Aalto University
School of Engineering

Digital control devices

KON-C2004 Mechatronics Basics
Raine Viitala 26.11.2024

Overview

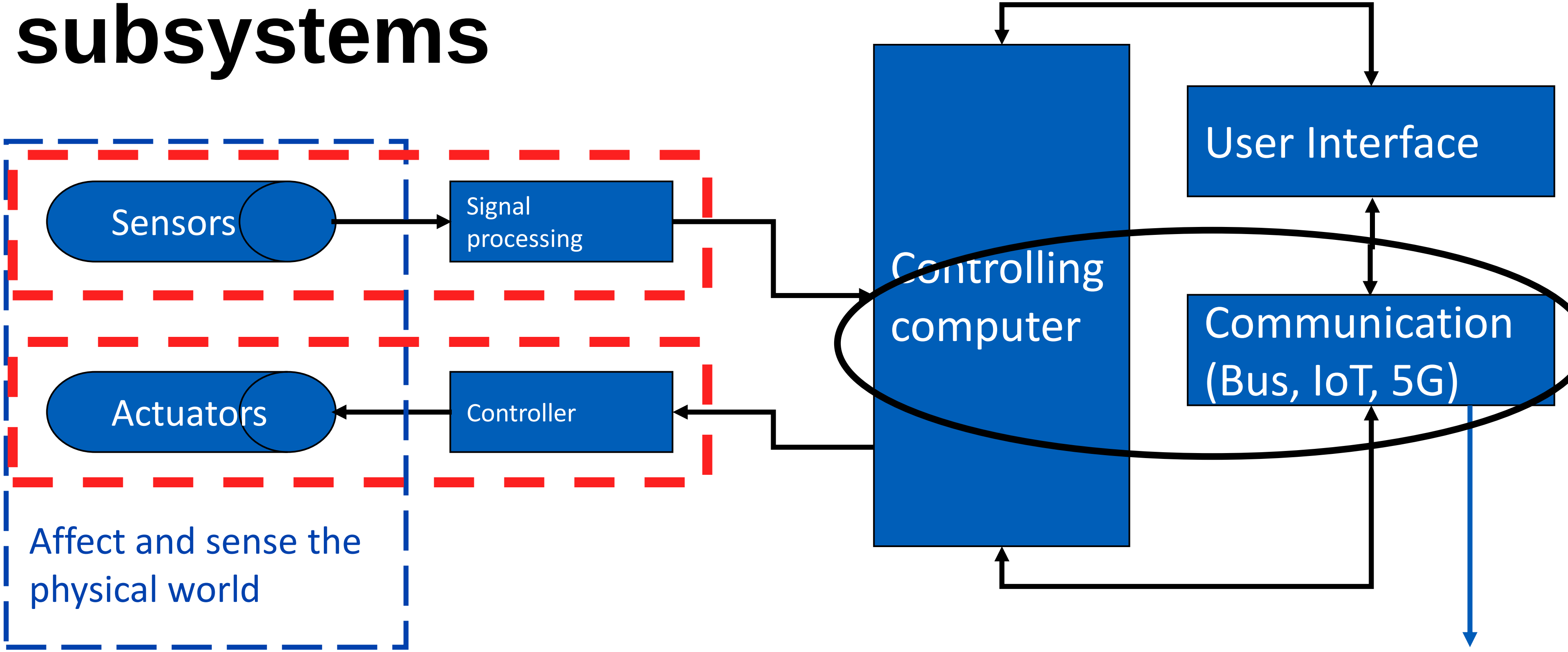
Real-time computing

Programmable logic controllers (PLC)

Other computing devices

Digital communication

Mechatronic machine - subsystems



Other systems and machines

Aalto-yliopisto
Aalto-universitetet
Aalto University

Real-time computing

Real-time

Guaranteed response in specified time frame

Hard realtime

- *Delayed result leads to system failure*

Firm

- *Delayed result is useless but some delays are tolerated*

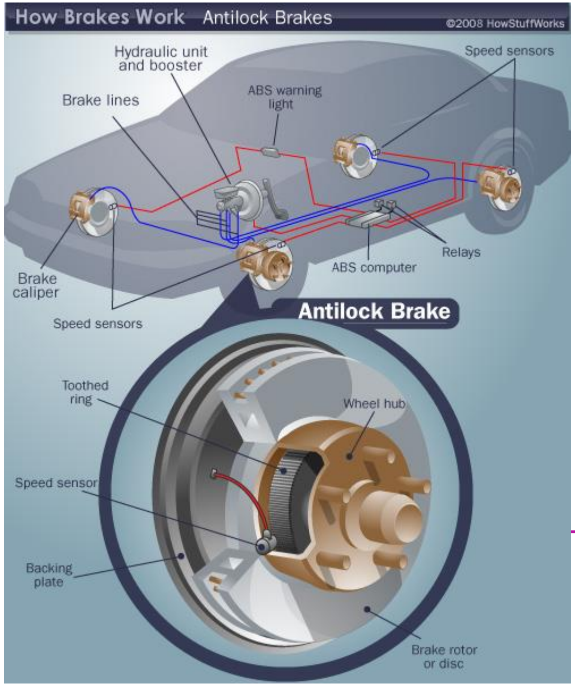
Soft realtime

- *Delay reduces the usefulness of the result*

Hard real time

Safety critical functions

- *Anti-lock braking etc.*
- *Fly-by-wire*



Firm real time

- *Control algorithms*
  - Performance and stability

Weekly exercises

solutions must be submitted in MyCourses before 10:00. Late submisissions are not accepted.

