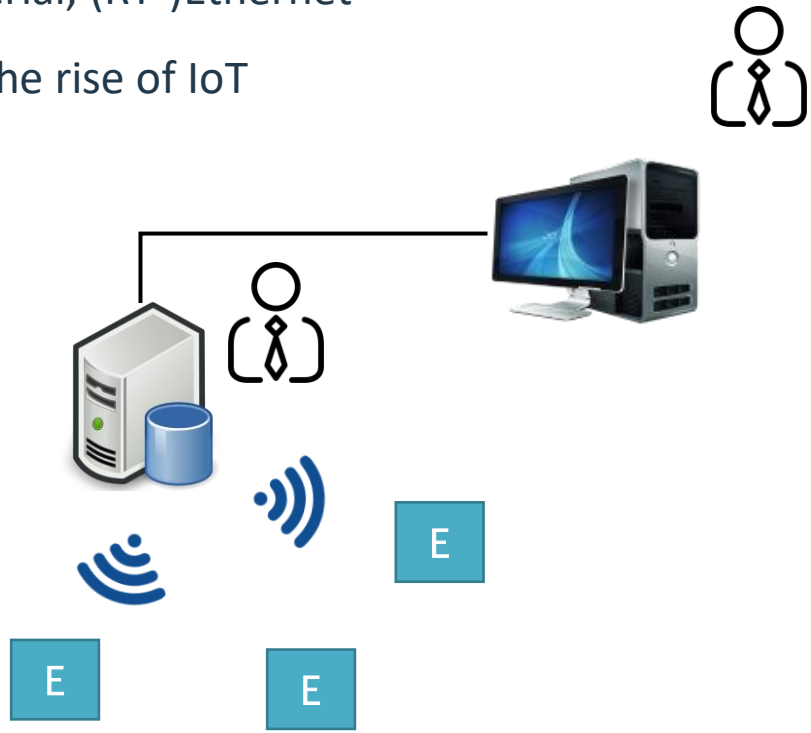
› Centralized aggregator

Connectivity *via* industrial standards

› Wired: flexray, CAN (automotive), serial, (RT-)Ethernet

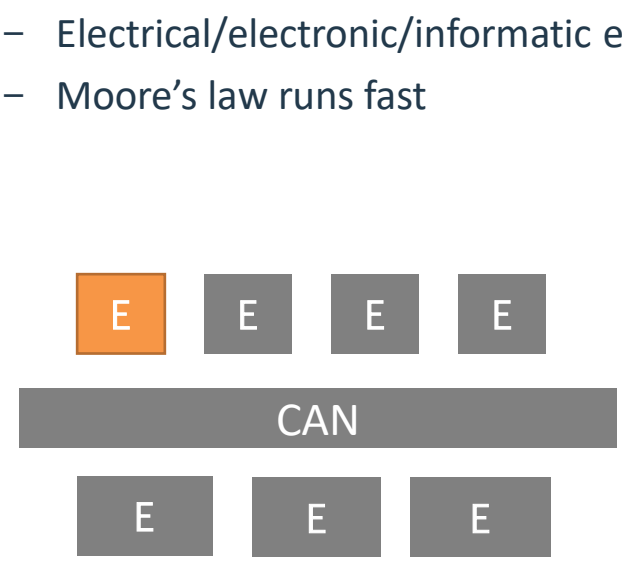
› Wireless: WiFi, (soon) 4/5G due to the rise of IoT

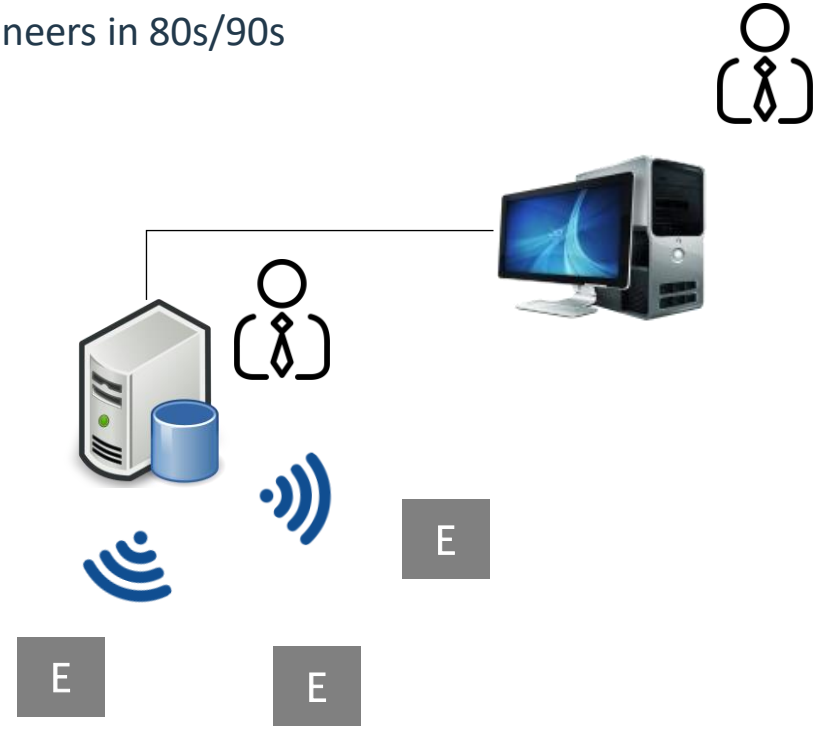


# Requirements for industrial edge devices

- Low cost and form factor might be key feature
  - …we can trade performance for that
  - Reliability, dependability, safety, certifications….
  - Reduced Size, Weight and Power (SWaP)
- Might be costly to update your plant to a new generation of processors
  - Several companies rely to old technologies (also, software tools!!)
  - Electrical/electronic/informatic engineers in 80s/90s
  - Moore's law runs fast



