

Industrial processors

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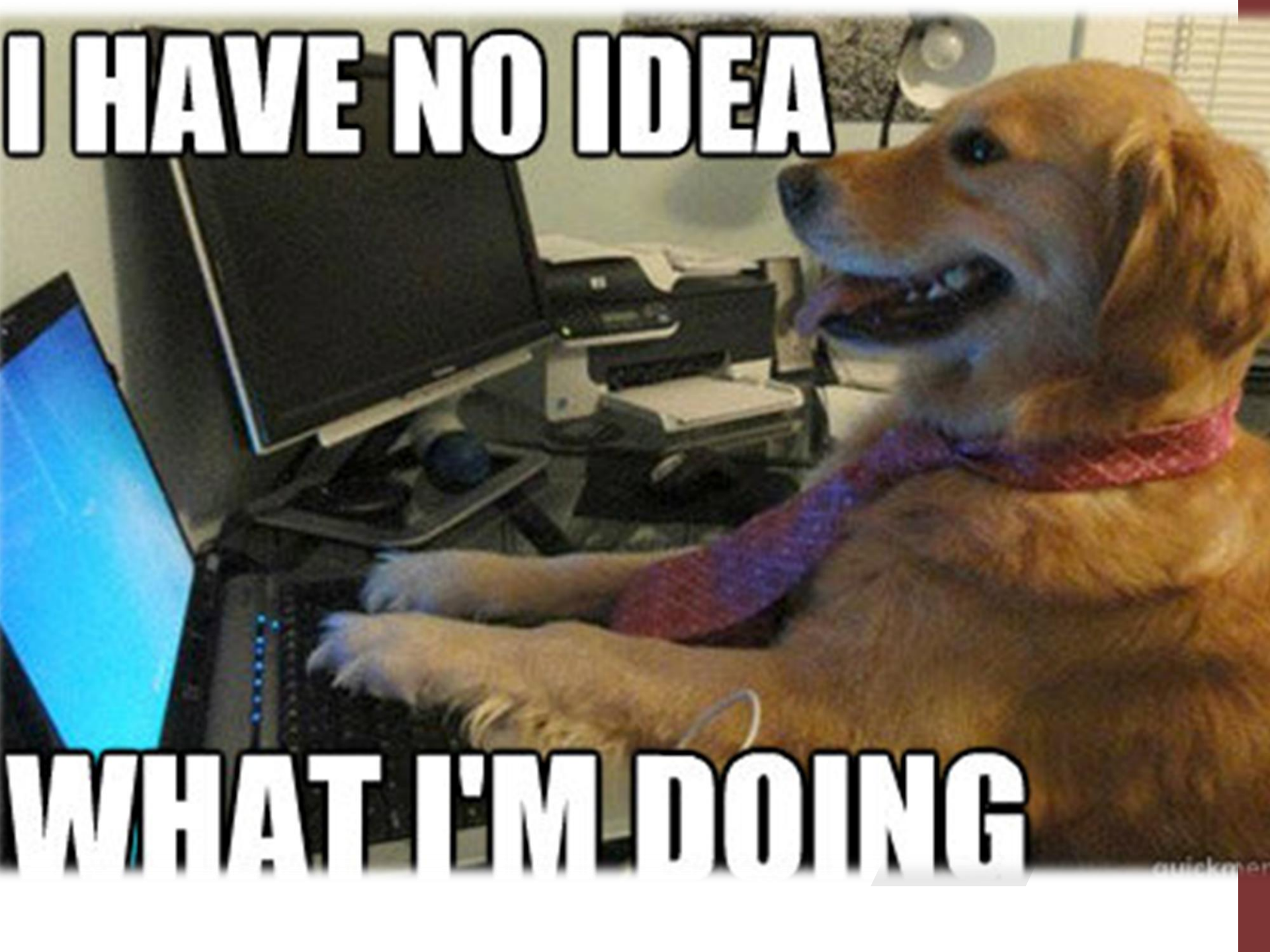