Soft real-time

Video playback, audio synthesizer

Real time ≠ high performance

Control system point of view

Control algorithm often relies on constant update interval

Too long delay -> unstable system

- *remember exercise!*

Sampling rate

- *Time between two updates of the control signal*

Delay

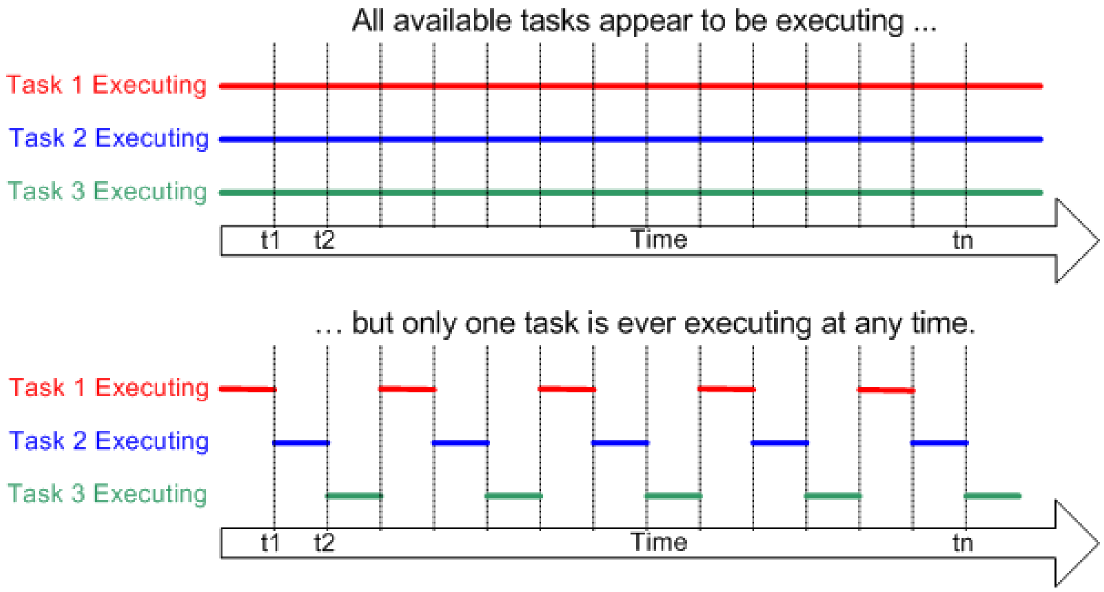
- *Time from input sampling to output*

Microcontroller real-time operation

Interrupt based scheduling

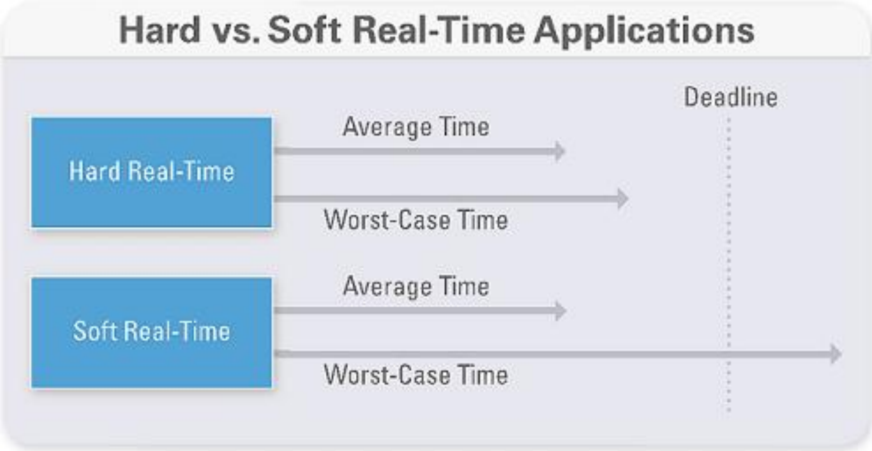
Possible tasks

- *Reading sensor input*
- *Control algorithm*
- *User interface*
- *Bus communication*



Real-time operating system

Definition: "A real-time behavior of a software system requires that each process or task execution must satisfy bounded response-time constraints or risk severe consequences, including failure."



http://www.ni.com/white-paper/14238/en/

Real-time operating systems

FreeRTOS

- *Microcontrollers*

Real-Time Linux

Simulink Real-Time with Speedgoat RT target computer and Labview Real-Time

- *Measurement and prototyping on PCs and FPGAs*

“Standard” Windows with real-time kernel extension (RTX)

PLCs

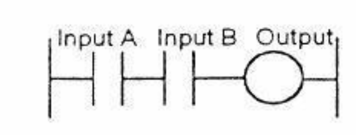
Programmable Logic Controllers

The traditional logic controller: Electromechanical relays

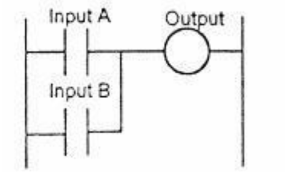
Still used for example in railway interlocking systems

Robust, long lifespan

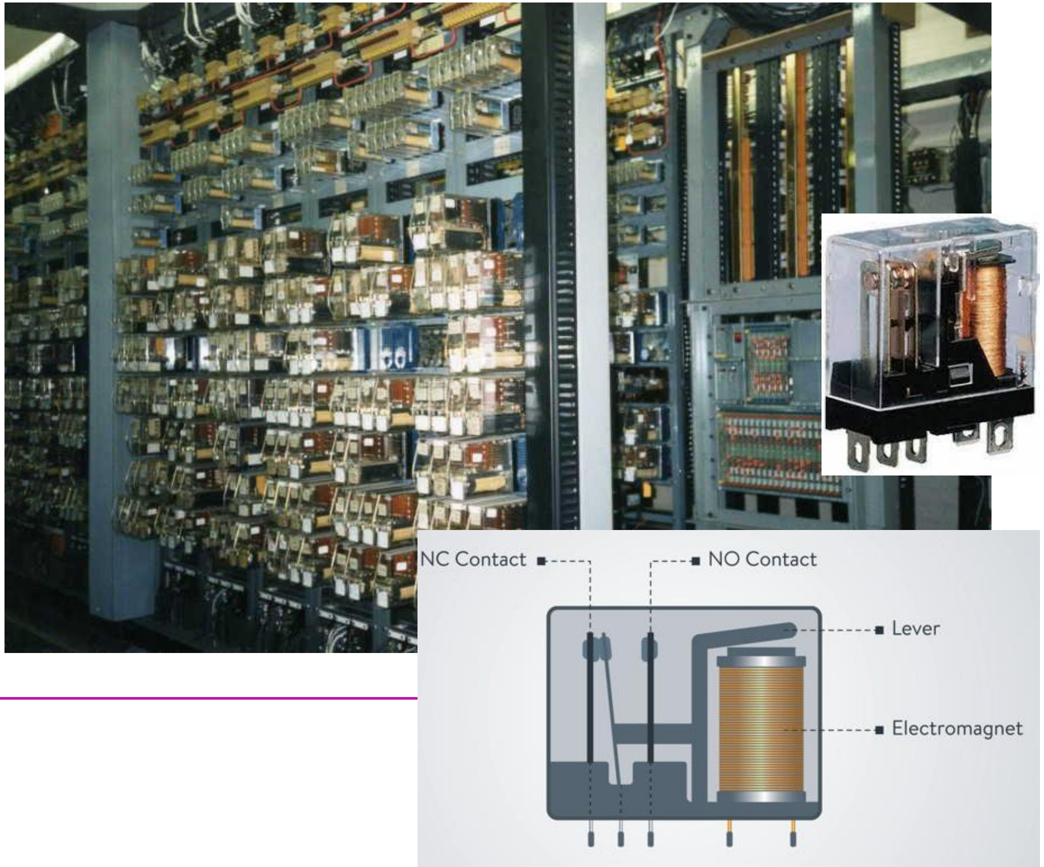
Expensive special relays

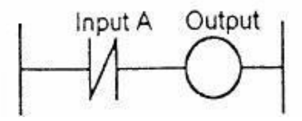


AND



OR





NOT

The better way: Programmable Logic Controller (PLC)

Resistant to

- *Electromagnetic interference*
- *Dust, vibration, heat resistant*

Modular

Off-the-shelf

Easy and simple to set up

- *In comparison to a microcontroller system*

DIN rail mounting

Higher voltage, better protected IO

http://i01.i.aliimg.com/img/pb/629/105/478/478105629_223.jpg

PLC vs microcontroller

PLC

- *Encased – protected from environment*
- *IO is protected? – from high voltage, outputs more current – does not break the whole device – often based on relays*
- *Modular – add more io*
- *Programmed with IEC 61131-3 languages – doable by an electrician*
- *Easily replaceable*
- *Expensive (not very)*

Microcontroller

- *Unprotected prototyping board*
- *For example 0-5 V low current I/O*
- *Programmed with low level language, for example C*
- *Extensions with communication bus and additional code*
- *Very cheap*

PLC vs PC

PLC

- *Program once, run forever*
- *Dedicated system*
- *Cheaper*
- *Programmable by electrician*
- *Limited user interface (buttons, maybe a screen)*
- *Built-in inputs*

PC

- *Lots of computing power*
- *Often regular software updates*
- *Display, flexible UI*
- *Inputs with extension cards*

PLC programming

Programmed typically with a PC (Ethernet, serial bus etc.)

