Control Systems

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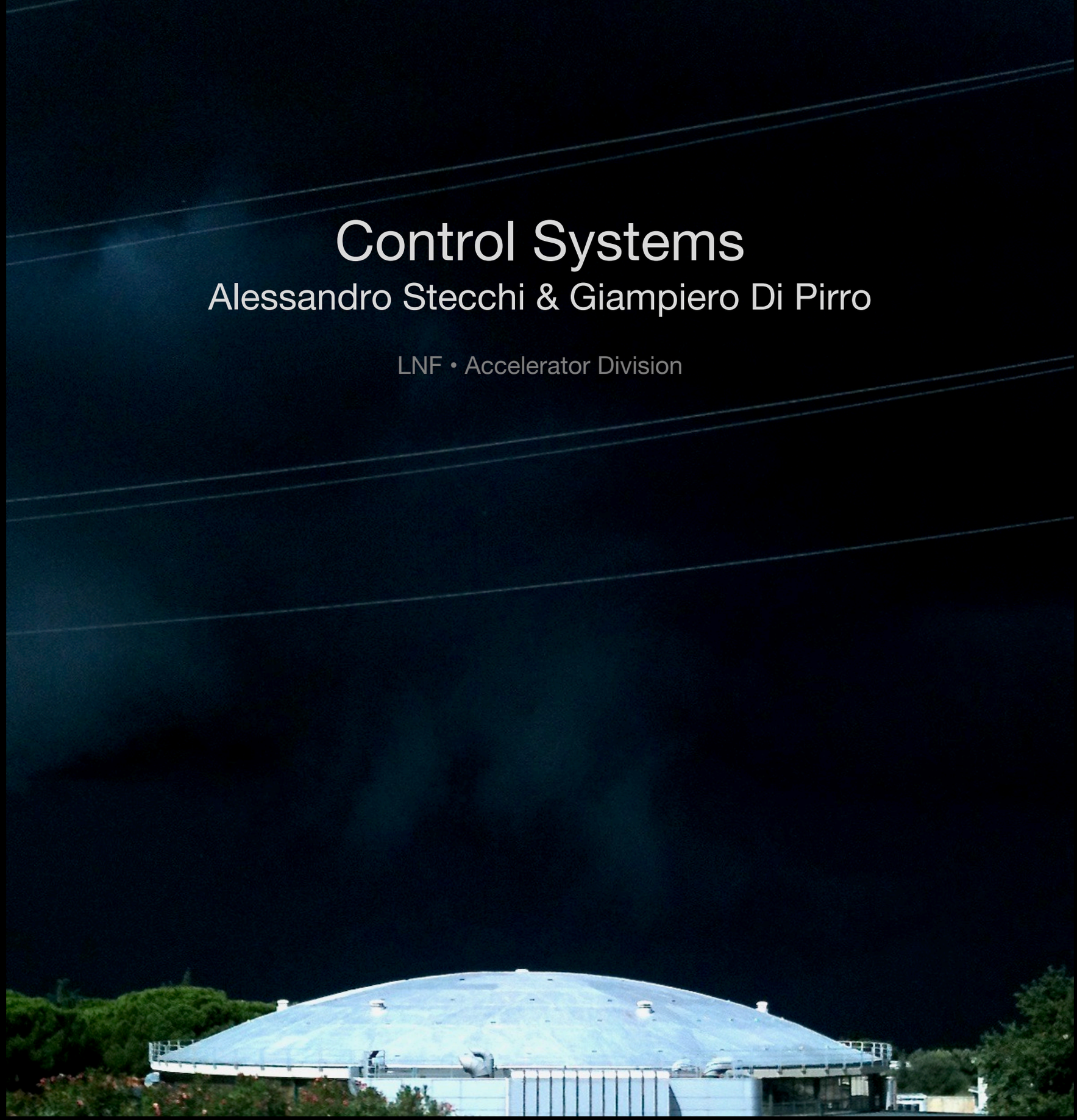
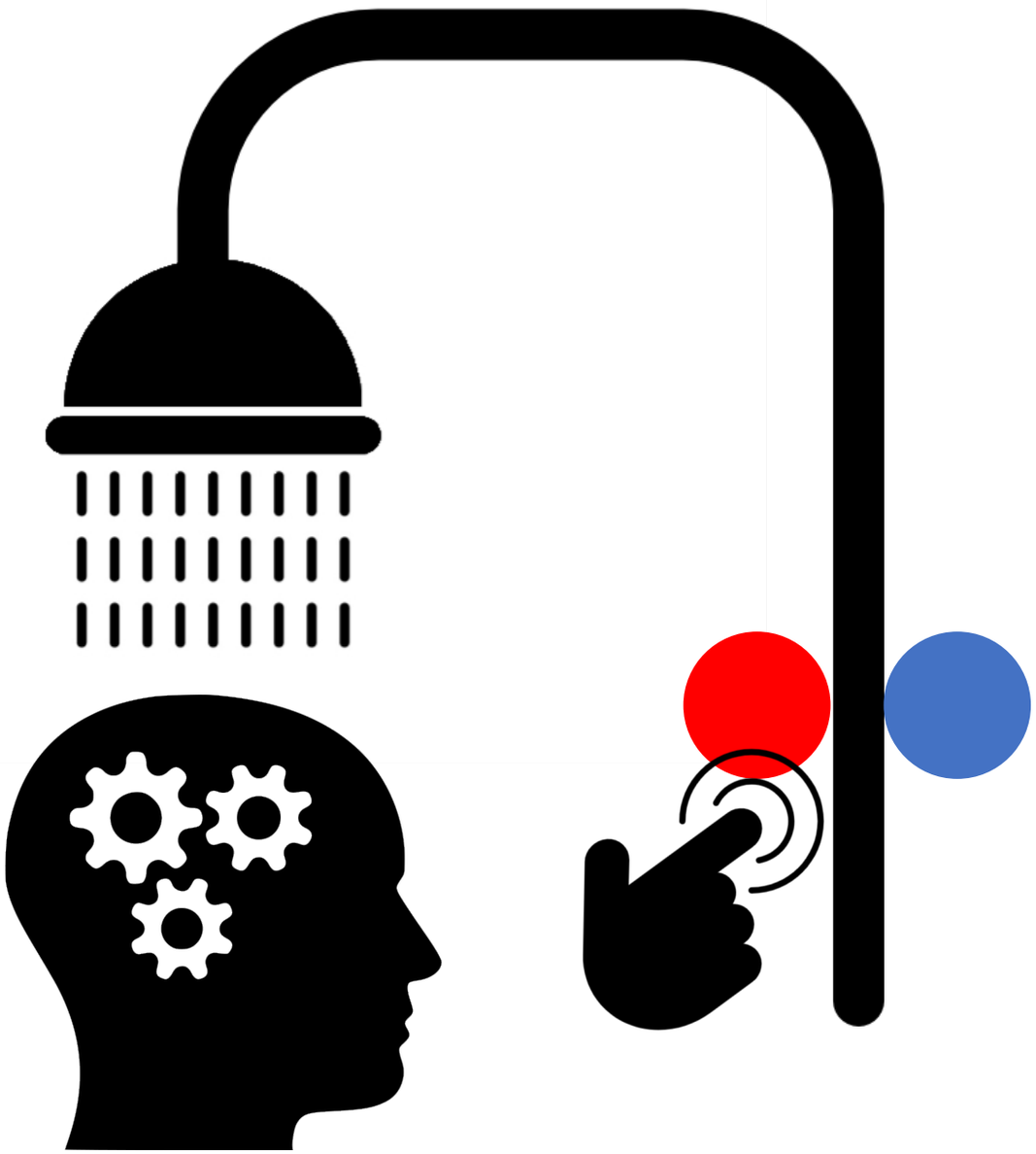
LNF • Accelerator Division




Video courtesy of SpaceX
SPEED
445
KM/H
ALTITUDE
0.4
KM
STAGE 1 TELEMETRY
ENTRY
LANDING
SECO-1
T+00:08:30
STARLINK
SPEED
23908
KM/H
ALTITUDE
211
KM
STAGE 2 TELEMETRY

A Control System is a system that allows the **output variables** of a **process** to be varied (or kept constant) according to **predetermined laws**.

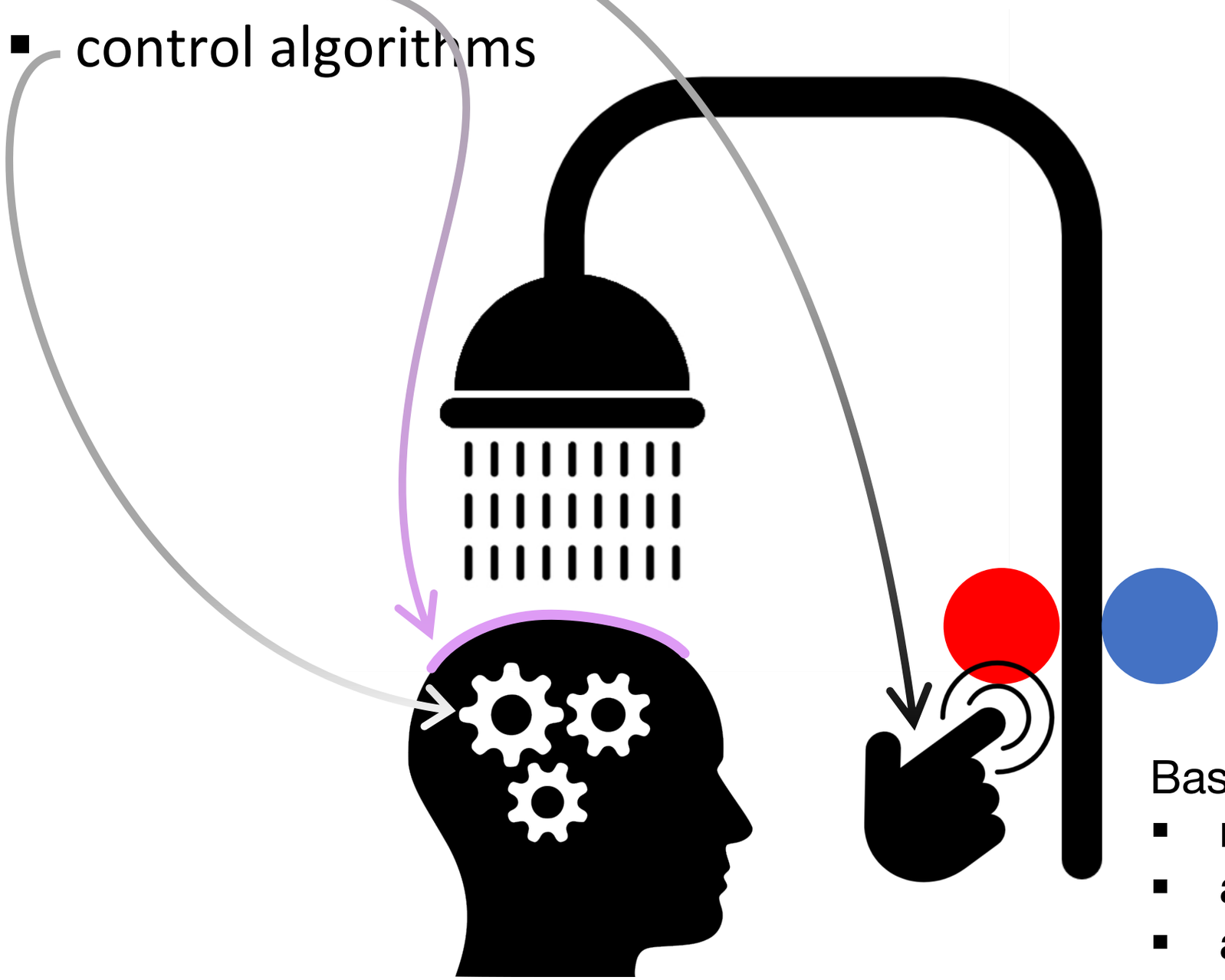


Open loop
Action is based on an algorithm and initial **static information**.

Closed loop
Action is based on an algorithm and **dynamic information** continuously read back from the controlled system.

Key elements of a Control System:

- actuators
- sensors
- control algorithms



Basic functions

- monitor
- actuating
- automatic adjustment

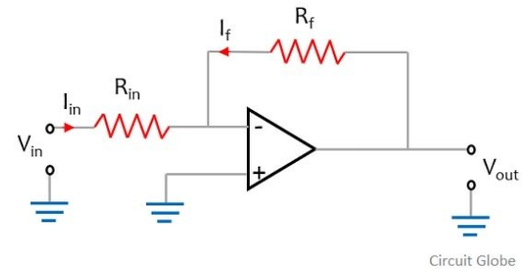
Fields of application of control systems