UNIMORE
UNIVERSITÀ DEGLI STUDI DI
MODENA E REGGIO EMILIA

High Performance
Real Time **Lab**

I HAVE NO IDEA

WHAT I'M DOING





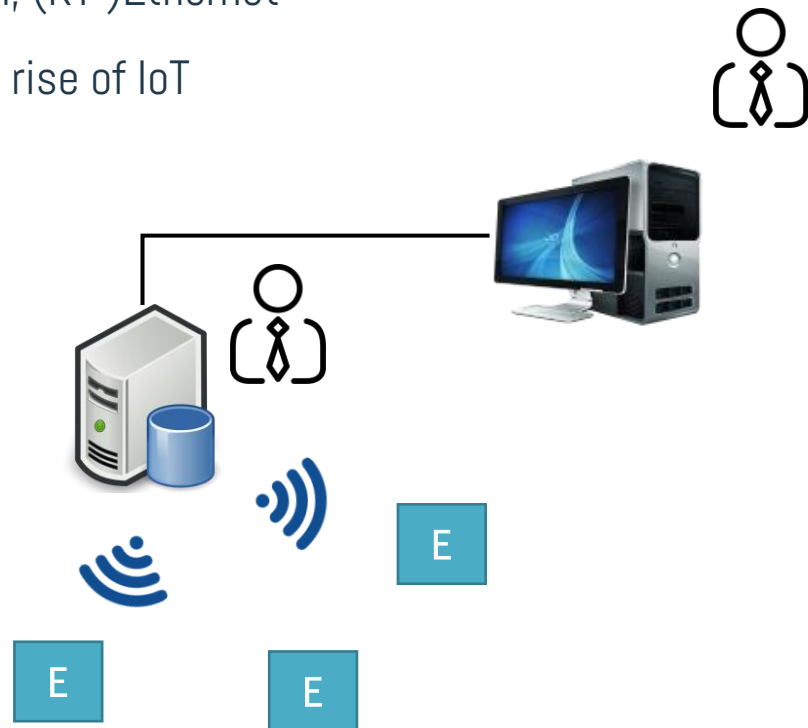
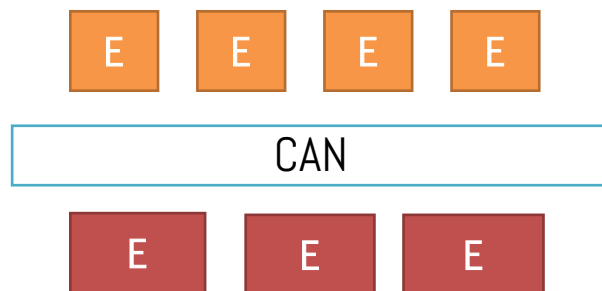
Industrial computing continuum

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

- › Embedded (*edge*) devices for plant control
- › Centralized aggregator or intermediate *fog* nodes

Connectivity *via* industrial standards

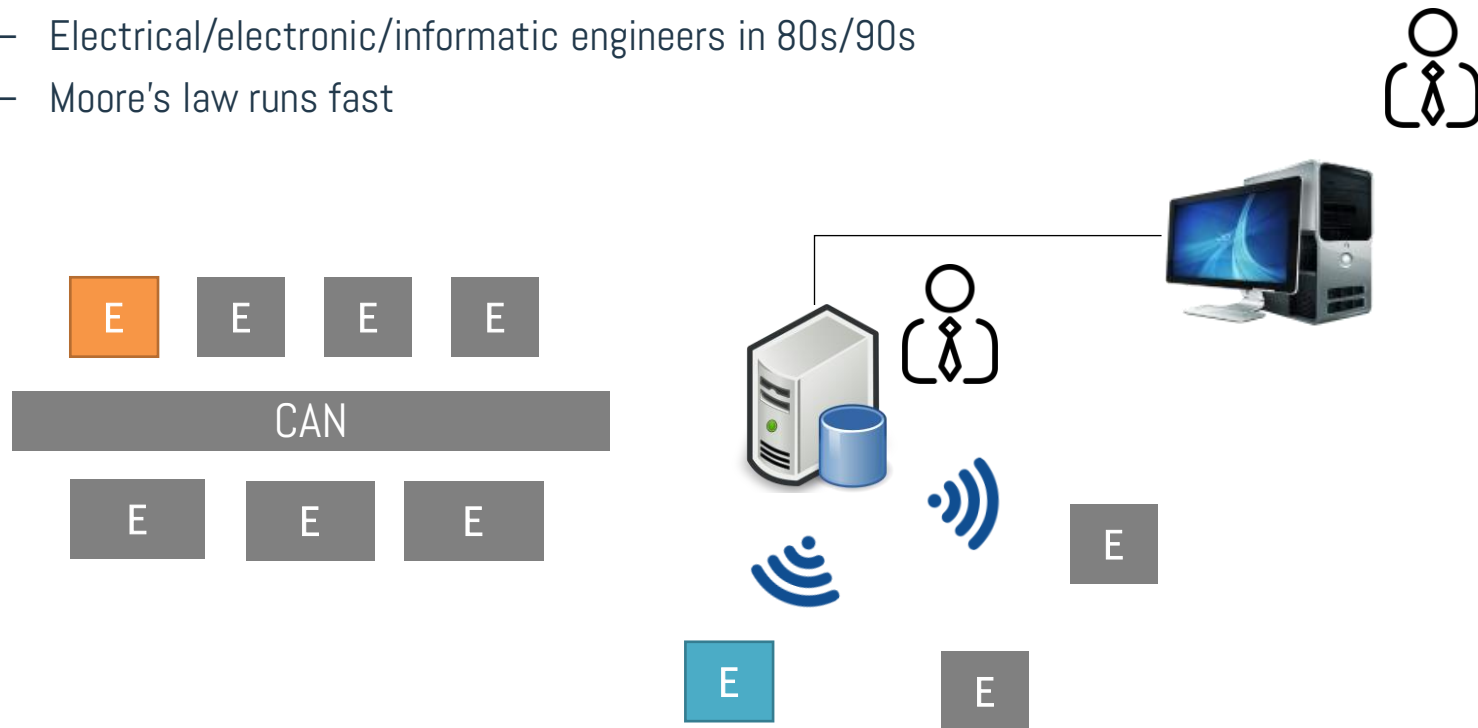
- › Wired: flexray, CAN (automotive), serial, (RT-)Ethernet
- › Wireless: WiFi, (soon) 4/5G due to the rise of IoT