# Families of edge processors

As opposite to GP/desktop systems, where more or less we know “who won”…

- Micro Controller Units – MCUs
- Digital Signal Processors - DSPs
- Micro Processor Units – MPUs
- Programmable Logic Controllers / PLCs

Now

More recently, heterogeneous architectures

- Multi-core host + accelerator
- Many-core processor, such as GPGPUs (but not only….)
- Field-Programmable Gate Arrays – FPGAs

….soon

# Micro Controller Units

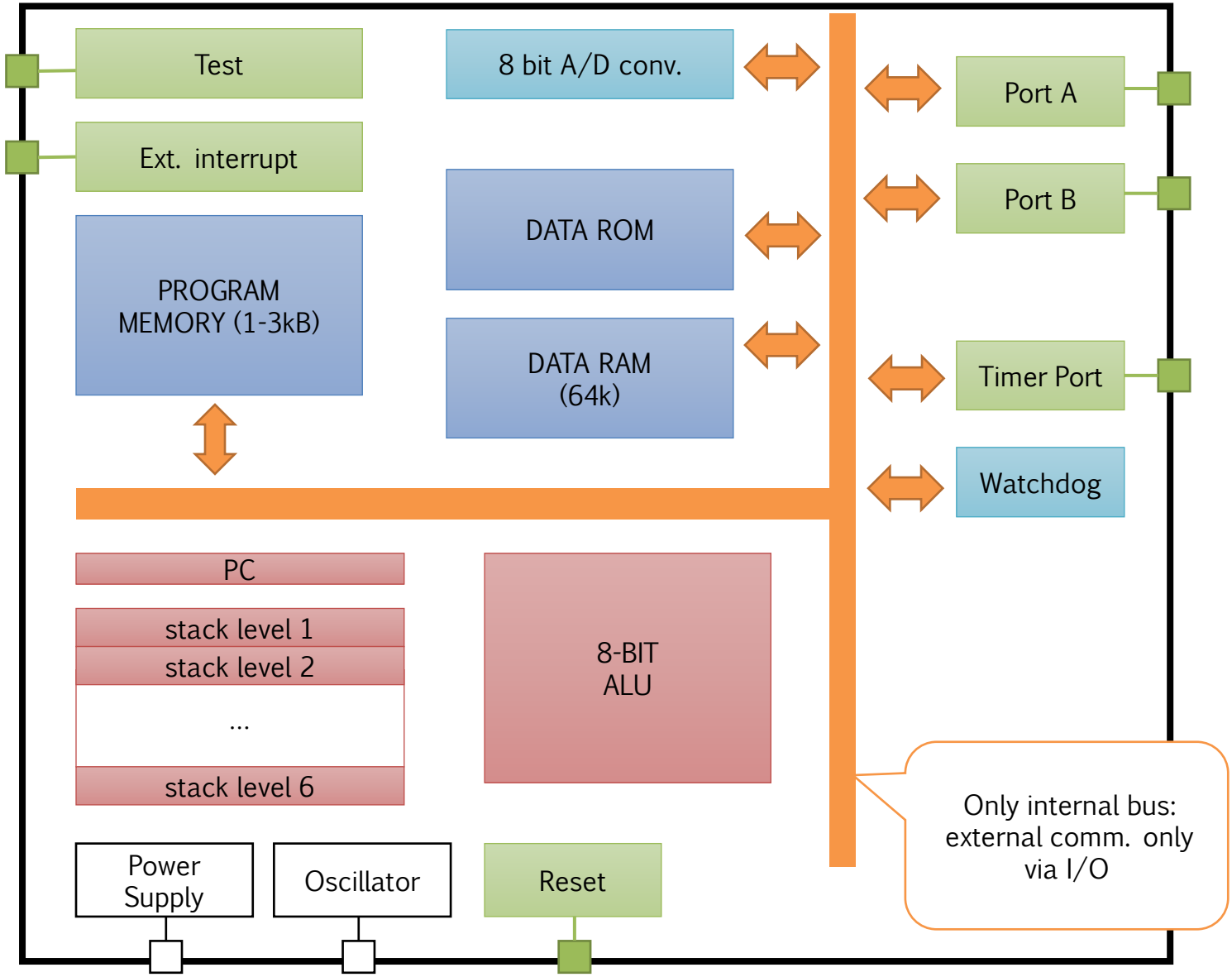
Lowest end that we will see

- 8, 16, 32-bit processors, limited memory
- Designed for I/O interaction, can poorly do more
- Also, programmability might suffer (ASM)

We will see (and play with)

- ST Microelectronic's SC6
- Arduino's first family
- Expressif's ESP8266 => ESP32 (NodeMCU)
- (Raspberry PI)

# STM's ST6


Test
Ext. interrupt
PROGRAM MEMORY (1-3kB)
8 bit A/D conv.
DATA ROM
DATA RAM (64k)
Port A
Port B
Timer Port
Watchdog
PC
stack level 1
stack level 2
...
stack level 6
8-BIT ALU
Power Supply
Oscillator
Reset
Only internal bus: external comm. only via I/O