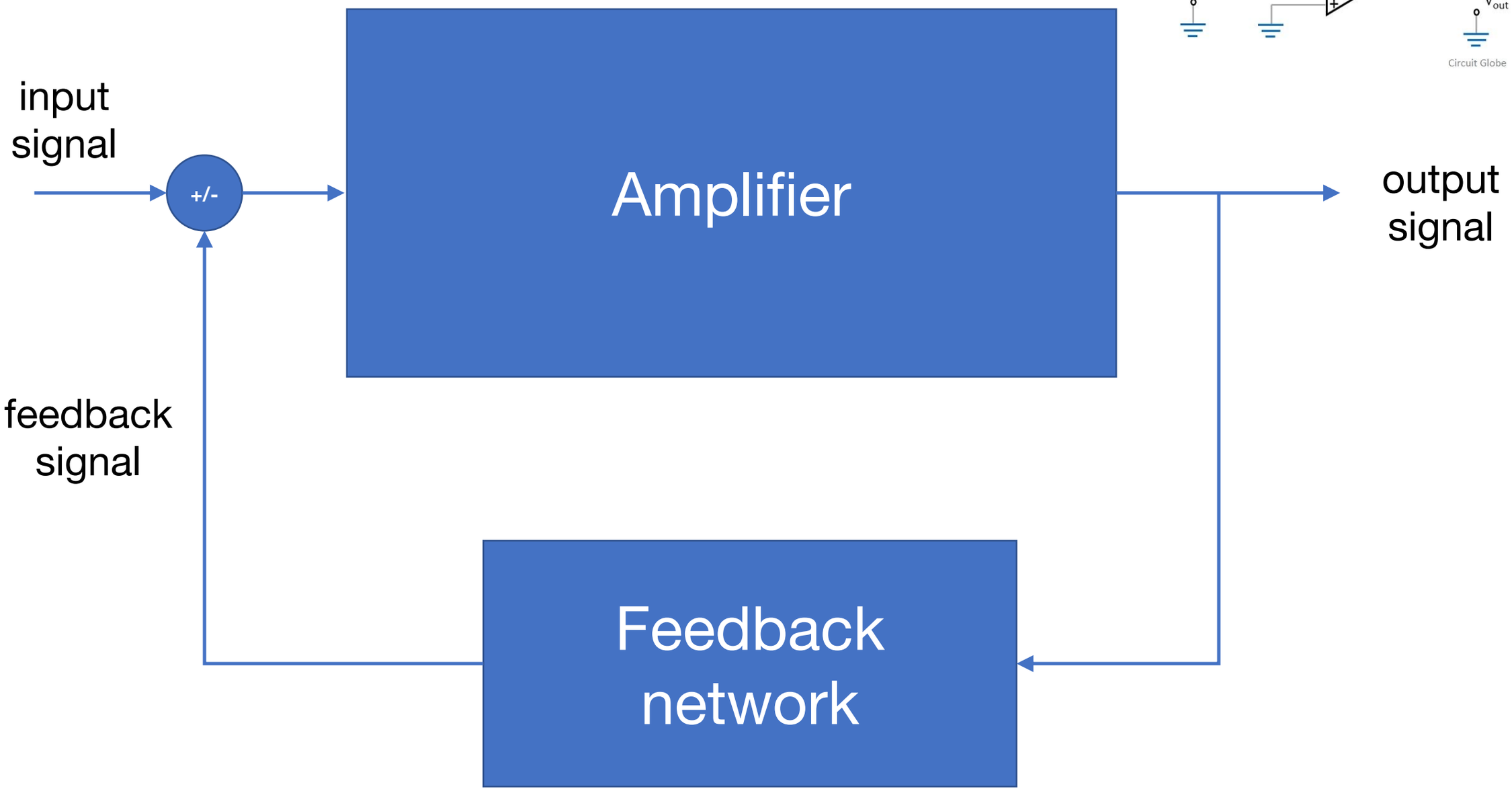
Civil, Social
- home automation
- automotive, aeronautics
- building climate control (ESCO: Energy Service Company)
- agriculture
- medical equipment, radiotherapy, diagnostics
- telecommunications

Industrial
- production lines (robots)
- prognostics
- thermal, electrical, nuclear power plants

Scientific
- automatic rovers, space probes
- astronomy
- experimental apparatus, detectors, particle accelerators

What physicists and engineers usually mean by *Control System*



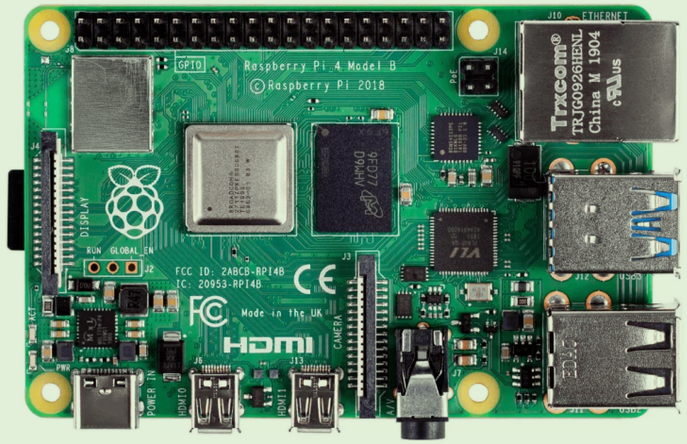


Controls adopting "CPUs"

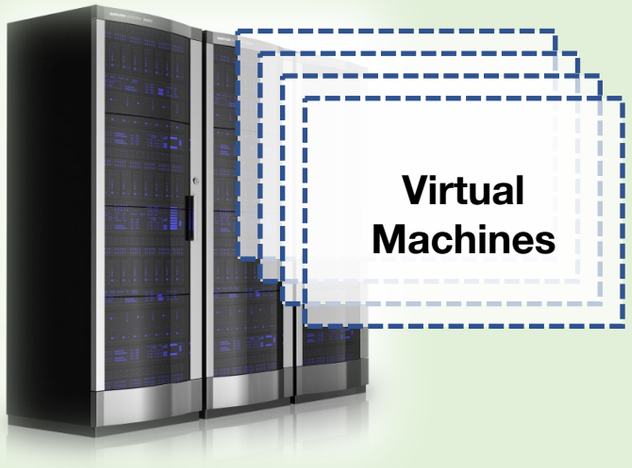
Computers **t ~ 1-10 ms**

PC

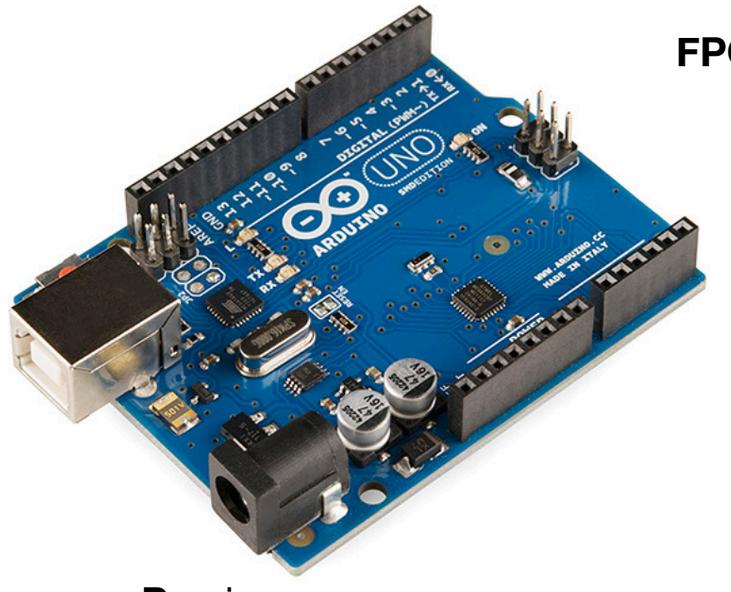
SBC: Single Board Computer



Embedded processor



FPGA: Field Programmable Gate Array
t ~ ns



mP: microprocessor
t ~ 1 ms

ASIC: Application-Specific Integrated Circuit

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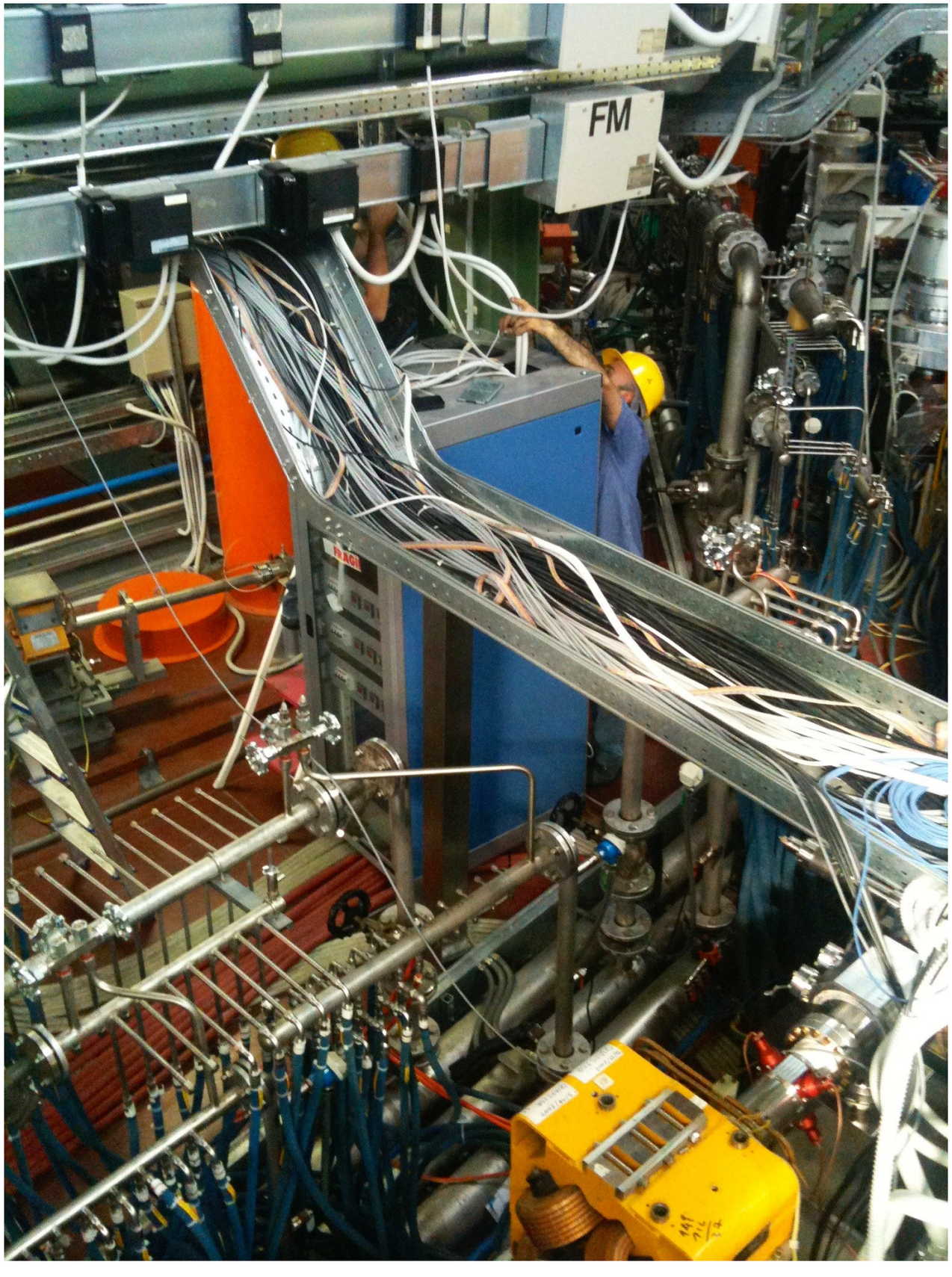
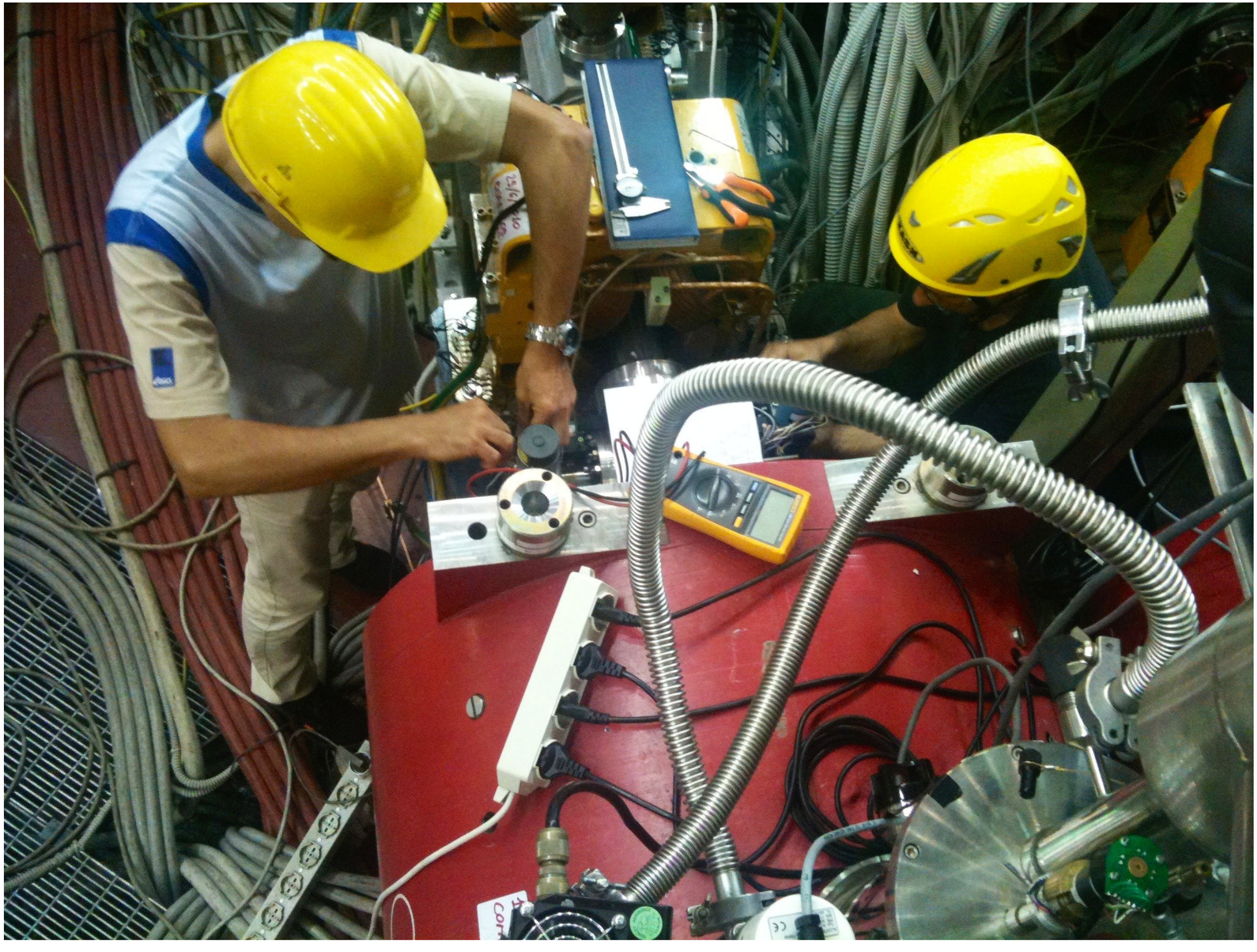
- astronomy
- **experimental apparatus, detectors, particle accelerators**