Requirements for industrial edge devices

- › Low cost and form factor might be key feature
 - ...we can trade performance for that
 - Reliability, dependability, safety, security, 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

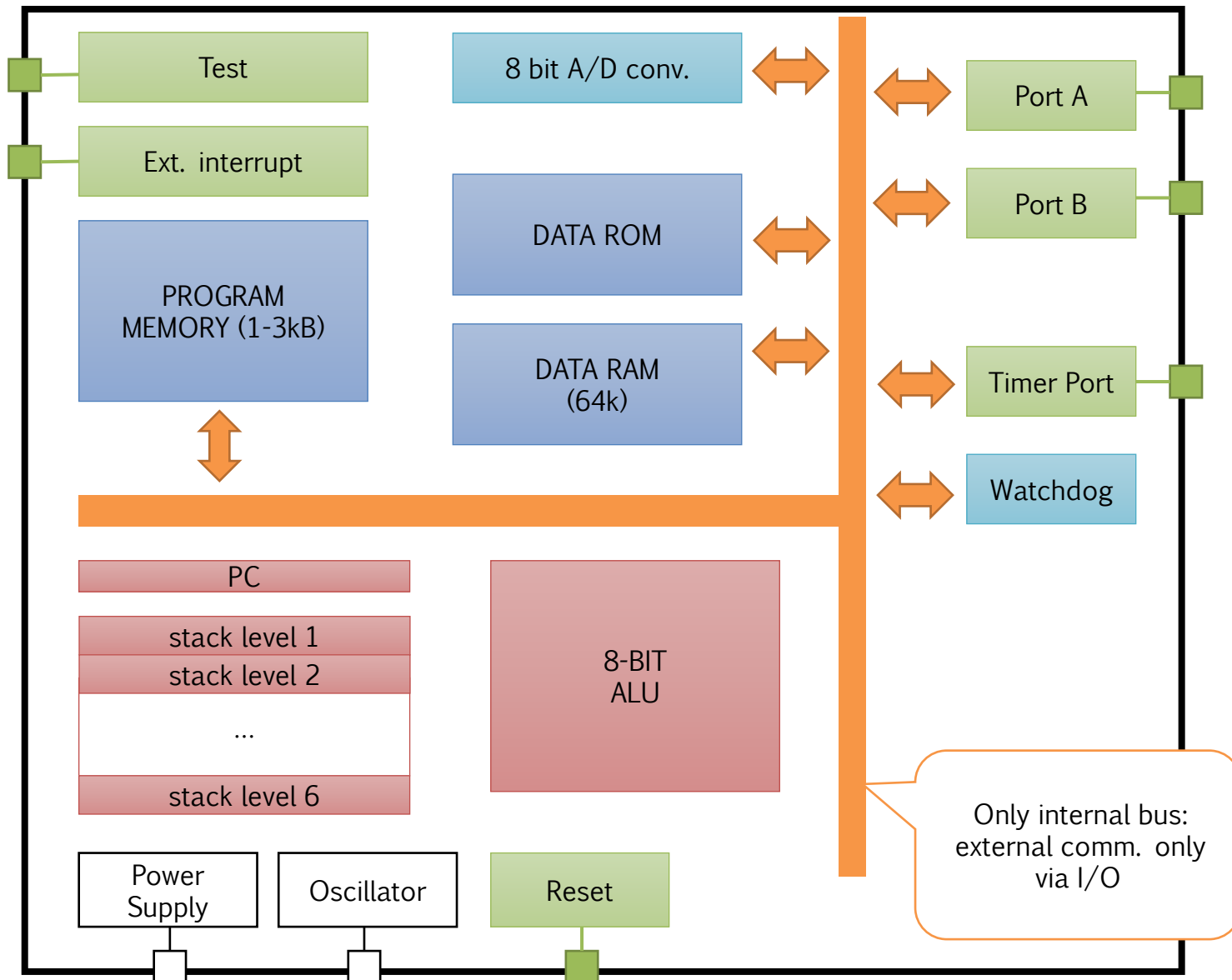
- › 8, 16, 32-bit processors, limited memory
- › Designed for I/O interaction, can poorly do more
- › Also, programmability might suffer (ASM)

We will see (and play with)

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



STM's ST6





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

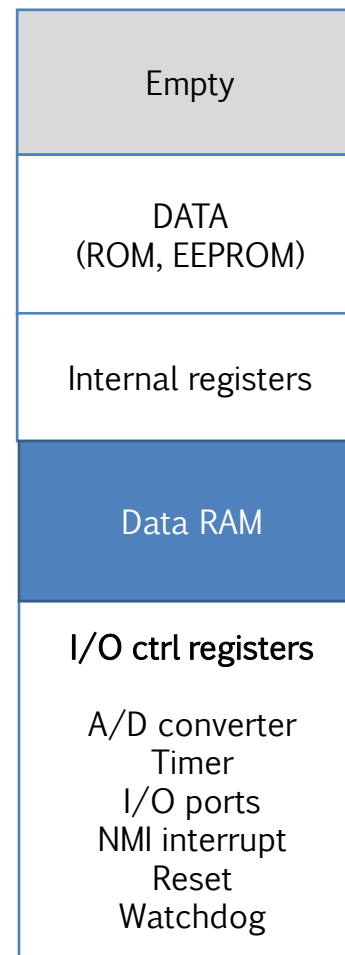
This is what programmers “see”