# Watchdog

Watchdog

Checks whether a ~~program~~ ~~process~~ processor is stuck, e.g., in deadlock, or infinite loop

In MCUs/single core, single thread machines it is a problem

- A watchdog circuit is basically a *x*-bit counter
- It **must** be **manually** reset every $\frac{2^x}{y \cdot 10^6}$ seconds (*y* = clk in Mhz) by software
- Else, it "takes care of the situation"
  - Typically => full reset

Modern system does not actually block the full machine (SW managed) nor resets it

- Multi-processing
- Preemption (we'll see..)
- OS-level controls on processes

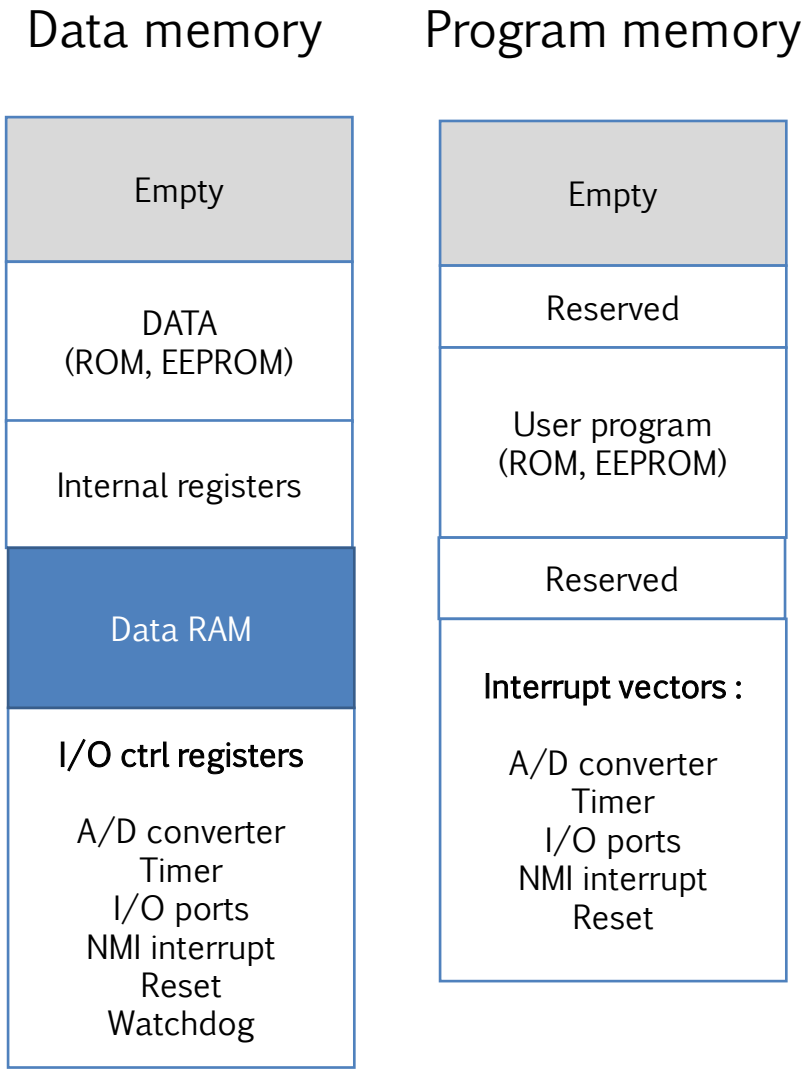
# Memory space

This is what programmers “see”