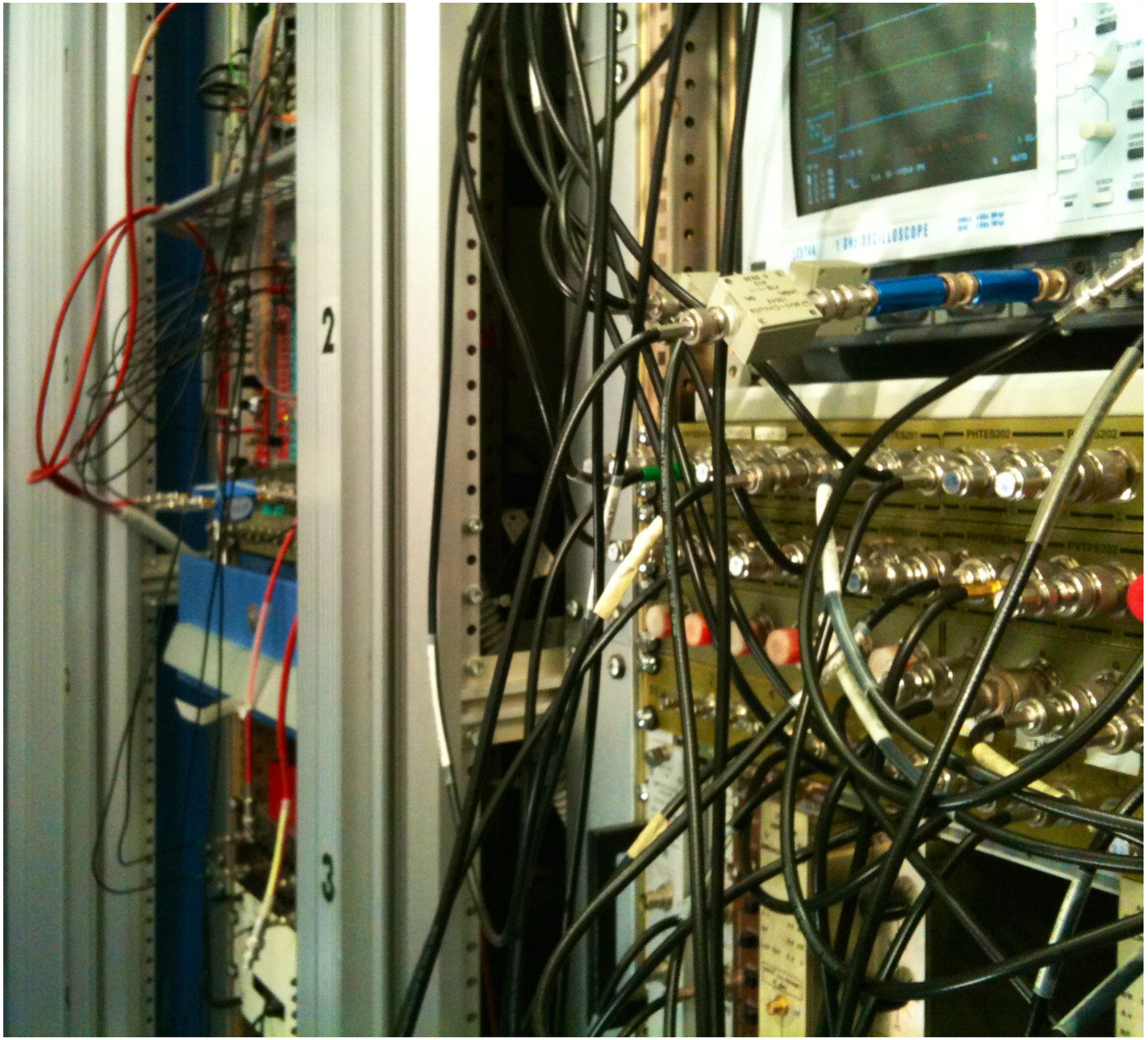
Control Systems – of complex plants – employing computers

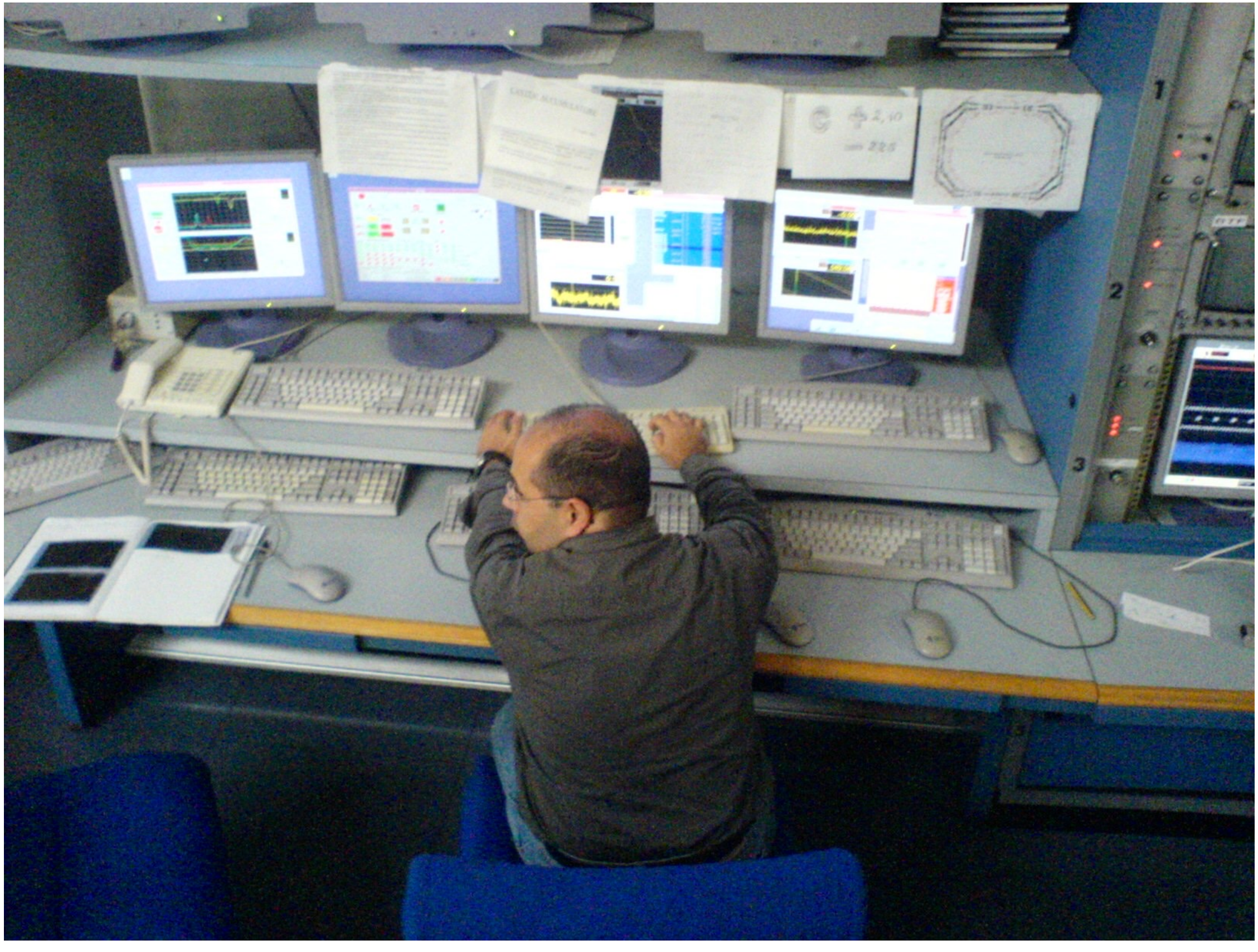
plant



plant → sensors/actuators







Design and Implementation

Definition of specifications and objectives to achieve

- performance
- functionality
- reliability

System modeling

- assessment of complexity and load estimation (processing power, throughput, latency, storage)
- design / adoption of control framework

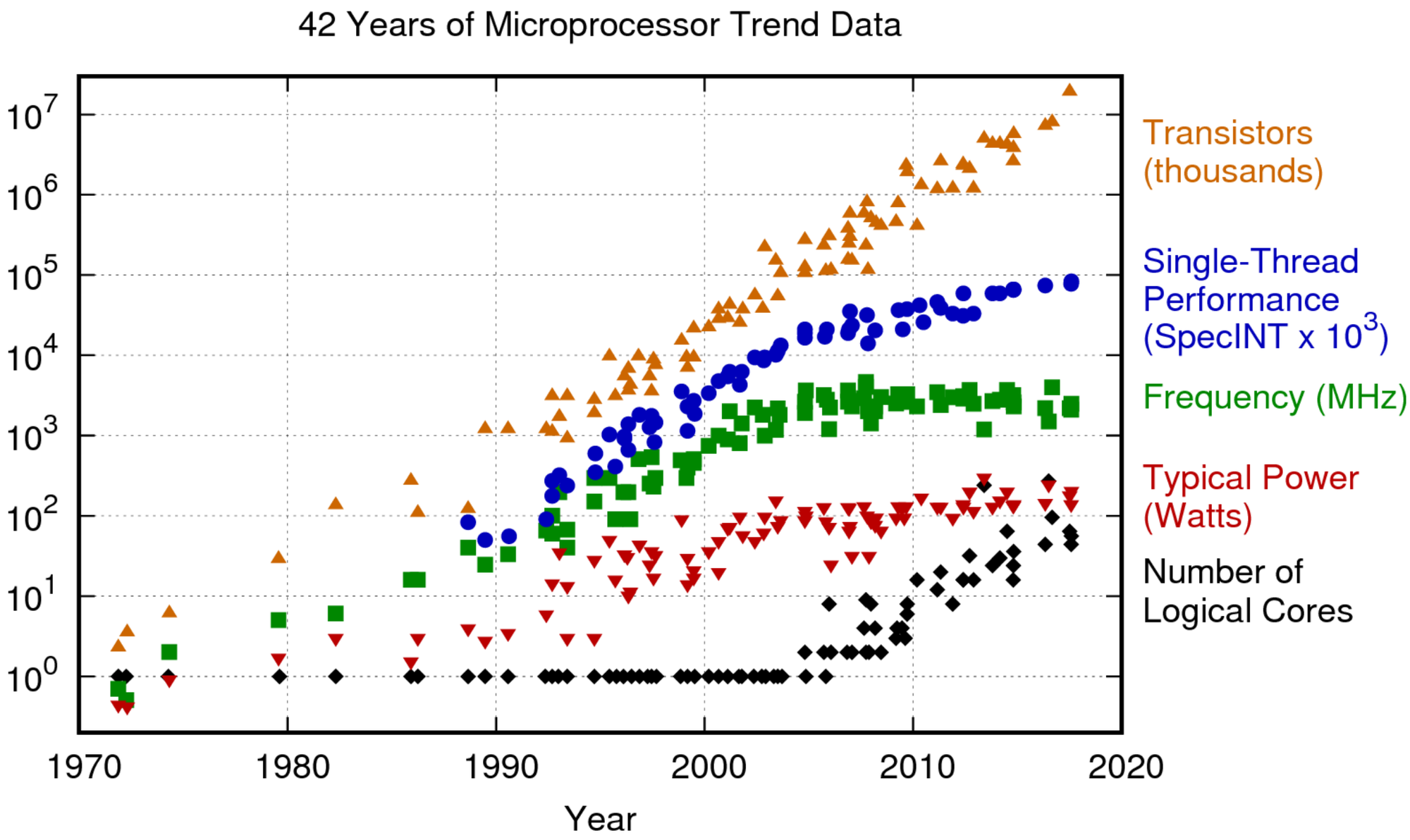
Development

- OOD, OOP (properties, methods)
- software development
- simulation
- engineering
- validation

General characteristics

- **open** to other systems (experiments, DAQ, machine protection, service plants);
- **easy** for the users (advanced UI, data import/export, calculation software interfacing);
- **scalable** according to plant size and required performance;
- **reliable** (no SPF, redundancy);
- **flexible** with respect to technological updates.