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

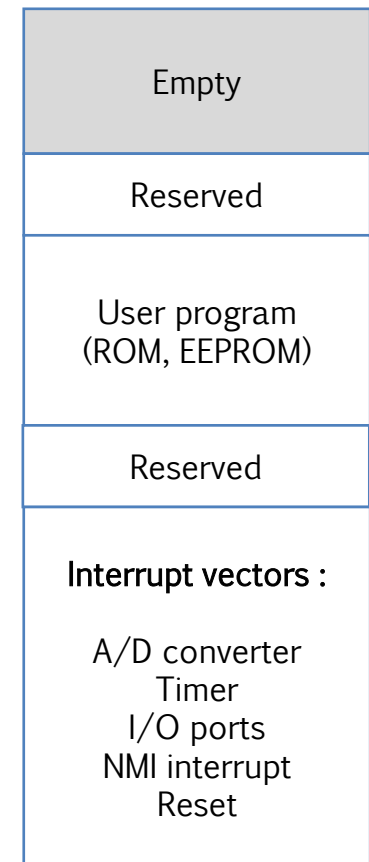
Program data (variables, ..) are in data RAM

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

Data memory

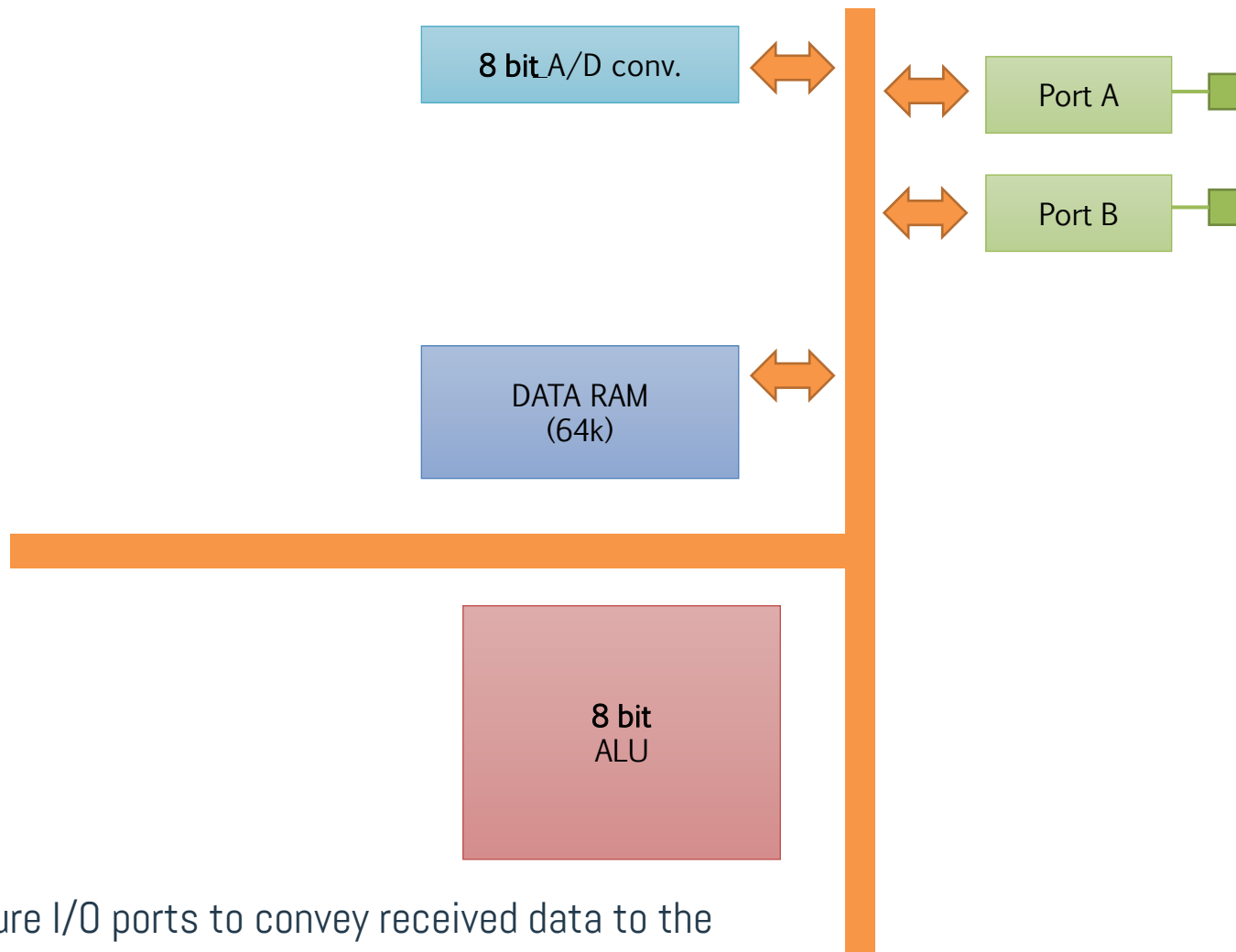


Program memory





A/D converter