Programming languages: IEC 61131-3

- *Ladder diagram (LD), graphical*
- *Function block diagram (FBD), graphical*
- *Structured text (ST), textual*
- *Instruction list (IL), textual*
- *Sequential function chart (SFC), has elements to organize programs for sequential and parallel control processing.*

Ladder diagram

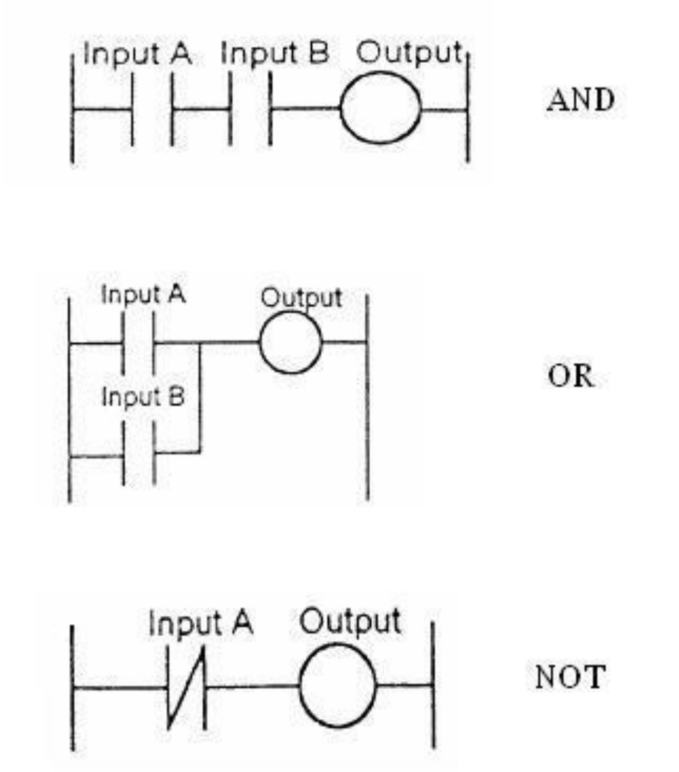
Similar to relay schematics

Understandable to electricians without any programming skills

By far the most used PLC language

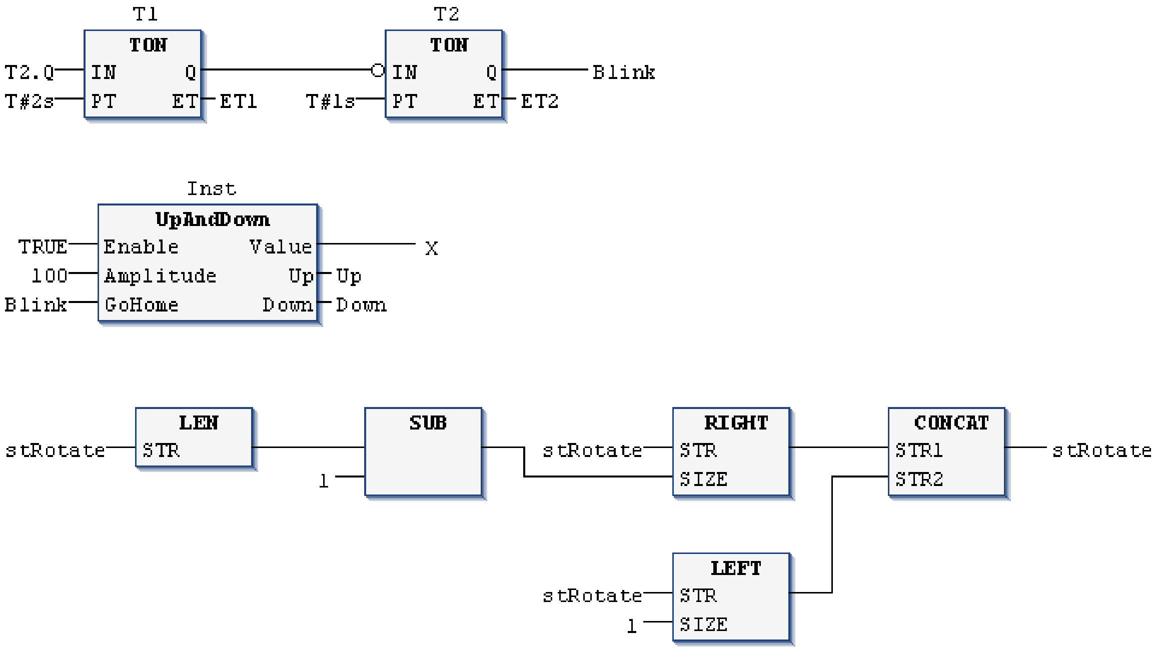
Also operators for

- *Mathematical operators*
- *Analog operators*
- *Timer operators etc.*



http://www.plcmanual.com/plc-programming

Function block diagram



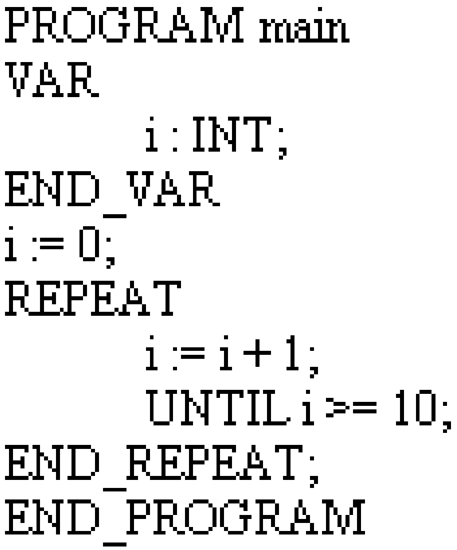
http://infosys.beckhoff.com/english.php?content=../content/1033/tc3_plc_intro/html/Function_Block_Diagram_FBD.htm&id=