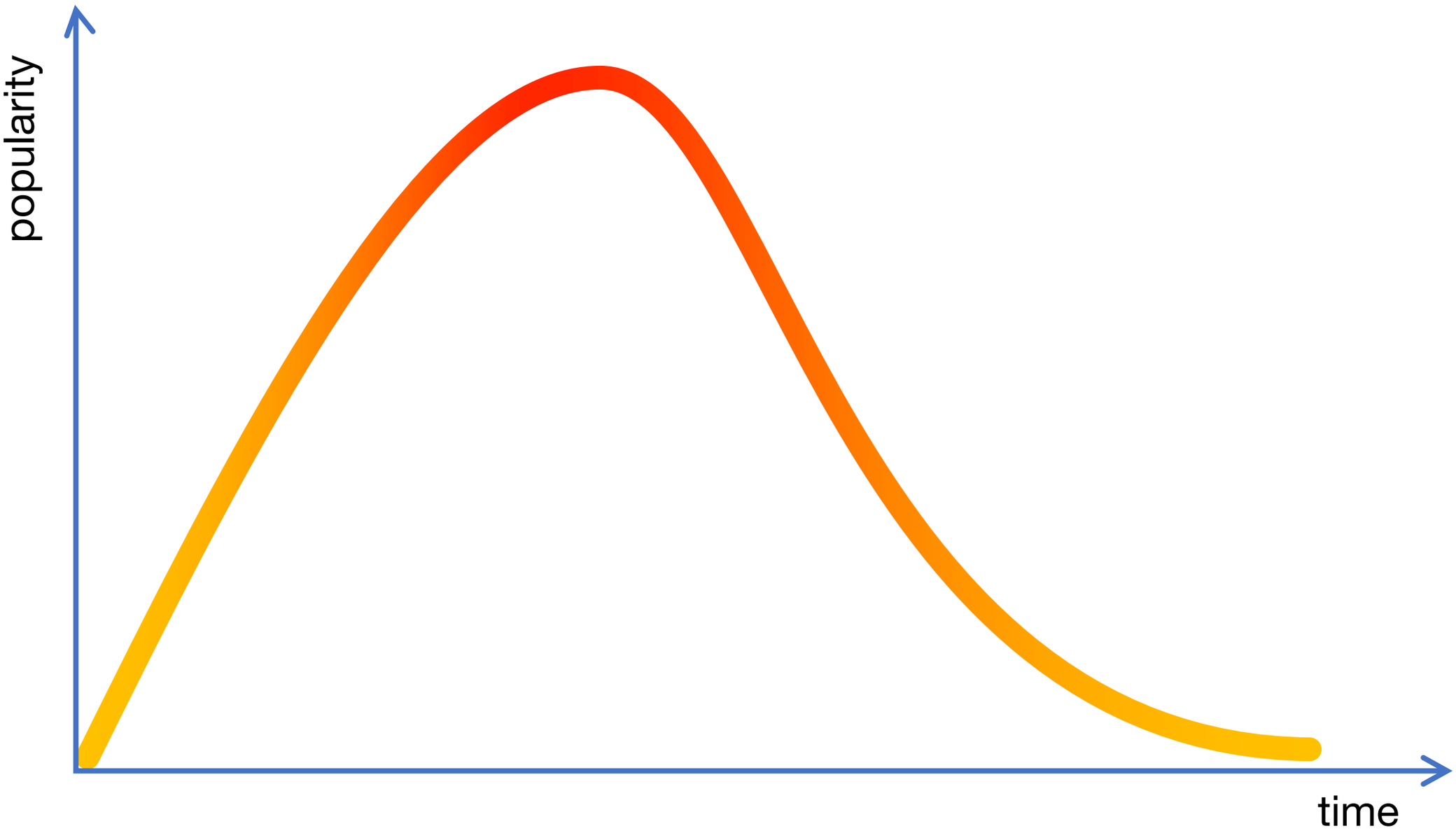
Technological growth



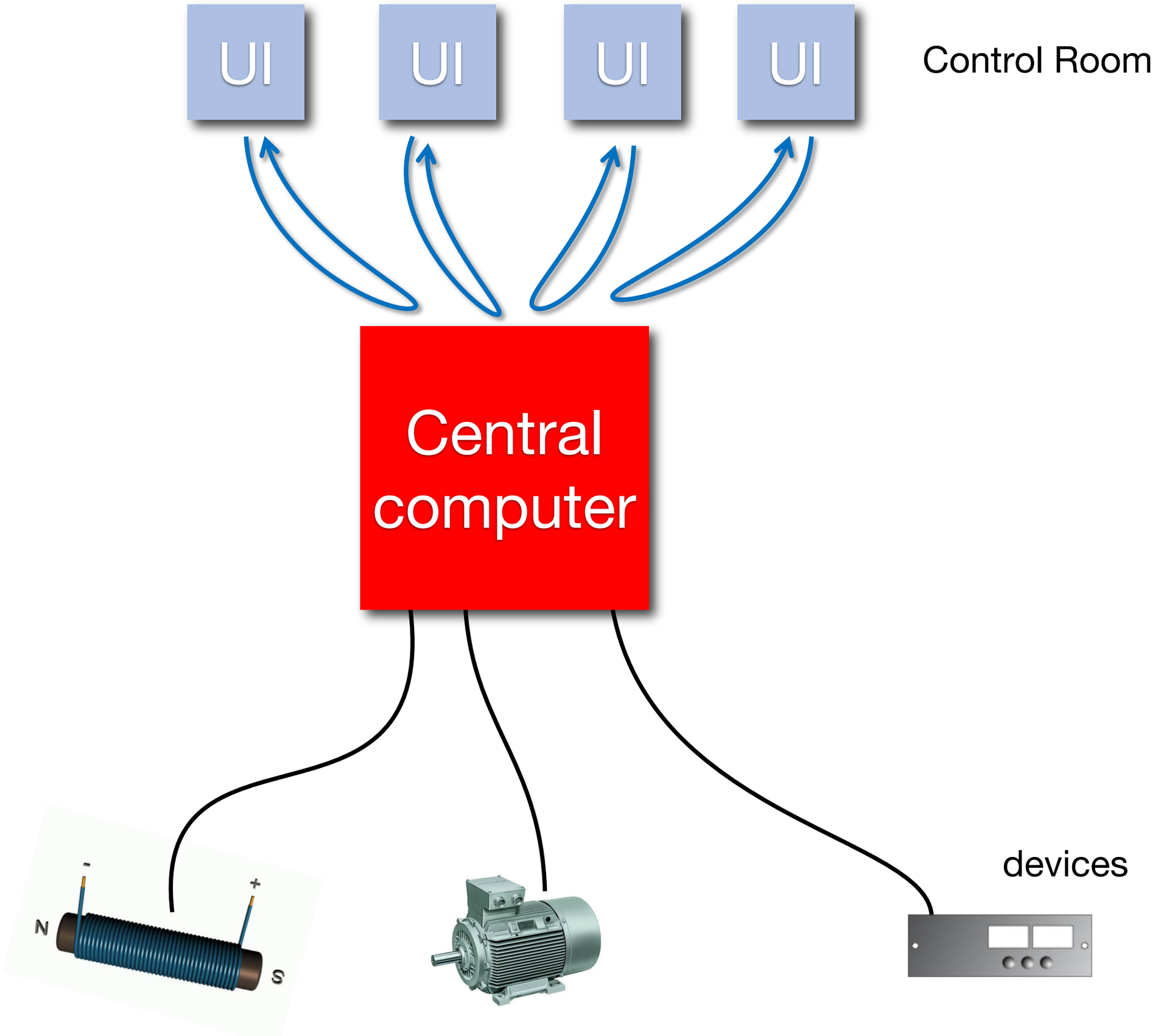
Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2017 by K. Rupp

Moore's law
the number of transistors in processors doubles every 18 months
-> limits on reducing the size of transistors below which unwanted 'parasitic' quantum effects would occur in electronic circuits.

Obsolescence of standards



The lesson is: a system has to be as independent as possible from hardware and software standards.