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

- › Use memory-mapped registers

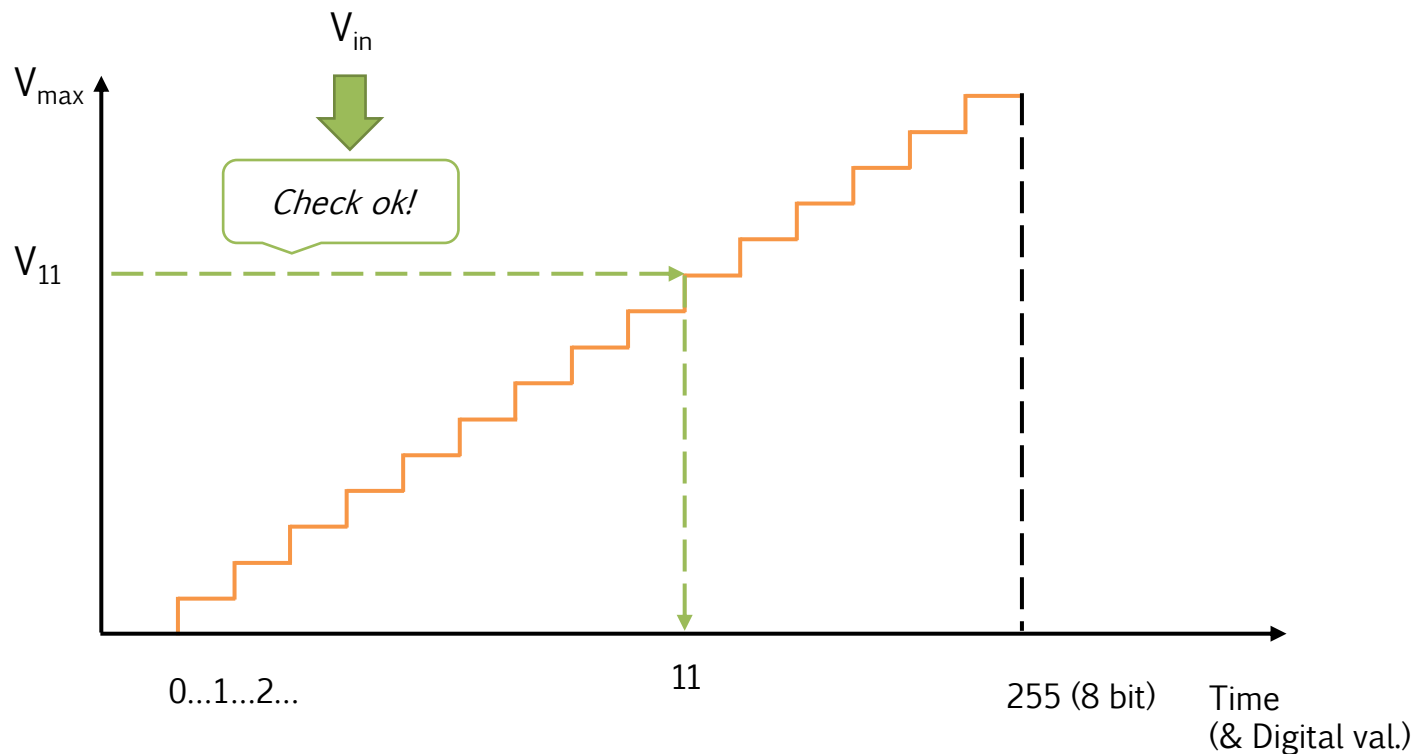


A/D conversion

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

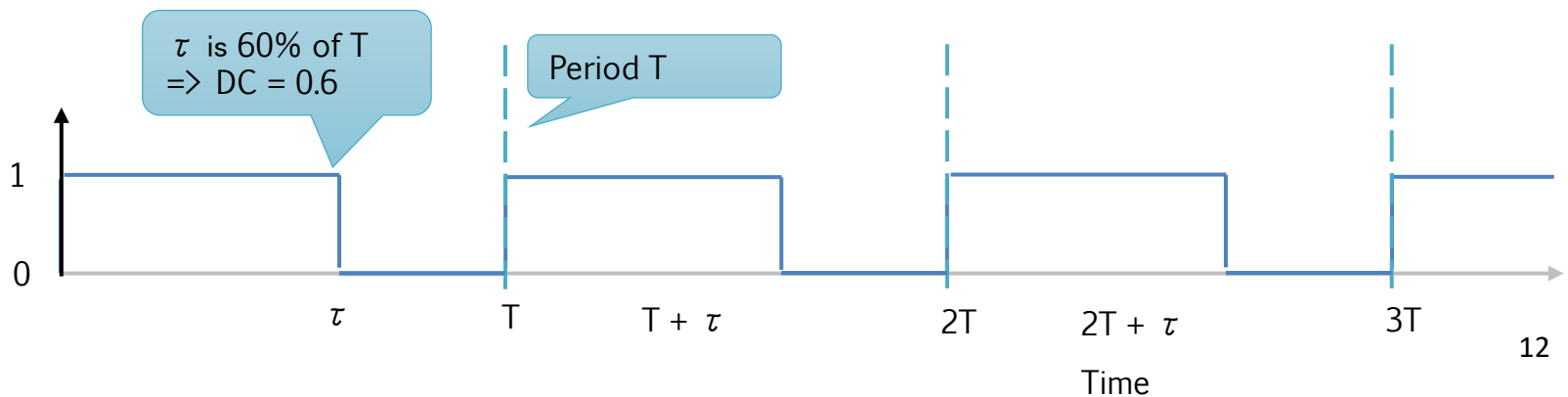
Generate a tension corresponding to a digital value stored in a register