Structured text

A bit like C or Pascal

Familiar expressions

- *If, while, for, function calls*

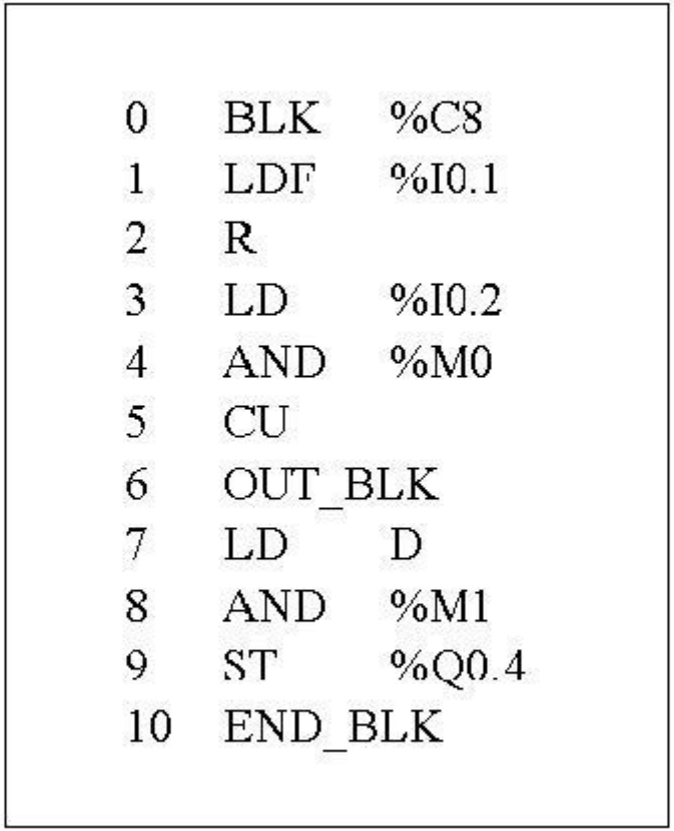


```
PROGRAM main
VAR
        i : INT;
END_VAR
i := 0;
REPEAT
        i := i + 1;
        UNTIL i >= 10;
END_REPEAT;
END_PROGRAM
```

http://www.thelearningpit.com/hj/plcs18.asp

Instruction list

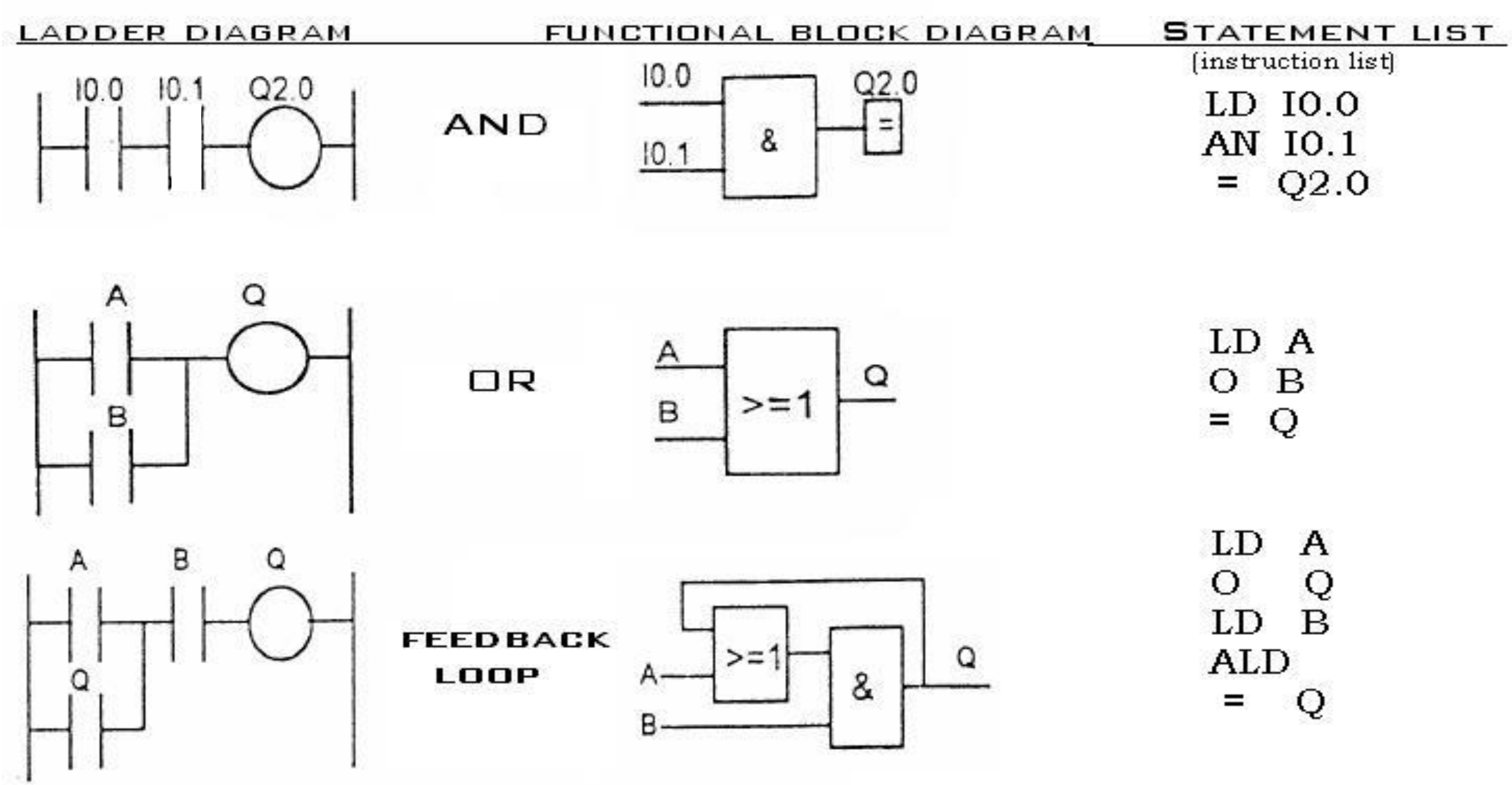
A bit like Assembly



```
0    BLK      %C8
1    LDF      %I0.1
2    R
3    LD       %I0.2
4    AND      %M0
5    CU
6    OUT_BLK
7    LD       D
8    AND      %M1
9    ST       %Q0.4
10   END_BLK
```

http://4.bp.blogspot.com/-V67KQWGCQC4/T30JnZx7saI/AAAAAAAAAcM/BygizcA-ASI/s1600/untitled.JPG

Ladder vs FBD vs IL



```
LD  I0.0
AN  I0.1
=   Q2.0
```

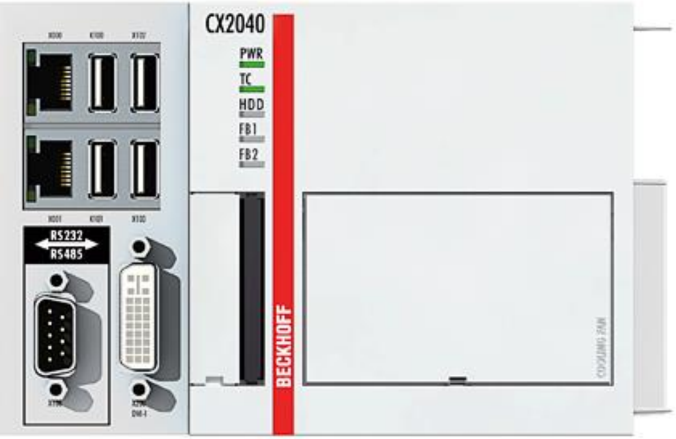
```
LD  A
O   B
=   Q
```

```
LD   A
O    Q
LD   B
ALD
 =   Q
```