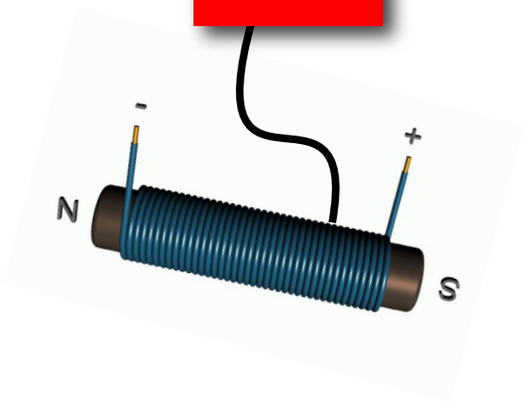

UI
UI
UI
UI
Control Room
Central computer
devices
-
+
N
S

UI UI UI UI

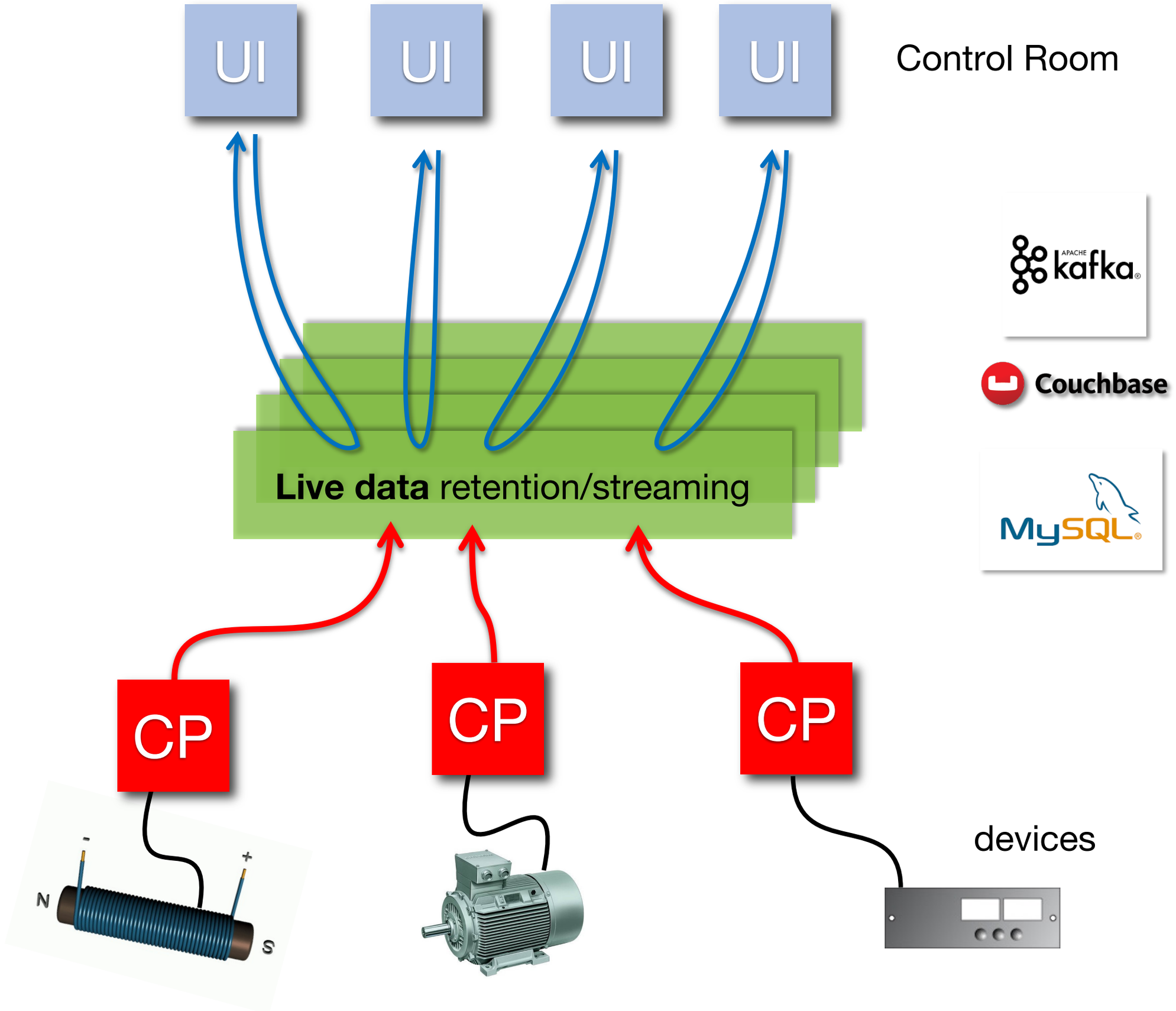
Control Room

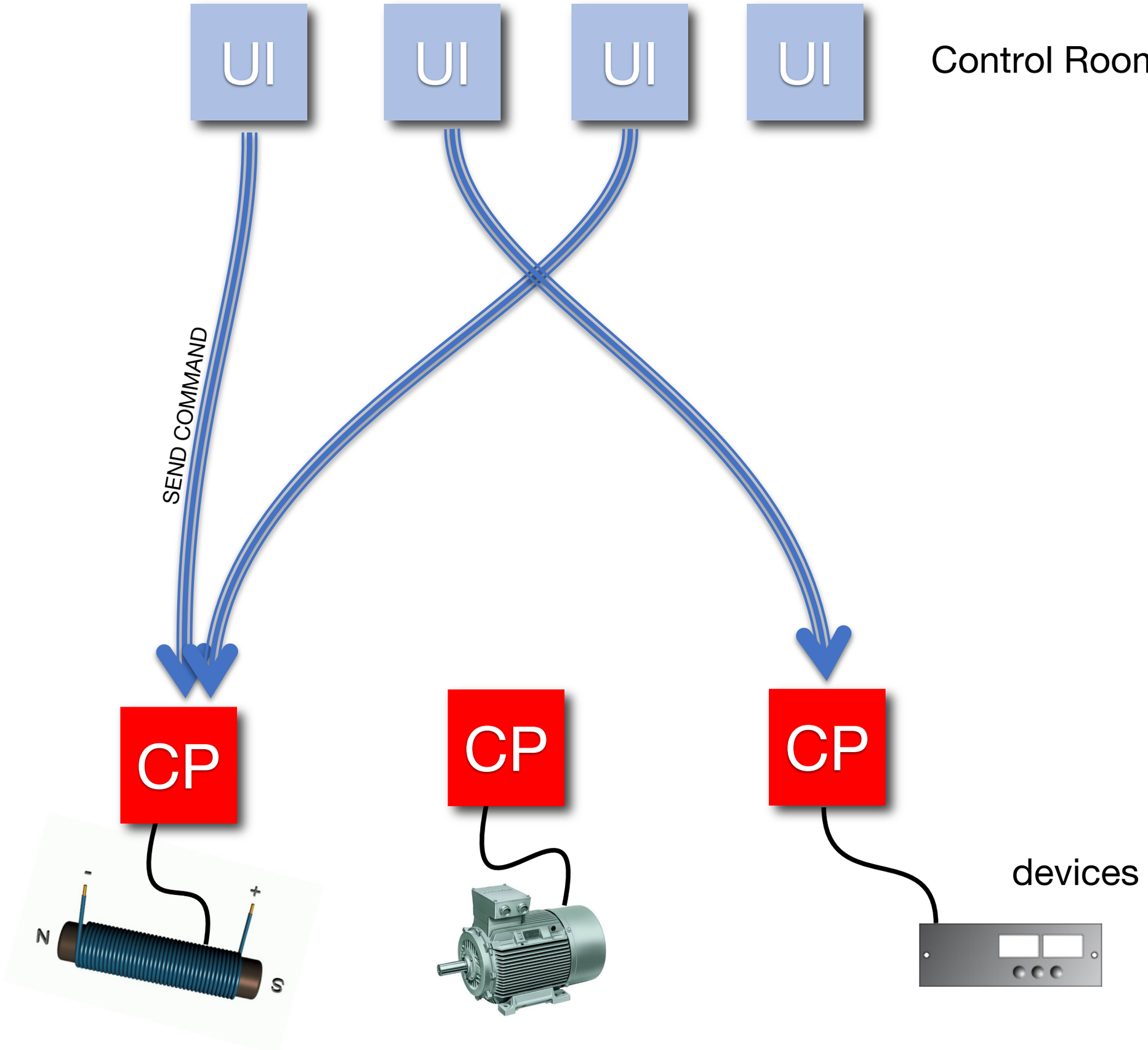
Live data request

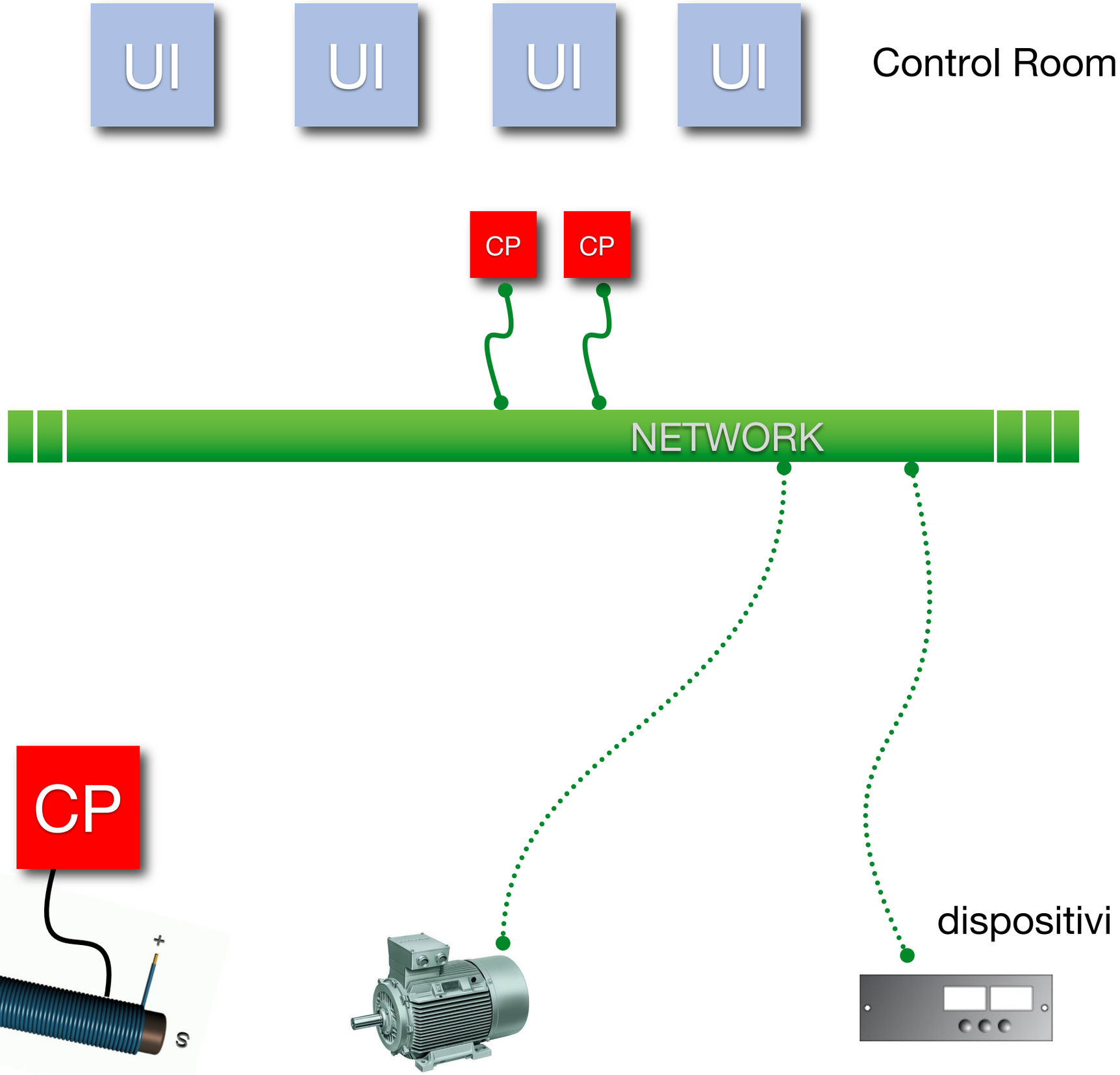
CP CP CP



devices


UI
UI
UI
UI
Control Room
Live data retention/streaming
CP
CP
CP
devices
N
S

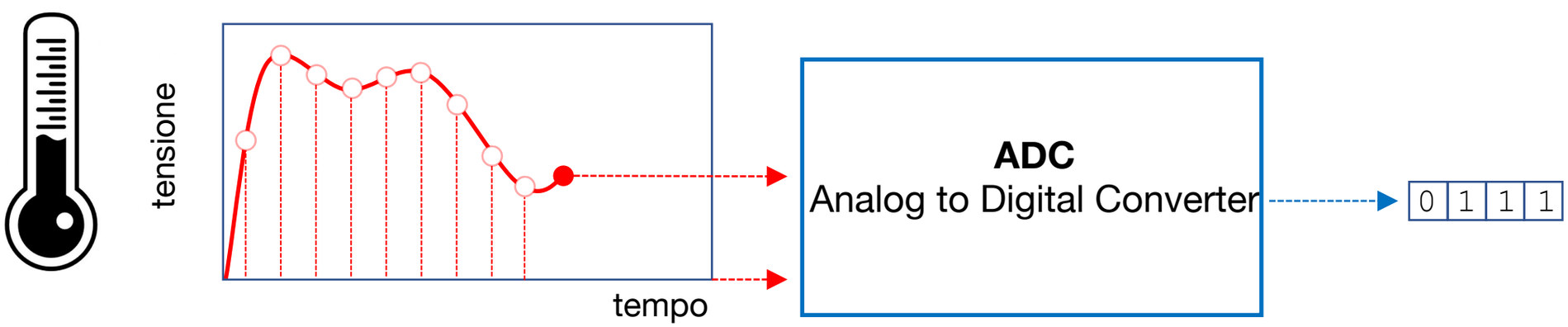

UI
UI
UI
UI
Control Room
SEND COMMAND
CP
CP
CP
devices
N
S
-
+

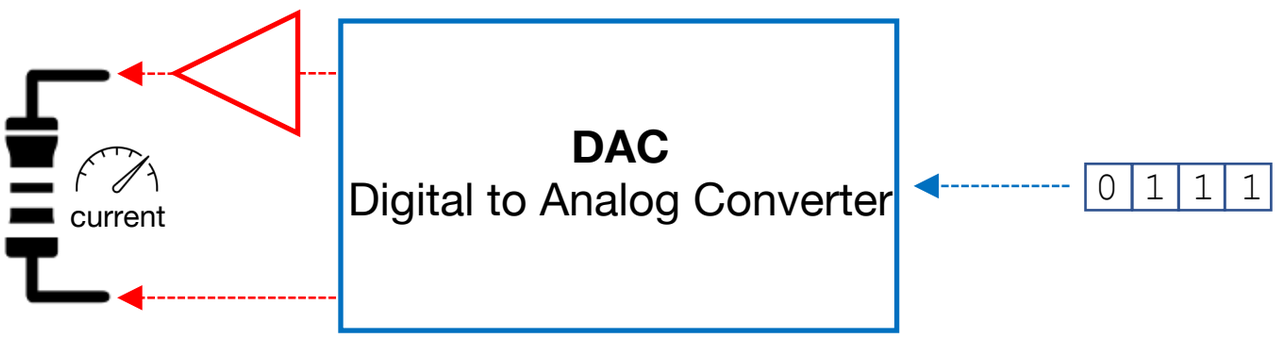

UI
UI
UI
UI
Control Room
CP
CP
NETWORK
CP
-
+
N
S
dispositivi

Basic features

- acquisition / implementation
- communication
- storage
- presentation
- analysis / correlation
- historization

- **acquisition / implementation**
- communication
- storage
- presentation
- analysis / correlation
- historization





- acquisition / implementation
- **communication**
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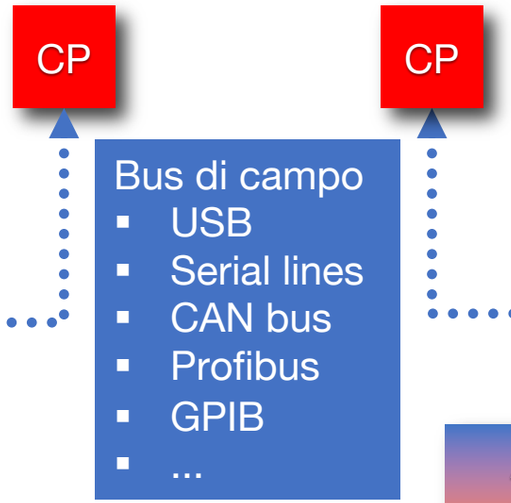
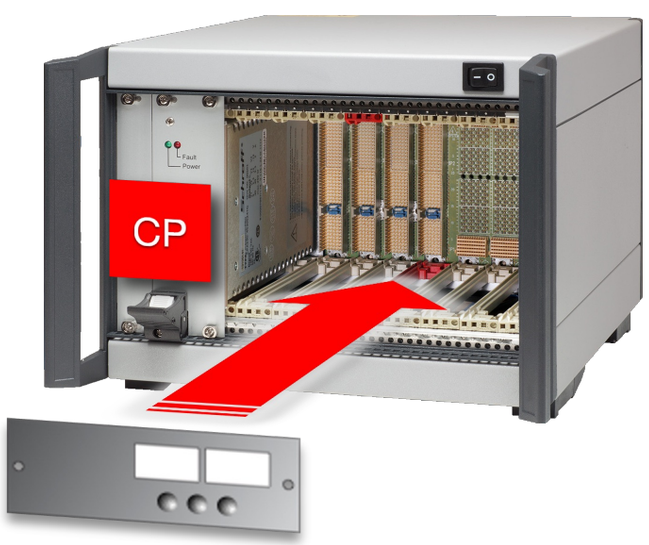


Embedded devices



Intelligent devices

Digital devices

Analog devices

- acquisition / implementation
- **communication**
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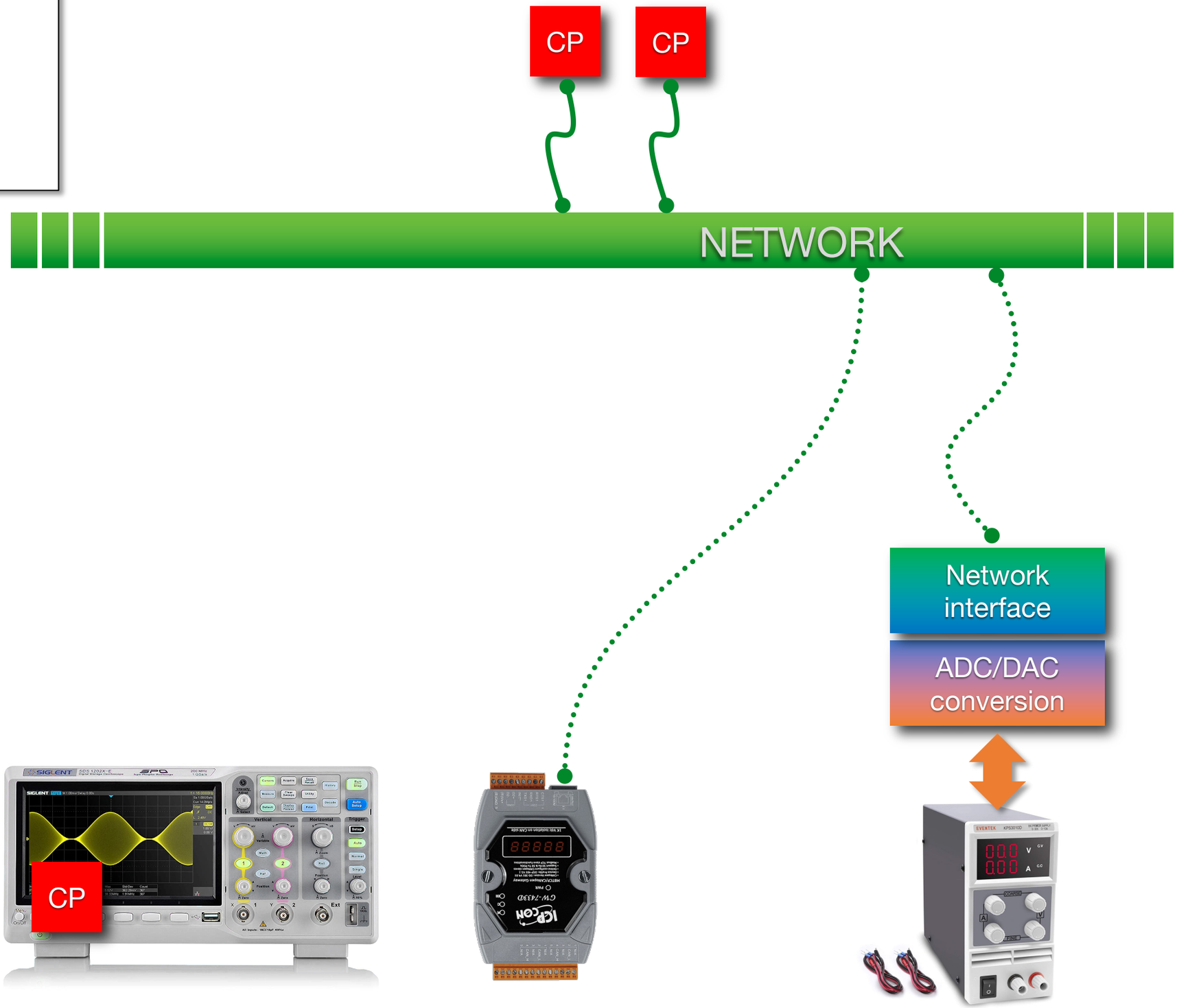
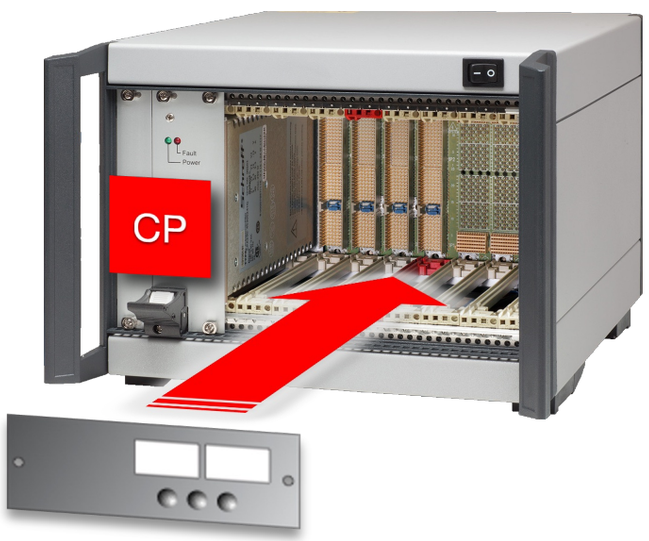
- historization



Embedded devices



Intelligent devices

Digital devices

Analog devices

- acquisition / implementation
- **communication**
- **storage**
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- historization

average size (@DAFNE)
~ 650 byte

```
{
float64 temperature_read;
char    units;
boolean status;
....
}
```

```
{
float64 current_read;
float64 current_set;
char    units;
boolean error;
....
}
```

```
{
float64 mag_field_read;
float64 mag_field_set;
int     polarity;
....
}
```

```
{
int     aperture;
int     time;
int     n_pixels_h;
int     n_pixels_v;
boolean status;
....
}
```

CP CP CP CP

650 byte

Nel mezzo del cammin di nostra vita
mi ritrovai per una selva oscura,
ché la diritta via era smarrita.