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

$$DC = \tau / T$$

How it works

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! 😊

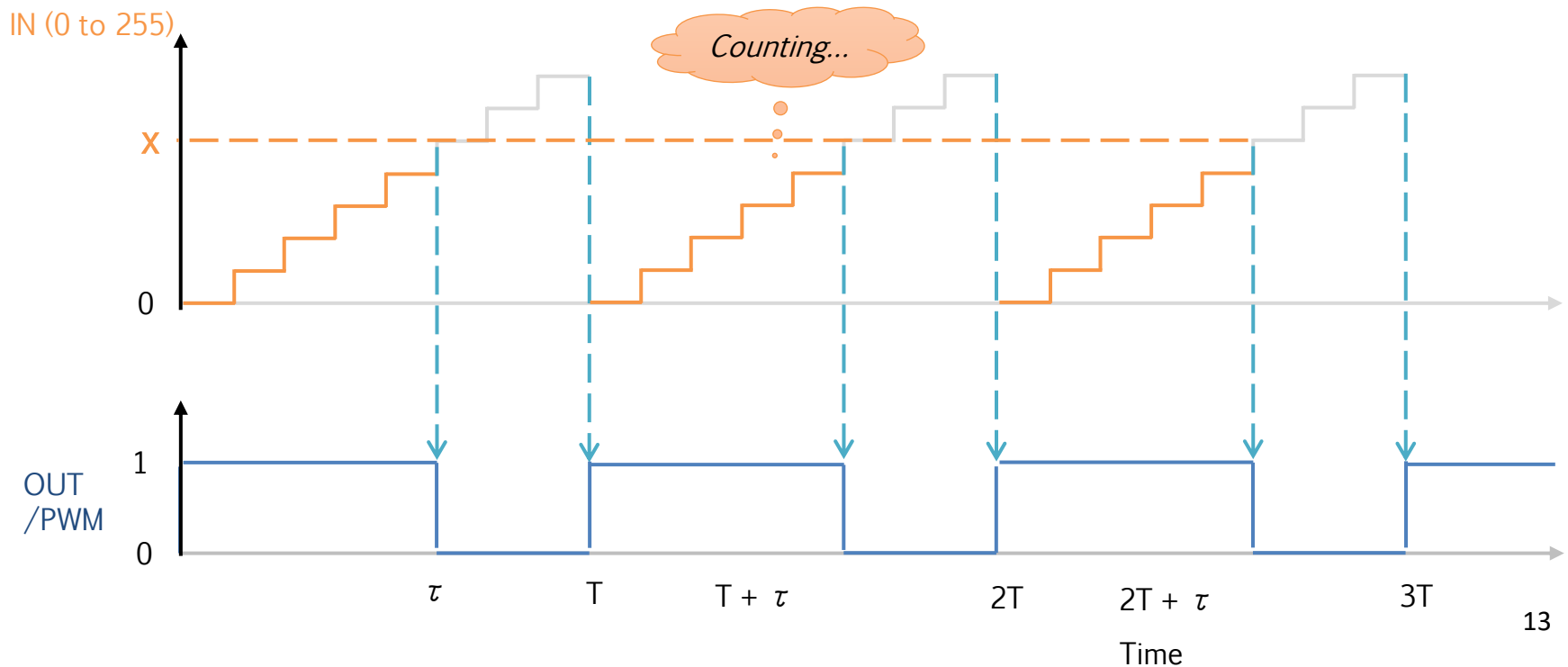




PWM – step 1

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





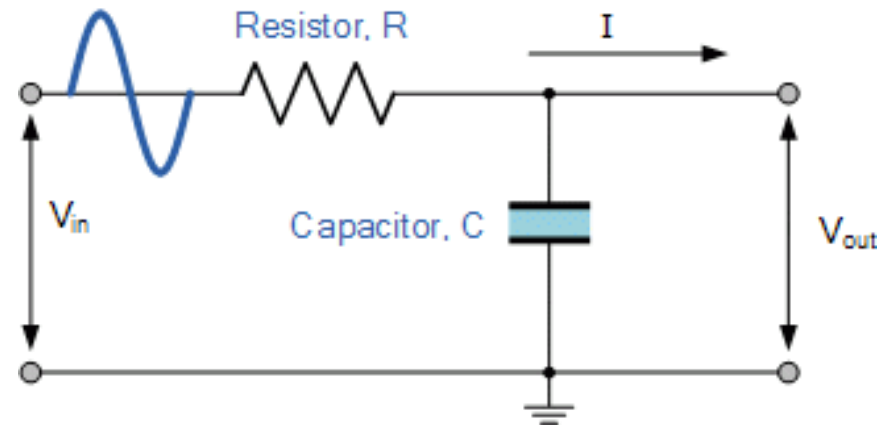
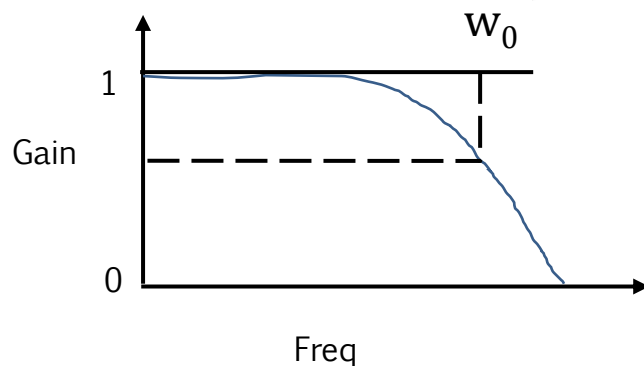
RC low-pass filter

Simple electric circuit with a Capacitor and a Resistance

› “Averages” the IN value

$$|V_{out}| = |V_{in}| \times \frac{1}{\sqrt{1 + \omega^2 R^2 C^2}}$$