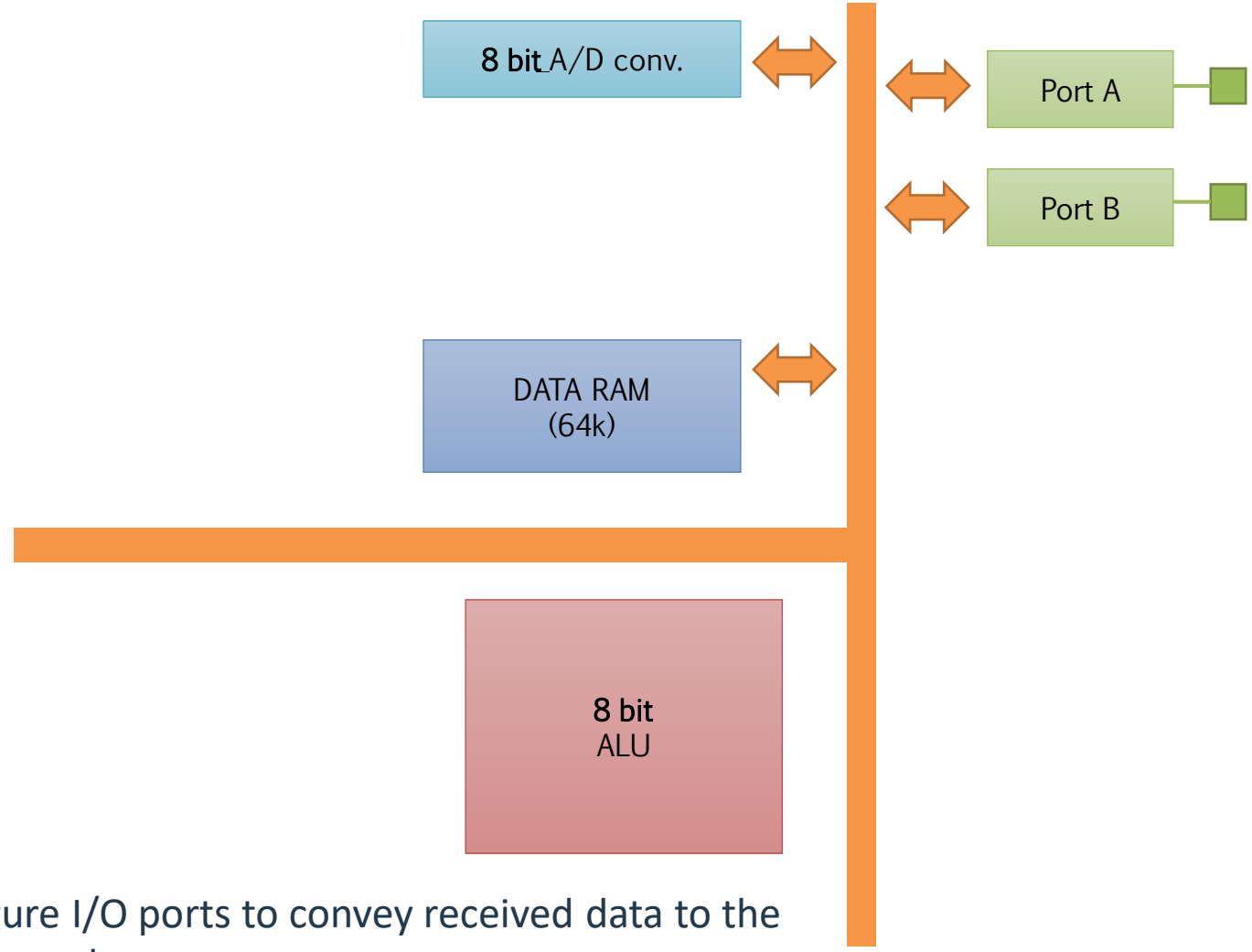
- Non-physical, here, abstracts the HW blocks
- != virtualized ☺

Program data (variables, ..) are in data RAM

- Stack, heap (..?)
- …if we could use high-level languages! (e.g., C)
- Might be necessary to work in ASM



# A/D converter




Configure I/O ports to convey received data to the A/D converter

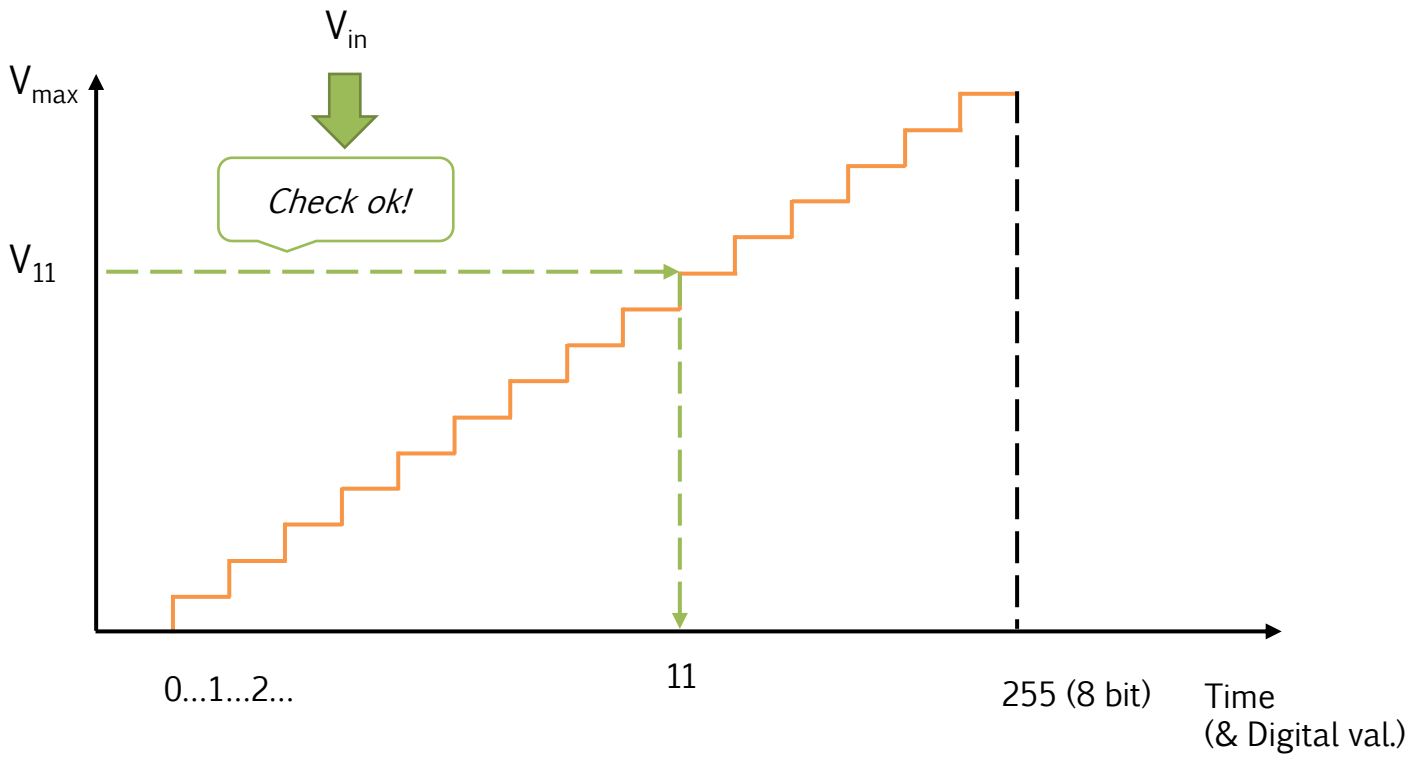
› Use memory-mapped registers

# A/D conversion

8 bit A/D conv.