http://www.plcmanual.com/plc-programming

Soft PLC

Example: Beckhoff industrial PCs

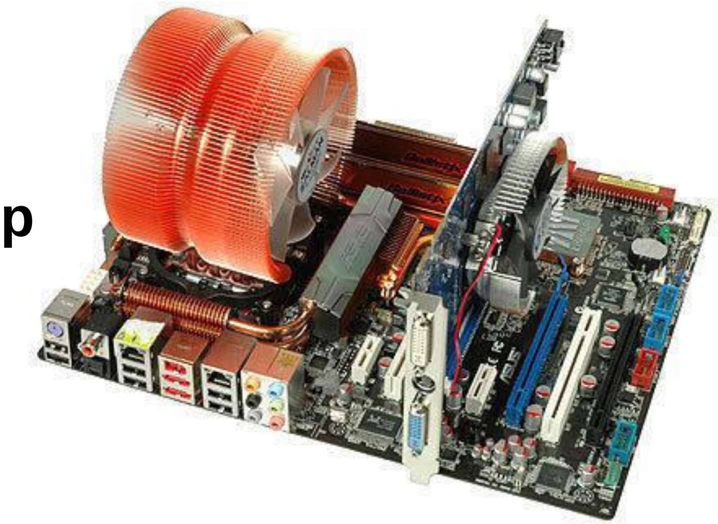


http://beckhoff.com/

Other computing devices

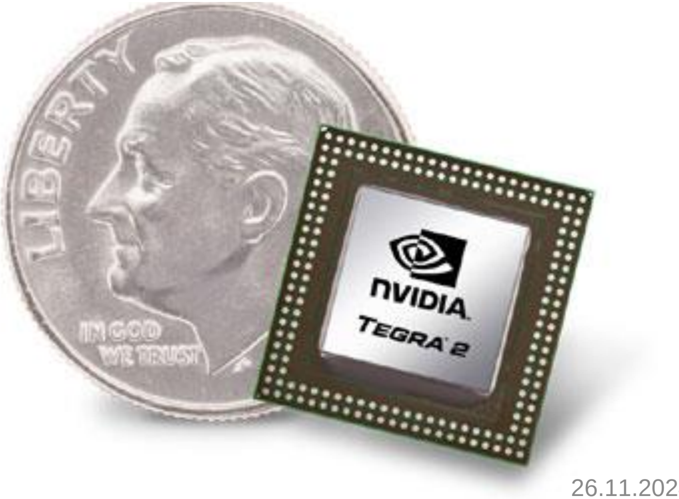
System on a chip (SoC)

http://www.ubergizmo.com/what-is/system-on-a-chip/



All components of a computer on one chip

- *Microprocessor*
- *Memories*
- *Peripherals*
    - Graphics and audio prosessors
    - Wireless transmitters
    - Battery management



Relatively low energy consumption

Used in cell phones and tablets

Example: Neo research platform for autonomous driving

Affordable hardware

- *Oneplus 3 cell phone*
  - Powerful SoC
  - Camera
  - GPS
- *CAN bus communication with car*

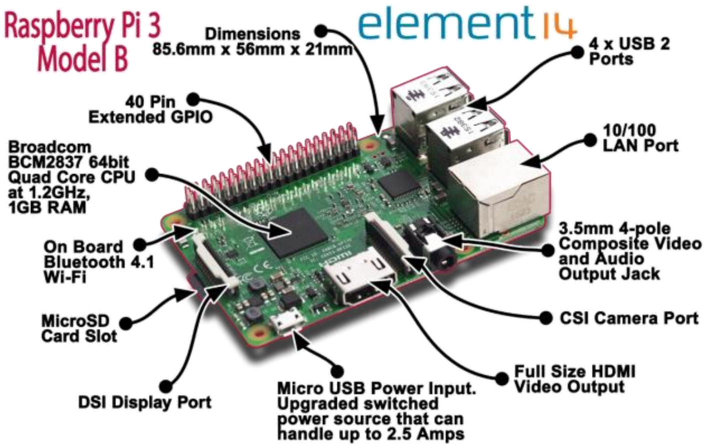
Open source software

- *Stripped Android*
- *Neural network*

Single board computers

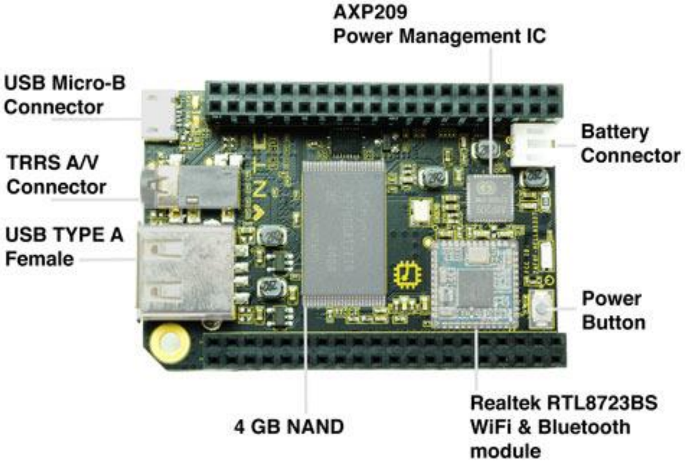
Raspberry Pi 3 – 35 $

- Broadcom BCM2837 SoC with 1.2 GHz processor, 1 GB RAM
- GPU, HDMI out
- Ethernet, Bluetooth, GPIO, MicroSD


Raspberry Pi 3 Model B
element14
Dimensions 85.6mm x 56mm x 21mm
4 x USB 2 Ports
40 Pin Extended GPIO
10/100 LAN Port
Broadcom BCM2837 64bit Quad Core CPU at 1.2GHz, 1GB RAM
3.5mm 4-pole Composite Video and Audio Output Jack
On Board Bluetooth 4.1 Wi-Fi
CSI Camera Port
MicroSD Card Slot
Full Size HDMI Video Output
DSI Display Port
Micro USB Power Input. Upgraded switched power source that can handle up to 2.5 Amps

CHIP – 9 $

- *1 GHz Allwinner R8 SoC, 512 MB RAM*
- *USB, composite video, Wifi, Bluetooth, GPIO*
- *4 GB onboard flash memory*
- *Battery management*



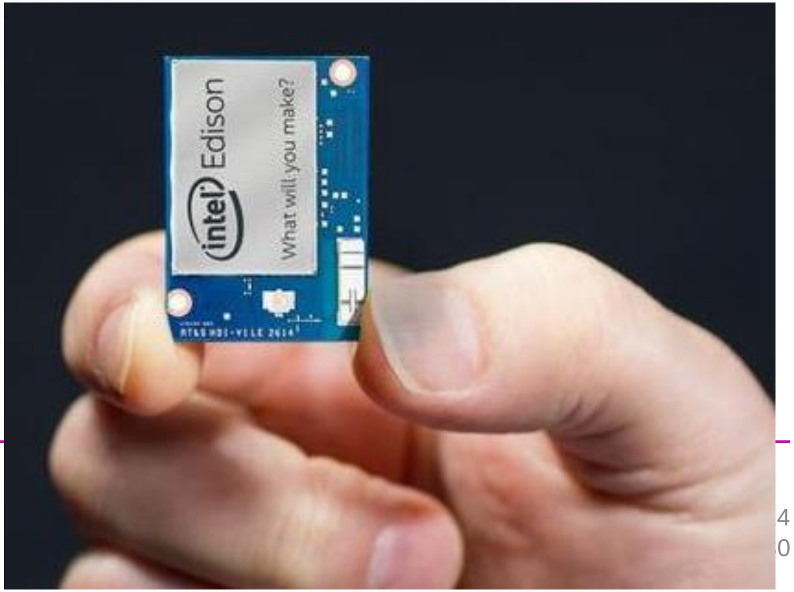
Computing modules

Raspberry Pi 3 - 30 $

- *Same SoC as in Raspberry Pi 3*
  - 1,2 GHz, 1GB RAM
- *4 GB flash memory*
- *SODIMM connector*