Frequency domain



$$\text{Cutoff freq } \omega_0 = \frac{1}{RC}$$



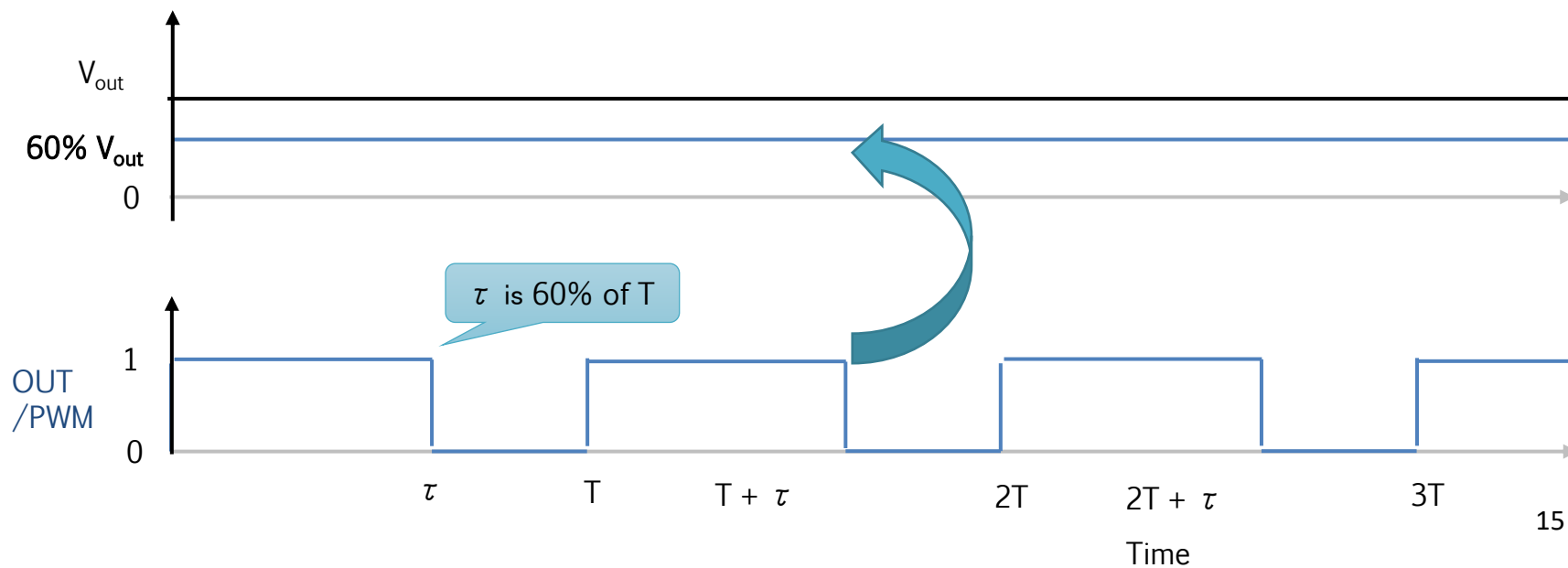
PWM – step 2

Now, compute the average for every T

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

Extremely useful in engine controls

ANALOG OUT





Application-Specific HW - 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

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

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

- › 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!