Using the internal wave generator of A/D module, our program

- Generate a signal with increasing $V_{in}$ (y-axis)
- Compare (in HW) it with the V received by the analog I/O port
- When equals, assign the corresponding digital value (x-axis)



# D/A conversion

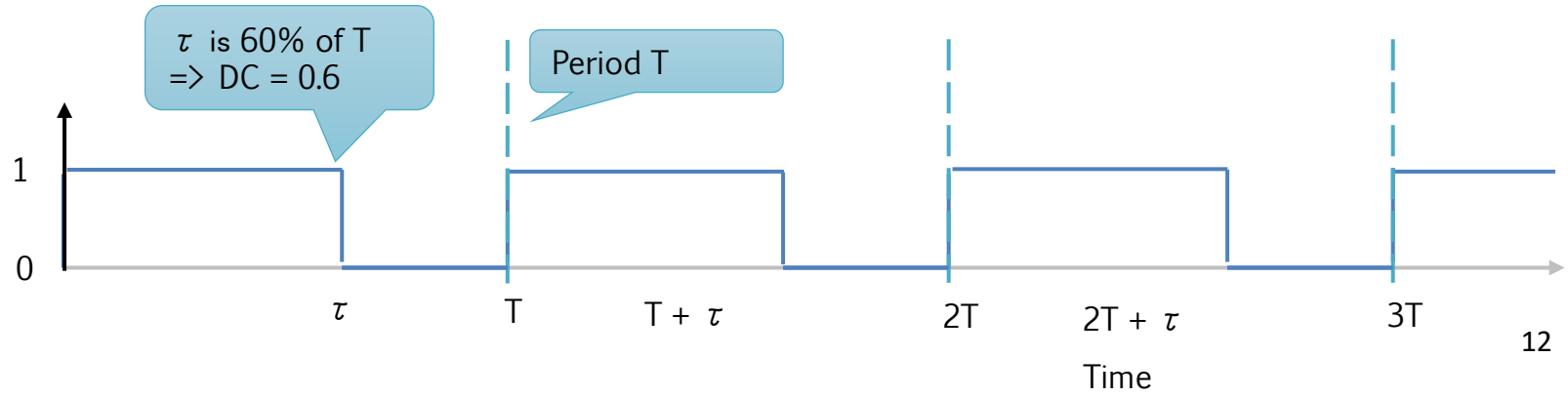
*Generate a tension corresponding to a digital value stored in a register*

- Not easy! Use Pulse-Width Modulation (PWM)
  - (Almost) fully implementable in SW!

How it works

DC = $\tau$ / T

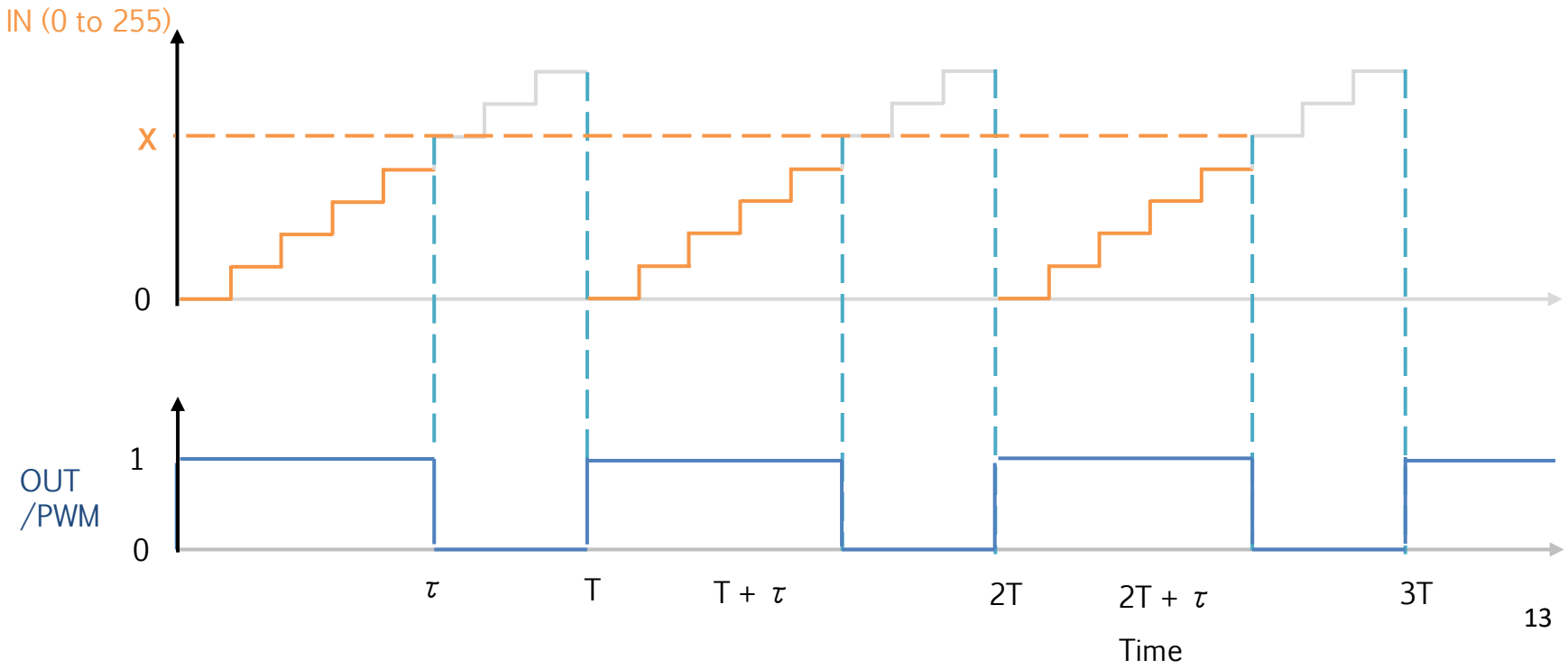
1. Generate a periodic signal of amplitude 1 whose **duty cycle** is proportional to the digital value we want to convert
2. Give it to a low-pass filter, to average (such as Resistor-Capacitor RC) circuit)
3. ..and enjoy your analog signal! ☺