Intel Edison – 50 $

- *500 MHz Atom, 512 MB RAM*
- *Integrated microcontroller*
- *4 GB flash*
- *Wifi, Bluetooth, 40 GPIO*
- *Linux, Arduino, C/C++, Python…*



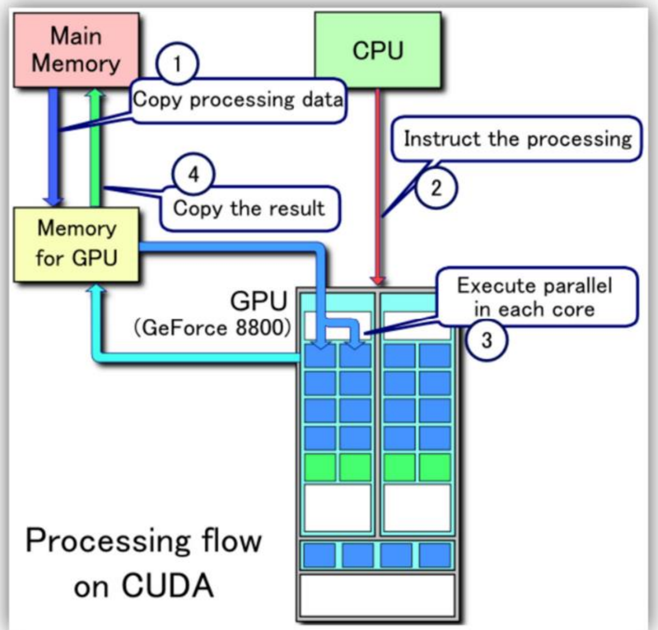
Graphics processors

CPU – a 1-8 cores, GPU – thousands of cores

- *Efficient parallel processing*
- *Non-regressive simulations, machine learning, neural networks*

Fast floating point value calculations

- *Signal and image processing*



http://www.rugged.com/sites/default/files/High%20Perfomance%20GPGPU%20for%20Embedded%20Systems.pdf

FPGA – field programmable gate array

Hardware implementation, no software

- *Programmatically reconfigurable logic circuit*

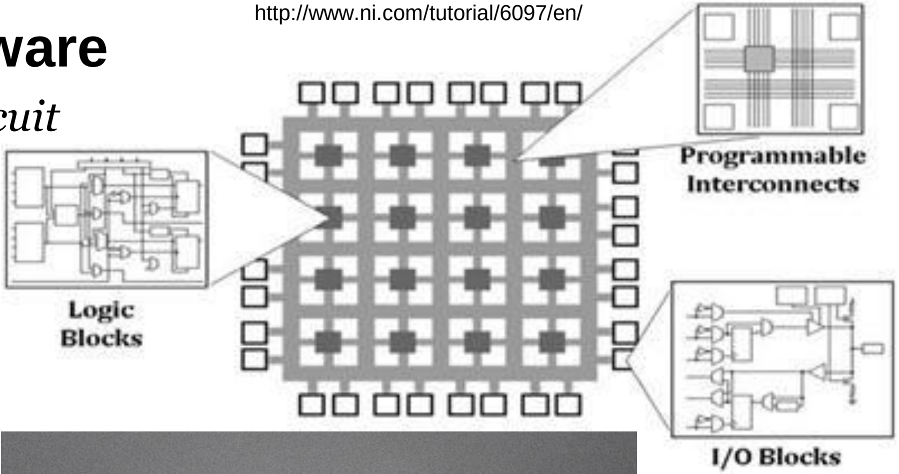
Parallel processing

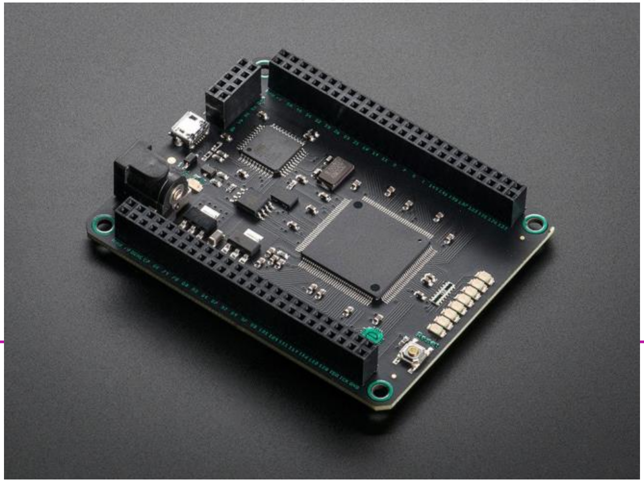
Very fast response time (<μs)

High performance per watt

Hardware Description Language

http://www.ni.com/tutorial/6097/en/





https://www.adafruit.com/products/1553

Digital communication

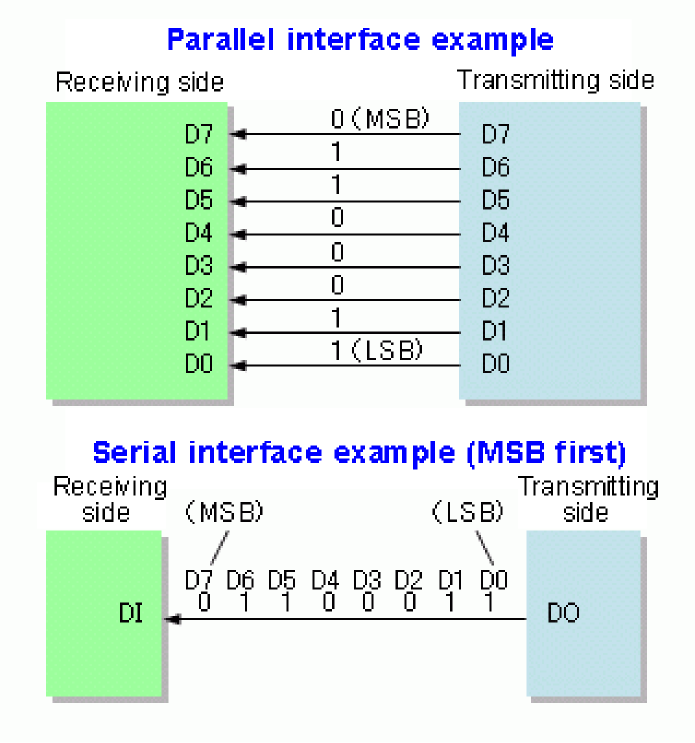
Parallel vs serial communication

Parallel

- *Bits transmitted simultaneously in parallel wires*

Serial

- *Bits sequentially in the same line*



http://en.wikipedia.org/wiki/Parallel_communication

Serial and parallel buses

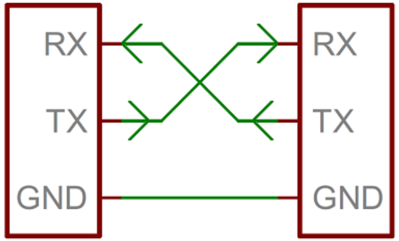
Serial

- *USB (Universal Serial Bus)*
- *Ethernet*
- *PCI-e, SATA*
- *RS-232*
- *I²C, SPI*
- *CAN, Profibus, Fieldbus foundation, AS-interface*