Ahi quanto a dir qual era è cosa dura
esta selva selvaggia e aspra e forte
che nel pensier rinova la paura!

Tant'è amara che poco è più morte;
ma per trattar del ben ch'i' vi trovai,
dirò de l'altre cose ch'i' v'ho scorte.

Io non so ben ridir com'i' v'intrai,
tant'era pien di sonno a quel punto
che la verace via abbandonai.

Ma poi ch'i' fui al piè d'un colle giunto,
là dove terminava quella valle
che m'avea di paura il cor compunto

guardai in alto e vidi le sue spalle
vestite già de' raggi del pianeta
che mena dritto altrui per ogne calle.

DAFNE ~1.4 Mbyte

Relational database →

```
{
float64 temperature_read;
char    units;
boolean status;
....
}
```

```
{
float64 current_read;
float64 current_set;
char    units;
boolean error;
....
}
```

```
{
float64 mag_field_read;
float64 mag_field_set;
int     polarity;
....
}
```

```
{
int     aperture;
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int     n_pixels_h;
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boolean status;
....
}
```
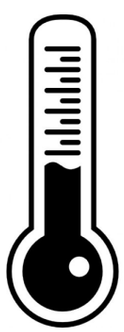
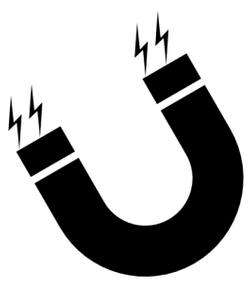





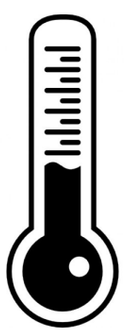
Relational database →

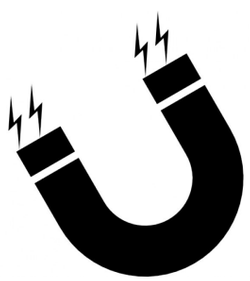
```
{
float64 temperature_read;
char    units;
boolean status;
....
}
```

```
{
float64 current_read;
float64 current_set;
char    units;
boolean error;
....
}
```

```
{
float64 mag_field_read;
float64 mag_field_set;
int     polarity;
....
}
```

```
{
int     aperture;
int     time;
int     n_pixels_h;
int     n_pixels_v;
boolean status;
....
}
```





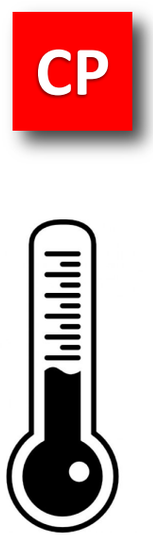
Relational database →

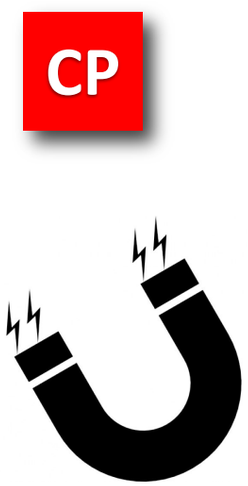
```
{
float64  temperature_read;
char     units;
boolean  status;
....
}
```

```
{
float64  current_read;
float64  current_set;
char     units;
boolean  error;
....
}
```

```
{
float64  magnetic_read;
float64  temperature_read;
int      orientation;
int      polarity;
::::
}
```

```
{
int      aperture;
int      time;
int      n_pixels_h;
int      n_pixels_v;
boolean  status;
....
}
```





serialized and **self-describing** data

Key	Value

my_string 0x16\0x00\0x00\0x00\0x02**hello**\0x00\0x06\0x00\0x00\0x00**world**\0x00\0x00

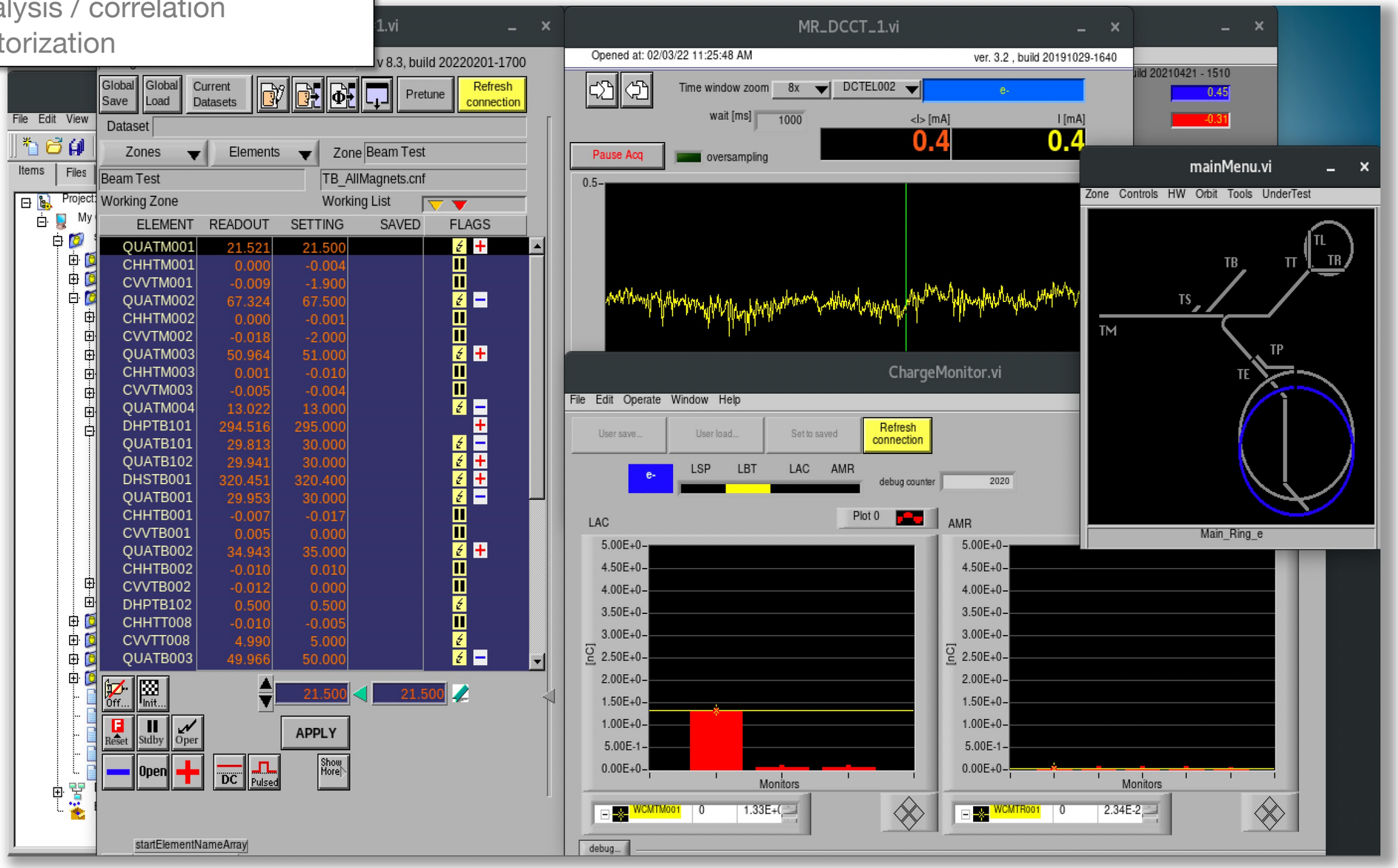
my_odd_data ..... another descriptive sequence .....

BSON serialization

\0x16\0x00\0x00\0x00	total document size
\0x02	0x02 = type string
hello\0x00	field name
\0x06\0x00\0x00\0x00world\0x00	field value (size of value, value, terminator)
\0x00	type EOO ('end of object')

- acquisition / implementation
- communication
- storage
- **presentation**
- analysis / correlation
- historization

User Interface



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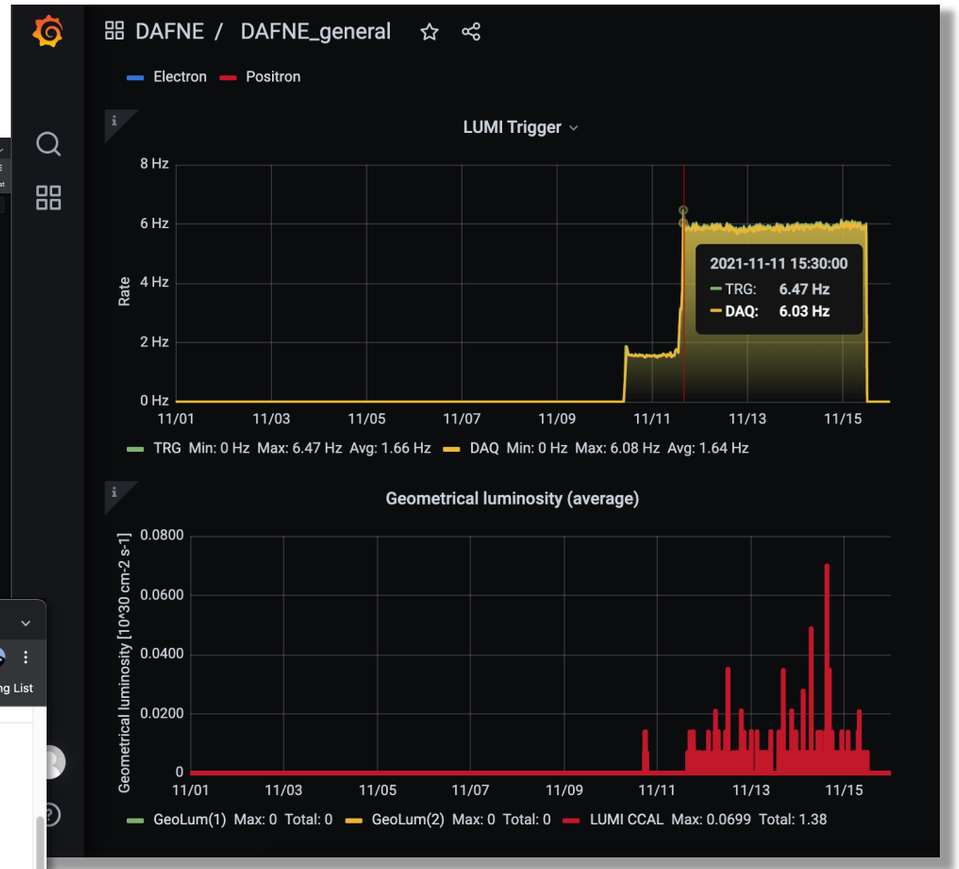
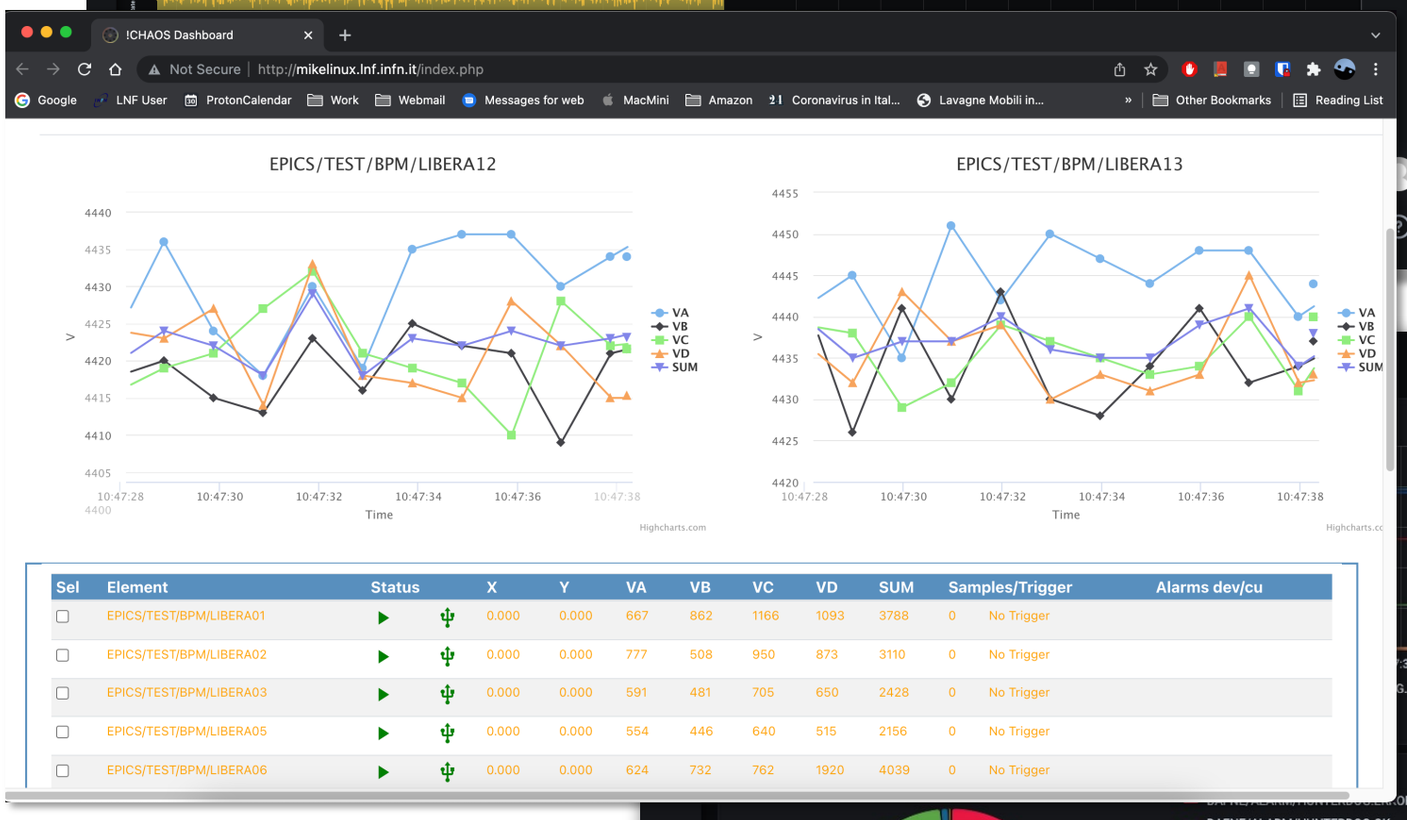
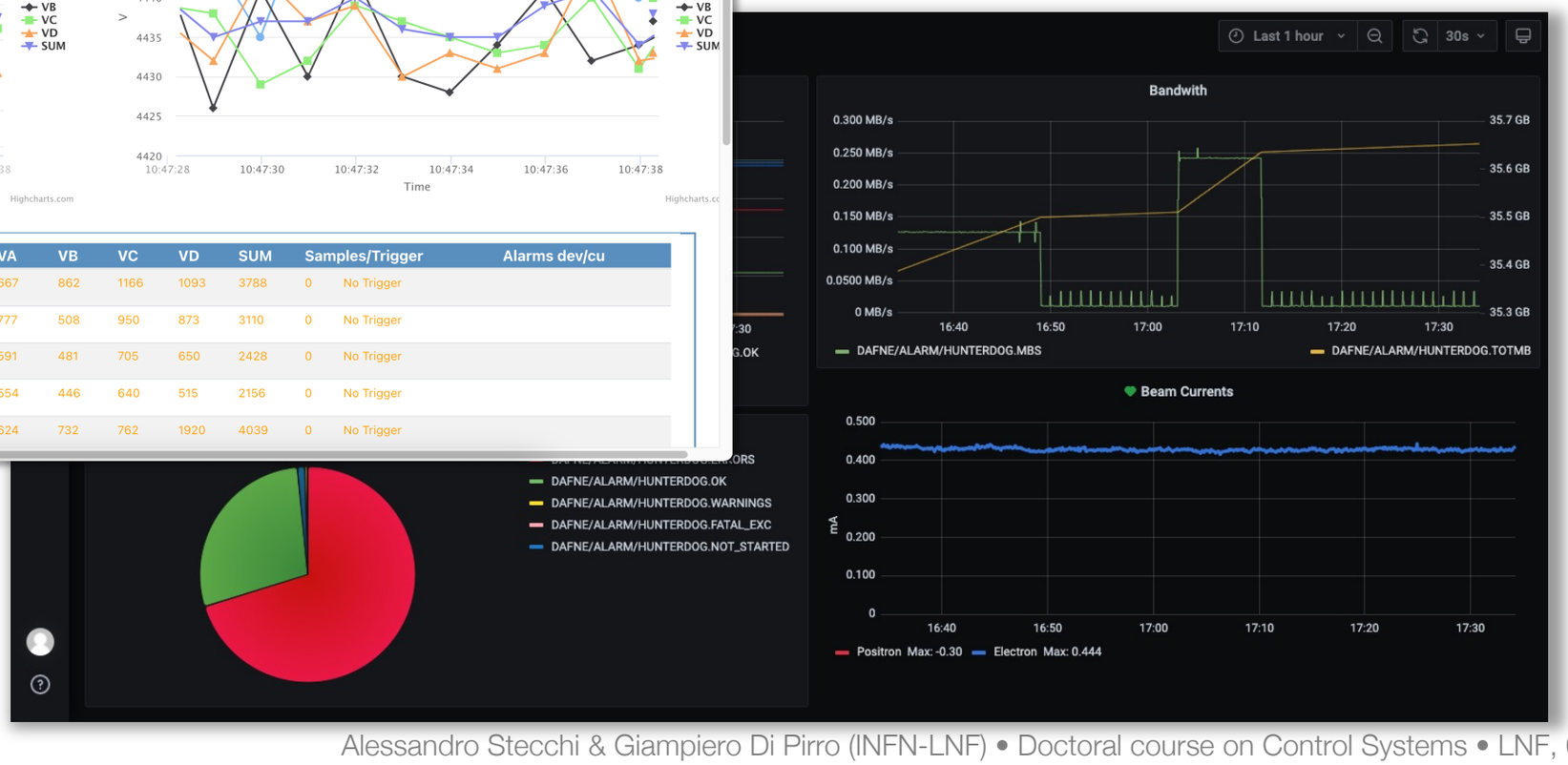
User Interface