# PWM – step 1

We need

- A register that counts from 0 to 255 (8-bit)
- An output port (bit) set to ‘1’ and becoming ‘0’ when input value matches the one of the register

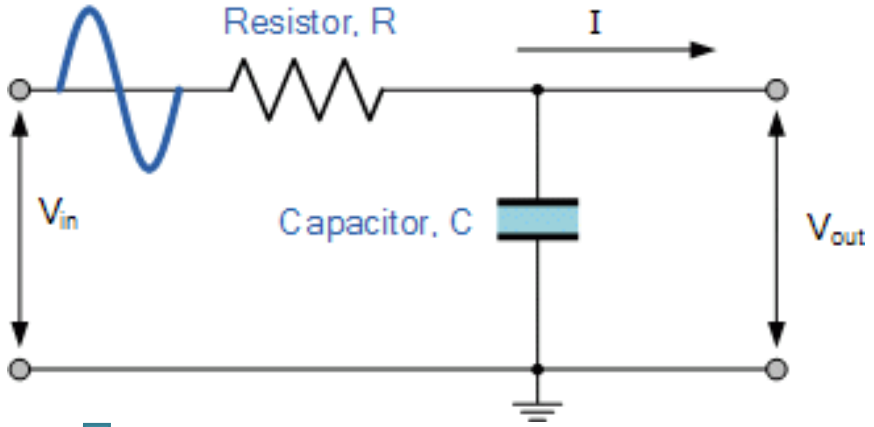


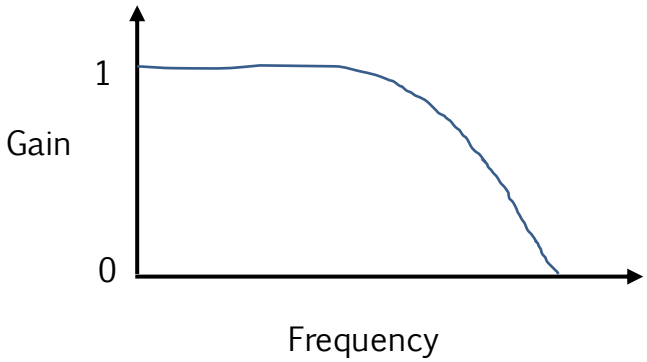
# RC low-pass filter

Simple electric circuit with a Capacitor and a Resistance

› “Averages” the IN value

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2}$$



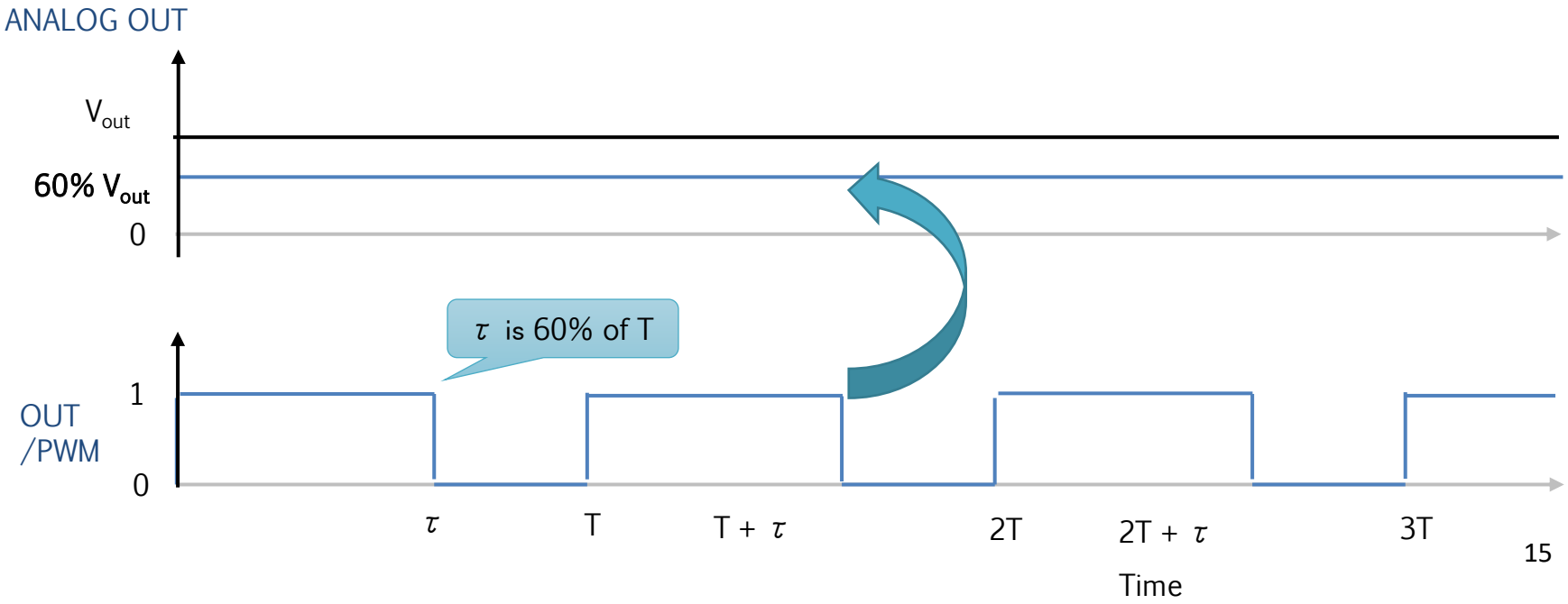



# PWM – step 2

Now, compute the average for every T

- Using a low-pass filter
- Plug it to output port
- *Et voilà*

**Extremely useful in engine controls**



# Digital Signal Processors

A family of MCUs explicitly designed for **digital** signal processing

› We have A/D converters..

Example: **Digital** Finite Impulse Response filter (FIR)