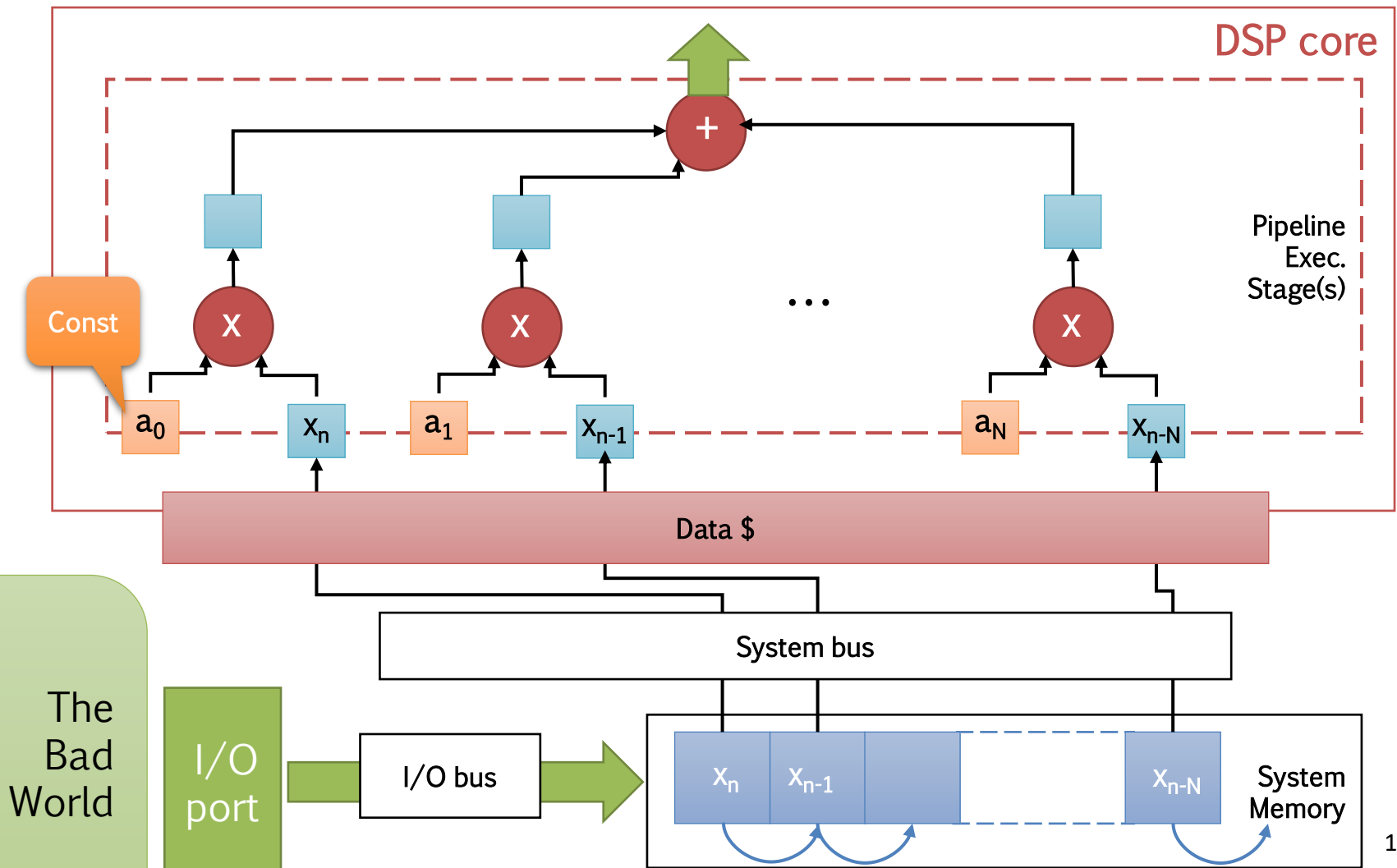
Assuming that

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



Data-parallel FIR

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





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 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....

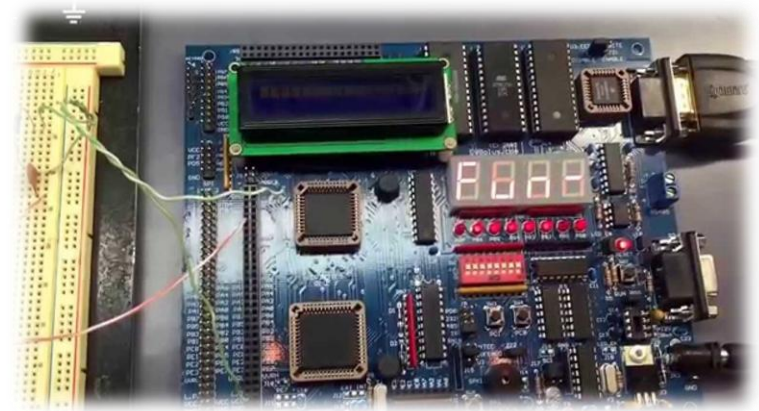
- › 8-bits might not be enough to capture wide data dynamics
- › Limited memory size
- › Poor programmability
 - In the worst case, assembly
- › Poor extendibility
- › Industry can stand more consuming, costly and bulky edge computers
 - Traded for performance



Micro Processor Units - MPUs

Motorola 68HC11

- › 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





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
 - Electrical diagrams
- › Structured Text – ST
 - Similar to Pascal/VB
- › Function Block Diagram – FBD
 - System level integration



PLC SIMATIC S7-1500

We will not see...

- › Sequential Functional Chart – SFC
 - Petri-net style
- › Instruction List – IL
 - ASM-like



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>