Sel	Element	Status		X	Y	VA	VB	VC	VD	SUM	Samples/Trigger		Alarms dev/cu
☐	EPICS/TEST/BPM/LIBERA01	▶	ψ	0.000	0.000	667	862	1166	1093	3788	0	No Trigger	
☐	EPICS/TEST/BPM/LIBERA02	▶	ψ	0.000	0.000	777	508	950	873	3110	0	No Trigger	
☐	EPICS/TEST/BPM/LIBERA03	▶	ψ	0.000	0.000	591	481	705	650	2428	0	No Trigger	
☐	EPICS/TEST/BPM/LIBERA05	▶	ψ	0.000	0.000	554	446	640	515	2156	0	No Trigger	
☐	EPICS/TEST/BPM/LIBERA06	▶	ψ	0.000	0.000	624	732	762	1920	4039	0	No Trigger	



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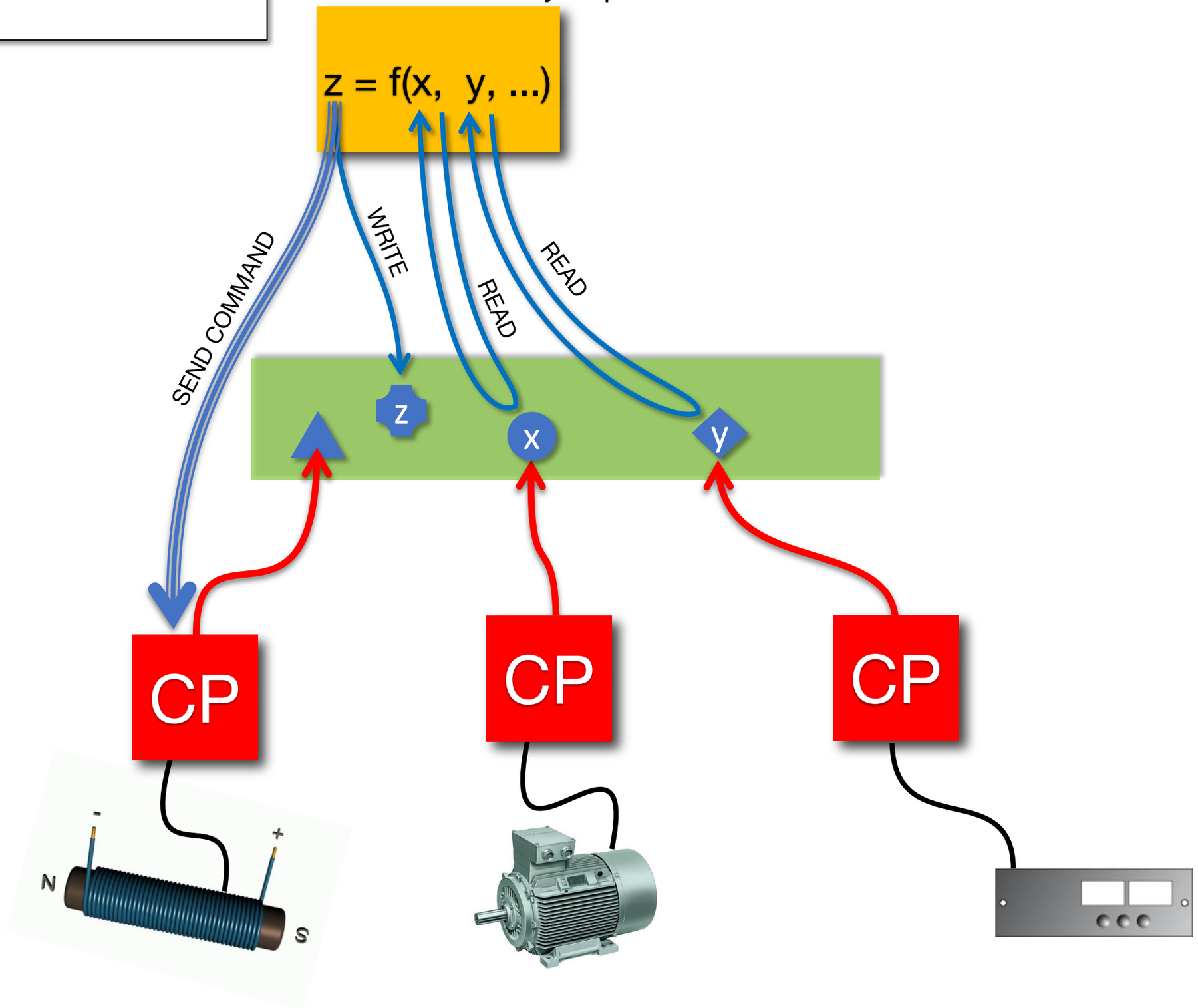
Correlation and analysis processes