› Computes the weighted sum of *N* timing samples of a discrete signal *x*

$$y_n = a_0 \cdot x_n + a_1 \cdot x_{n-1} \ldots a_N \cdot x_{n-N}$$

$$y_n = \sum_{i=0}^{N-1} x_{n-i} \cdot a_i$$

› Typically, discrete time series

› N is also called *order* and specifies “how much in the past” we go

# How to implement it?

$$y_n = a_0 \cdot x_n + a_1 \cdot x_{n-1} \dots a_N \cdot x_{n-N}$$

- (Assume time series…)
- We can't accumulate multiplied values, as every sample is multiplied with a different coefficient a
- We can keep a buffer in memory of the last N-1 samples, and slide on it (aka: sliding window)

Compute multiplications in parallel, then sum

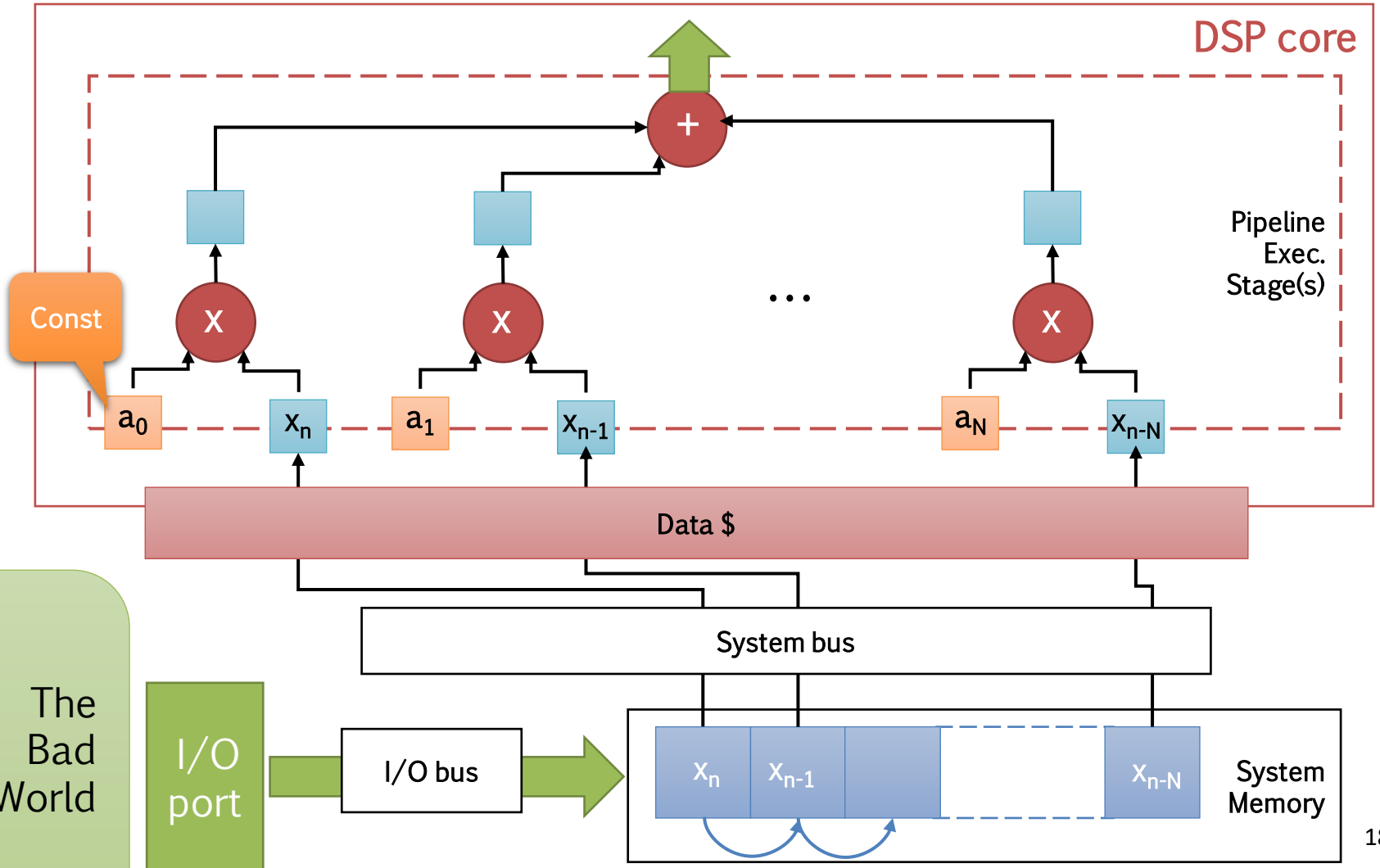
- Parallel programming patterns: reduction, data parallelism
- The principle behind GPUs!