Parallel

- *PCI*
- *SCSI*
- *IDE*
- *Printer port*

RS-232

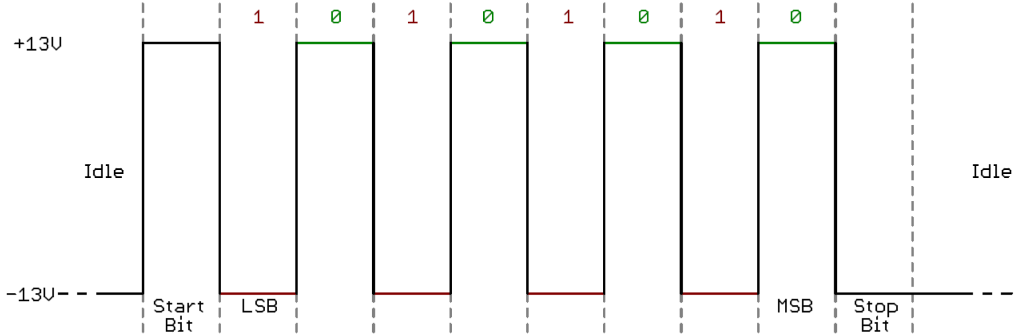


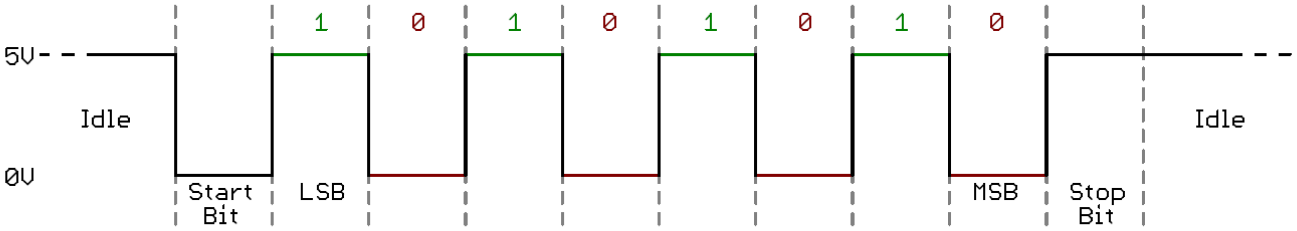
Also known as ”Serial bus”

Voltage level 3-15 V

- *Negative = 1*
- *Positive = 0*
- *Also TTL (0-5 V)*

< 0.5 Mbit/s





https://learn.sparkfun.com/tutorials/serial-communication

Field buses

AS-Interface

Modbus

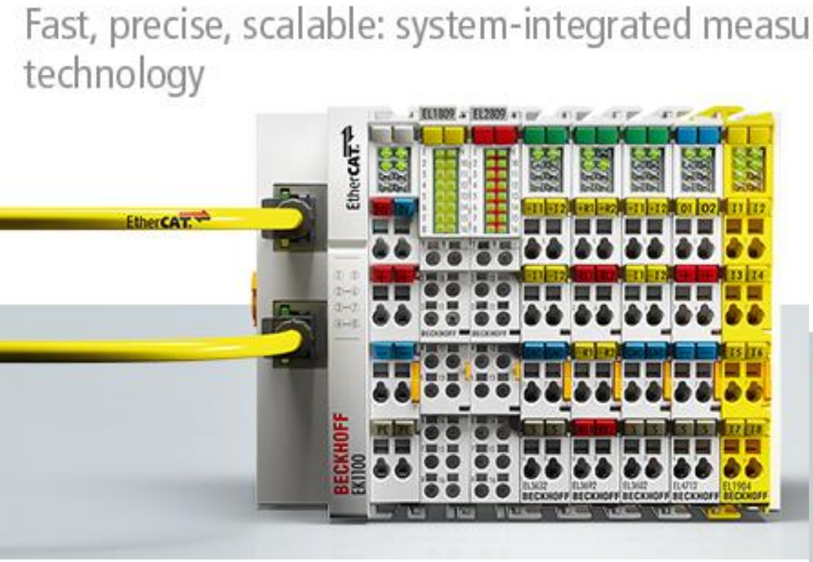
Foundation Fieldbus

Profibus/Profinet

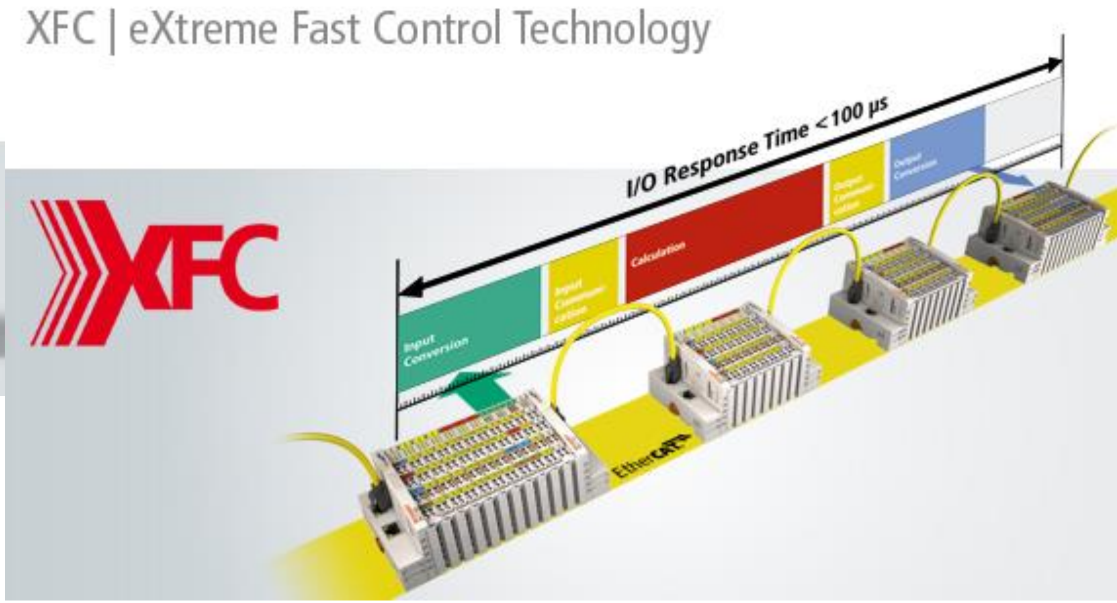
Interbus

EtherCAT

Example: EtherCAT bus



Fast, precise, scalable: system-integrated measurement technology



XFC | eXtreme Fast Control Technology

http://beckhoff.com/

Industrial wireless communication

”Generic RF”