Assuming that

- We have a N-wide execution pipeline
- Our memory bandwidth can read N samples in parallel
- Else, we create stages

# Data-parallel FIR

$$y_n = a_0 \cdot x_n + a_1 \cdot x_{n-1} \ldots a_N \cdot x_{n-N}$$




The Bad World

# DSP typical ingredients

Like standard MCUs...but…

- Wide and simple pipeline for data parallelism
  - Multipliers, accumulators
- Wide data bus to avoid staging
  - Similar problem also for exec pipeline, but it's it's much more exacerbated in busses!
- Fast I/O and A/D, D/A conversion
  - Typically, ~~interacts with the world~~ Cyber-Physical System CPS

Often, problem-dependent architecture

- Clock frequency depends on how fast is input data sampling
- Register size (16, 32-bit) and data type (fixed, double) depends on the signal we want to process

A recent example: Texas Instrument's Keystone II

# Limits of MCUs

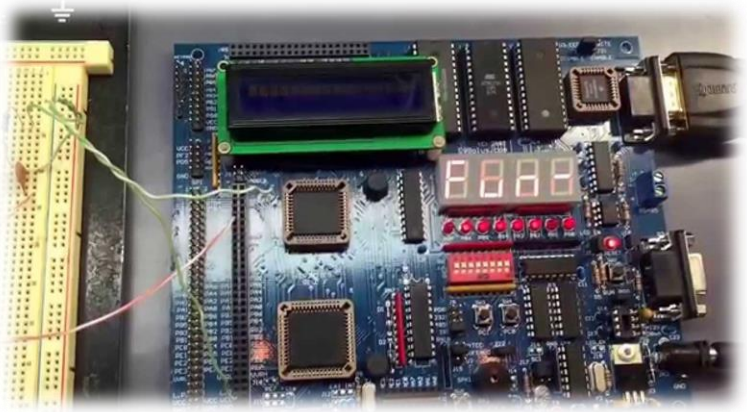
As complexity of applications grows….

- 8-bits might not be enough to capture wide data dynamics
- Limited memory size
- Poor programmability
  - In the worst case, assembly
- Poor extendibility
- Industry can stand more consuming, costly and bulky edge computers
  - Traded for performance

# Micro Processor Units - MPUs

- Embed “standard” processors
  - 16… 32… 64 bit
  - Also, Intel!
  - Advanced RISC Machines (ARM) is **the big guy** here
- Desktop-like memories and programmability
  - C, C++..
- Rich I/O and connectivity
  - A/D, D/A, watchdog..
  - Support for industrial-grade fieldbusses such as CAN
  - Traditional connectivity (ETH, Wireless..)
- Typically, built to be mounted in racks
- Easily extendable
  - Arduino, Raspberry Pi are very simple, low-cost samples
  - ExpressIF’s ESP8266 (NodeMCU) and ESP32

*Motorola 68HC11*



# Programmable Logic Controllers - PLCs

Designed for industrial controls

› Drive electricity via relays

Typically have

› Central processing units

+

› Rich set of actuation interfaces the plant

Used to build wide SCADA systems

› Supervisory Control And Data Acquisition


PLC SIMATIC S7-1500

# Programmable Logic Controllers - PLCs

Programmed *via*

- **Ladder diagram**
  - We'll see this..
- Function Block Diagram – FBD
  - For electronics
- Sequential Functional Chart – SFC
  - Petri-net style
- Instruction List – IL
  - ASM-like
- Structured Text – ST
  - Similar to Pascal/VB


PLC SIMATIC S7-1500

# References

**Course website**

- http://hipert.unimore.it/people/paolob/pub/Industrial_Informatics/index.html

**My contacts**

- paolo.burgio@unimore.it
- http://hipert.mat.unimore.it/people/paolob/

**Resources**

- Alessandro Fantechi, «Informatica Industriale», Città Studi Edizioni
- Giacomo Bucci, «Calcolatori elettronici: architettura e organizzazione», McGraw-Hill Education
- A "small blog"
  - http://www.google.com