- *<1 GHz*

Bluetooth

- *2,4-2,5 GHz*

Wifi

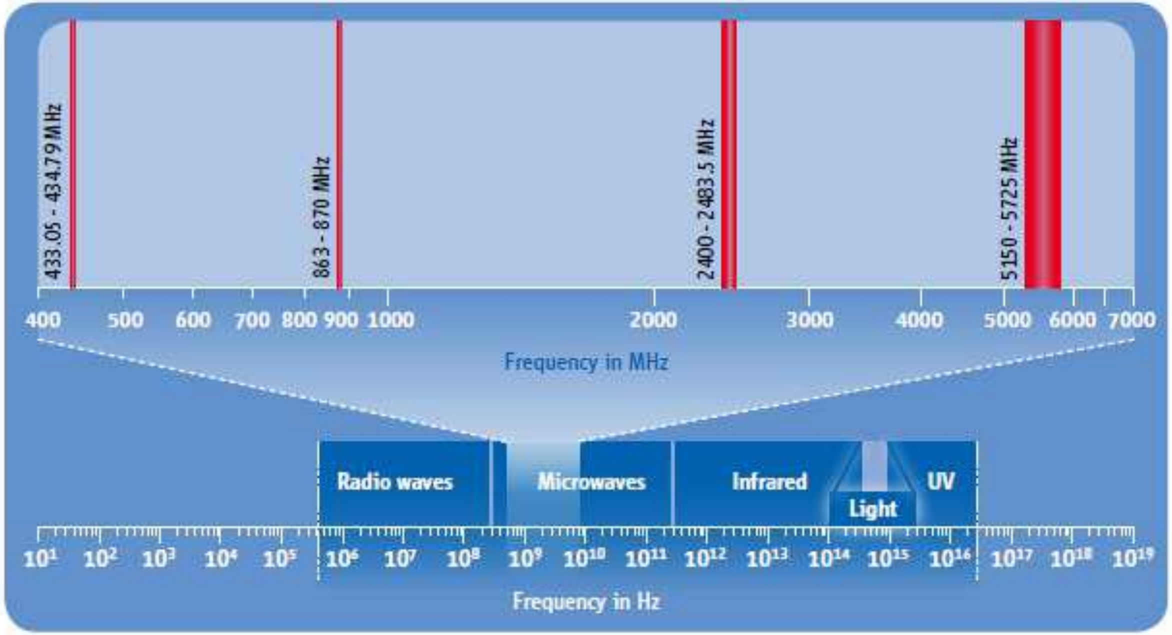
- *2,4-5 GHz*

IEEE 802.15.4

- *2,4 GHz*
- *Wireless HART Zigbee, ISA100.11a*

5G

RFID



http://www.iestcfa.org/presentations/sies11/keynote_Svensson.pdf

Summary

Real-time computing is required for most control systems

Microcontrollers are for embedded systems and hobby stuff

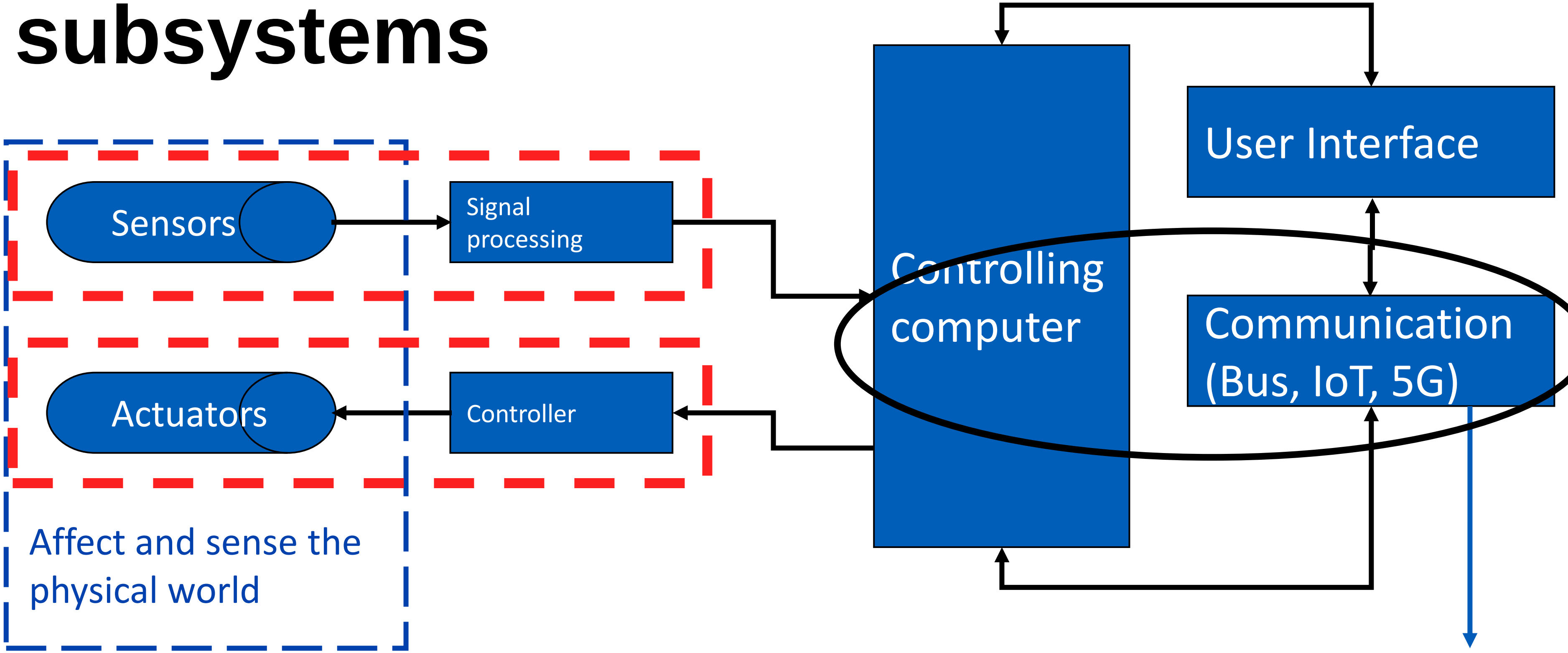
PLC is the multipurpose logic tool of industry

- *Robust, simple*

There is no universal digital communication standard in the industry, instead several competing standards

What is the future of wireless industrial communication?

Mechatronic machine - subsystems



Other systems and machines

Exam 12.12.2024 12.00-16.00

- **The exam is arranged locally**
  - Exam tasks will be published in MyCourses – very similar to exercises.
  - All material can be used, except generative AI.
  - MyCourses exam page “Exam 12.12.2024” will have detailed instructions. Please read them before the exam starts.
- **You must go to a certain computer classroom depending on the first letter of your last name**
  - Y430, U256 or U257 (Undergraduate center) – distribution will be published in MyCo.
  - The gatekeeper password to open the exam tasks in MyCourses will be delivered in the computer classroom.
  - The password is visible, and the gatekeeper is active 12.00-13.00 -> you must join within that time.
  - Entering the classroom is possible before 12.00 and 12.15-13.00.
- **No communication allowed between the students**
- **No chatGPT or other generative AI allowed**
  - We will monitor the computer screens with a specified exam software in the classrooms.
  - The students will be monitored with exam attendants walking around in the classroom

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The end

Give feedback!

*In your feedback, please consider your answers from the **learning** viewpoint, not the convenience.*