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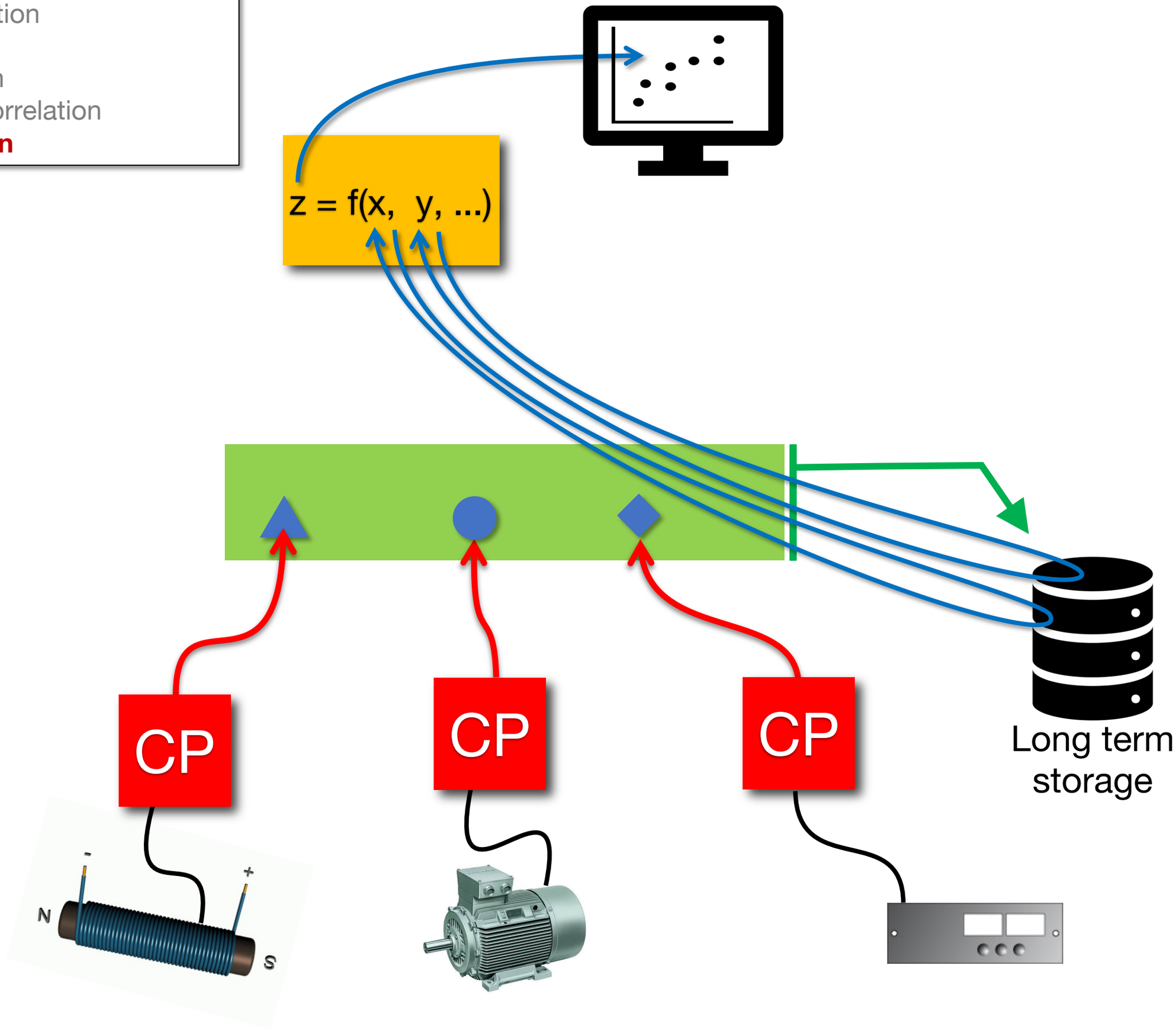
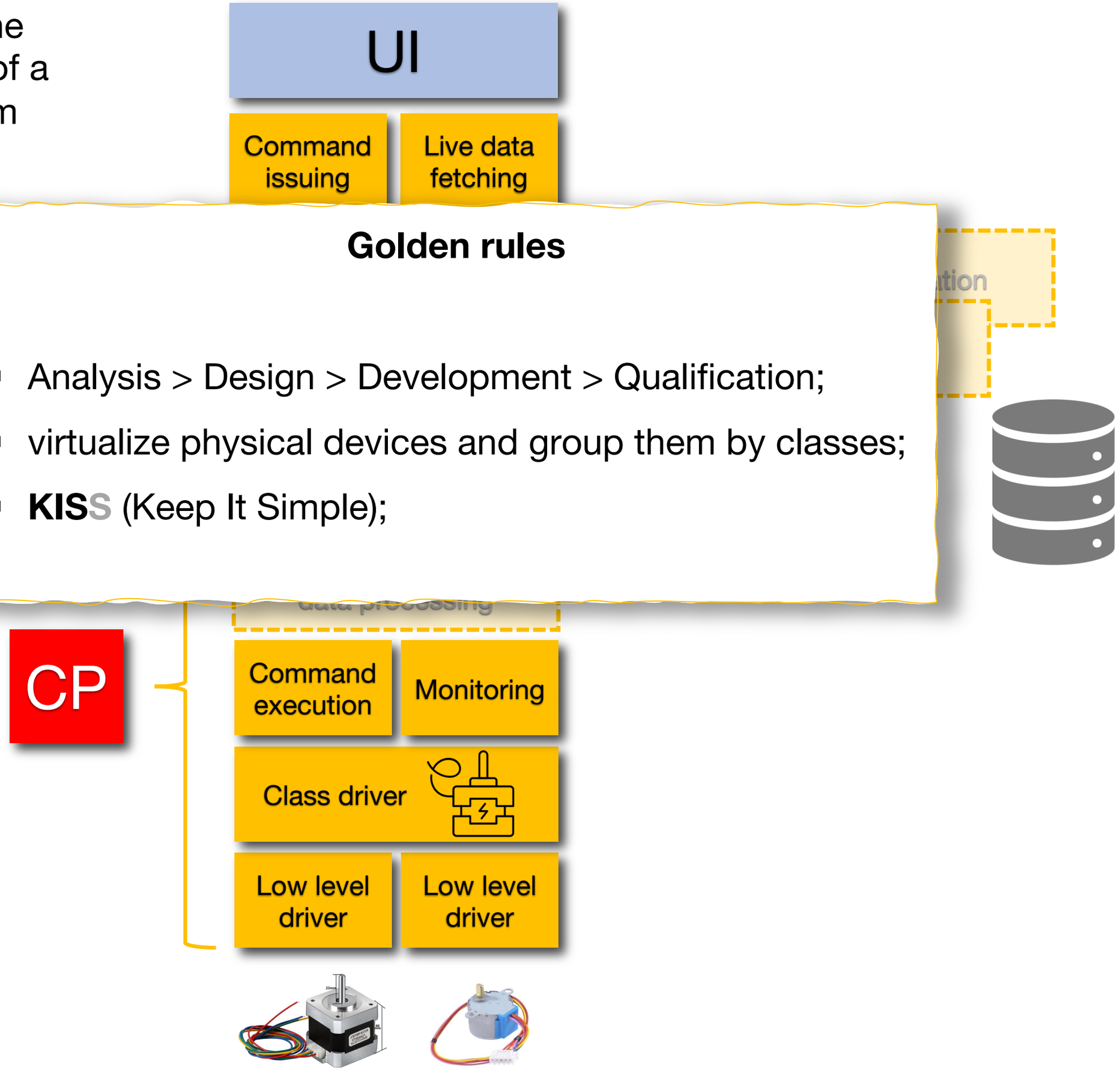
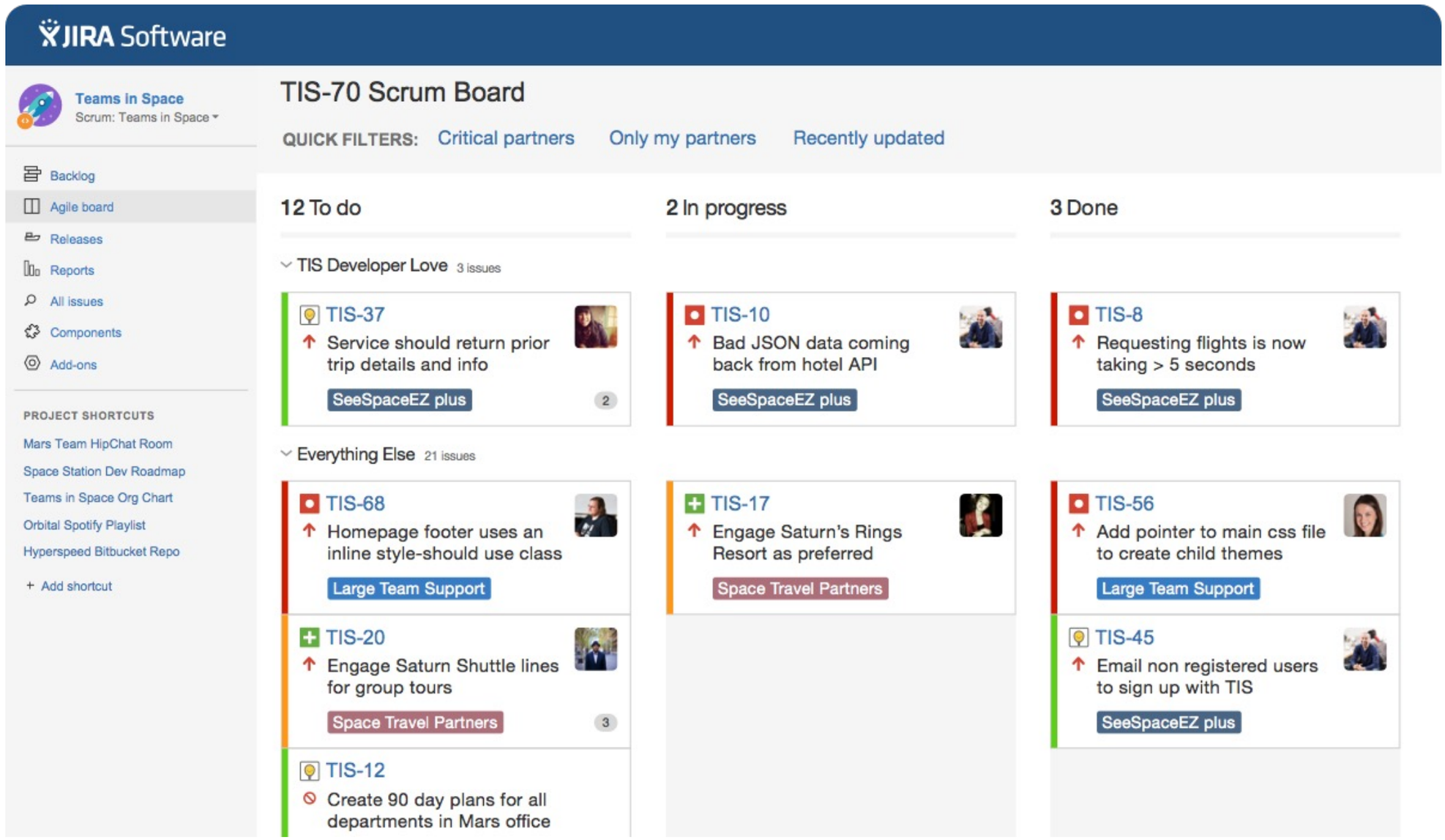


How to face the development of a Control System



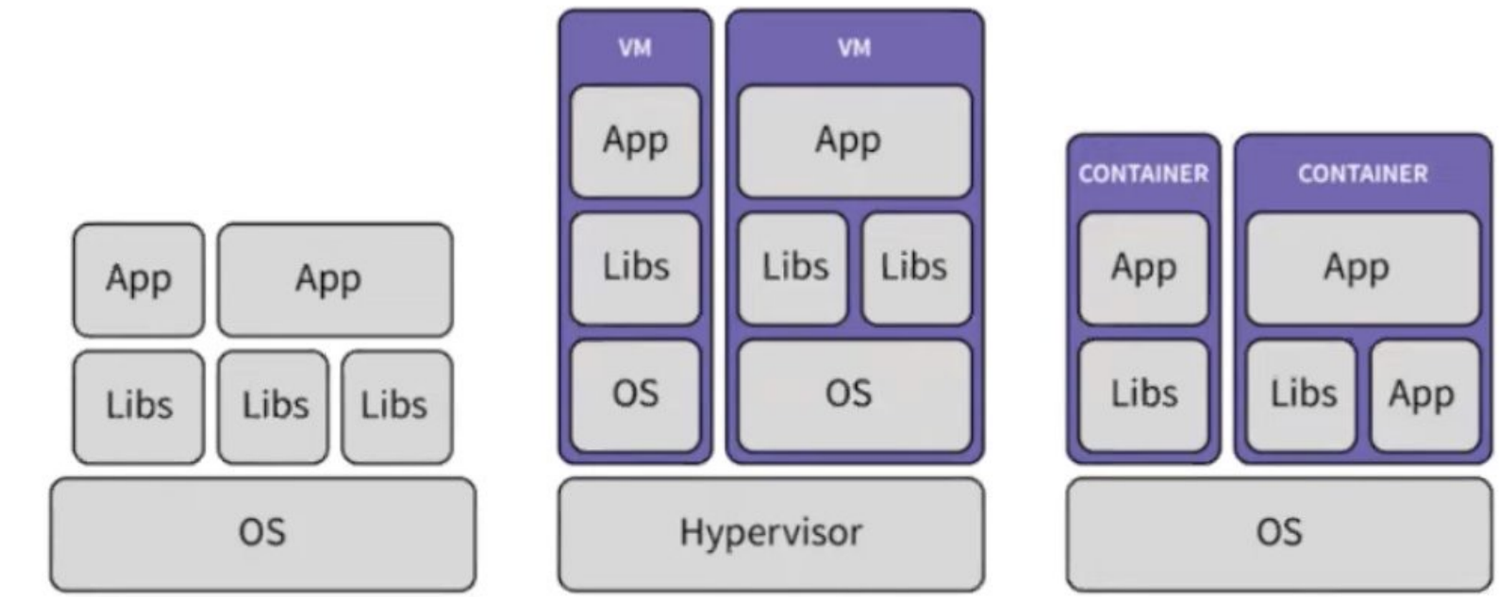
Good methods & practices

- Development: Agile approach, CI/CD, DevOps
- Documentation, Asset Management
- Project tracking



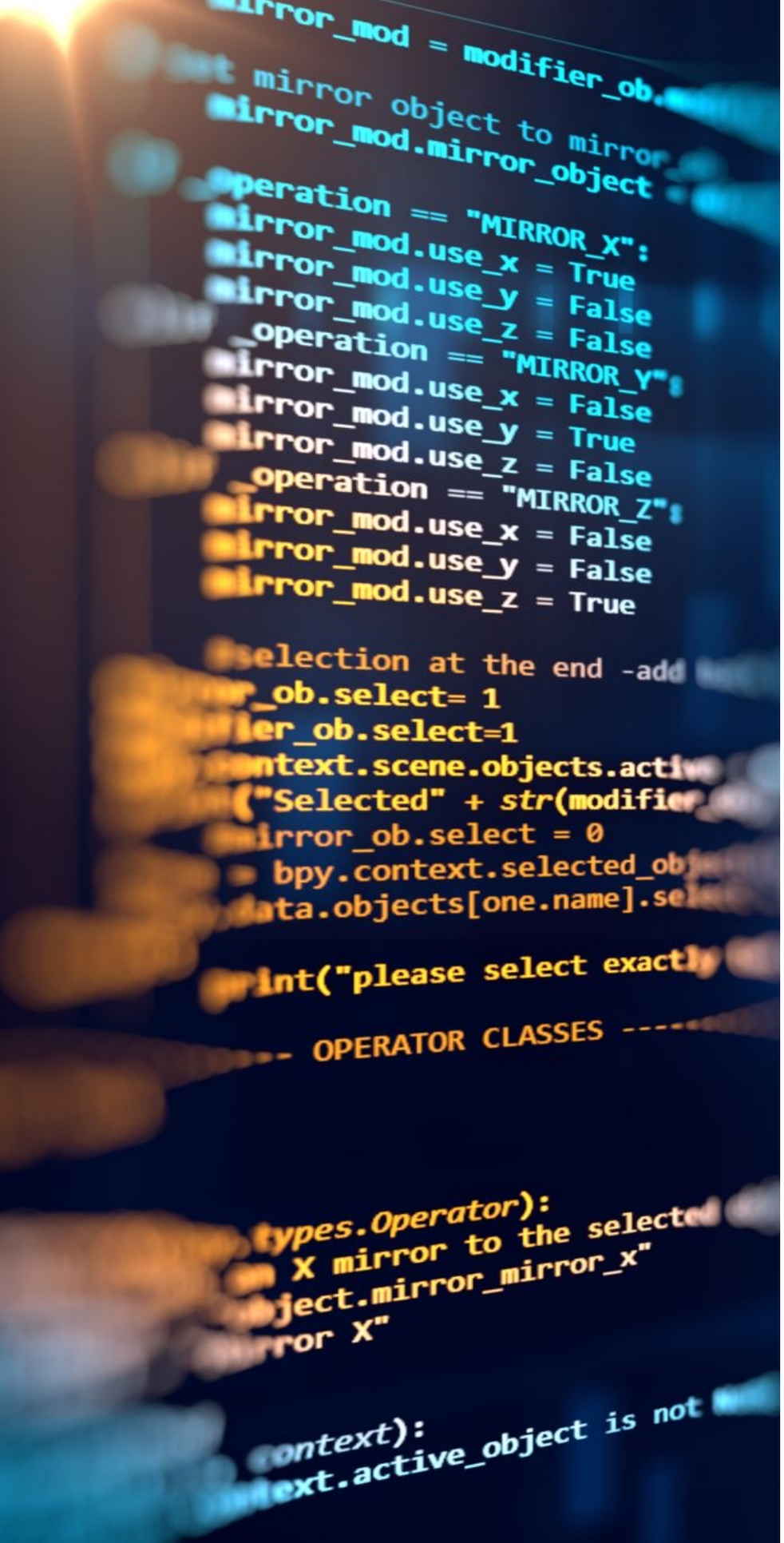
IT trends

- Big data
- AI
- Virtualization, Dockers, Orchestrators



Containers, like VMs, isolate an application and its dependencies into a self-contained unit that can run anywhere.

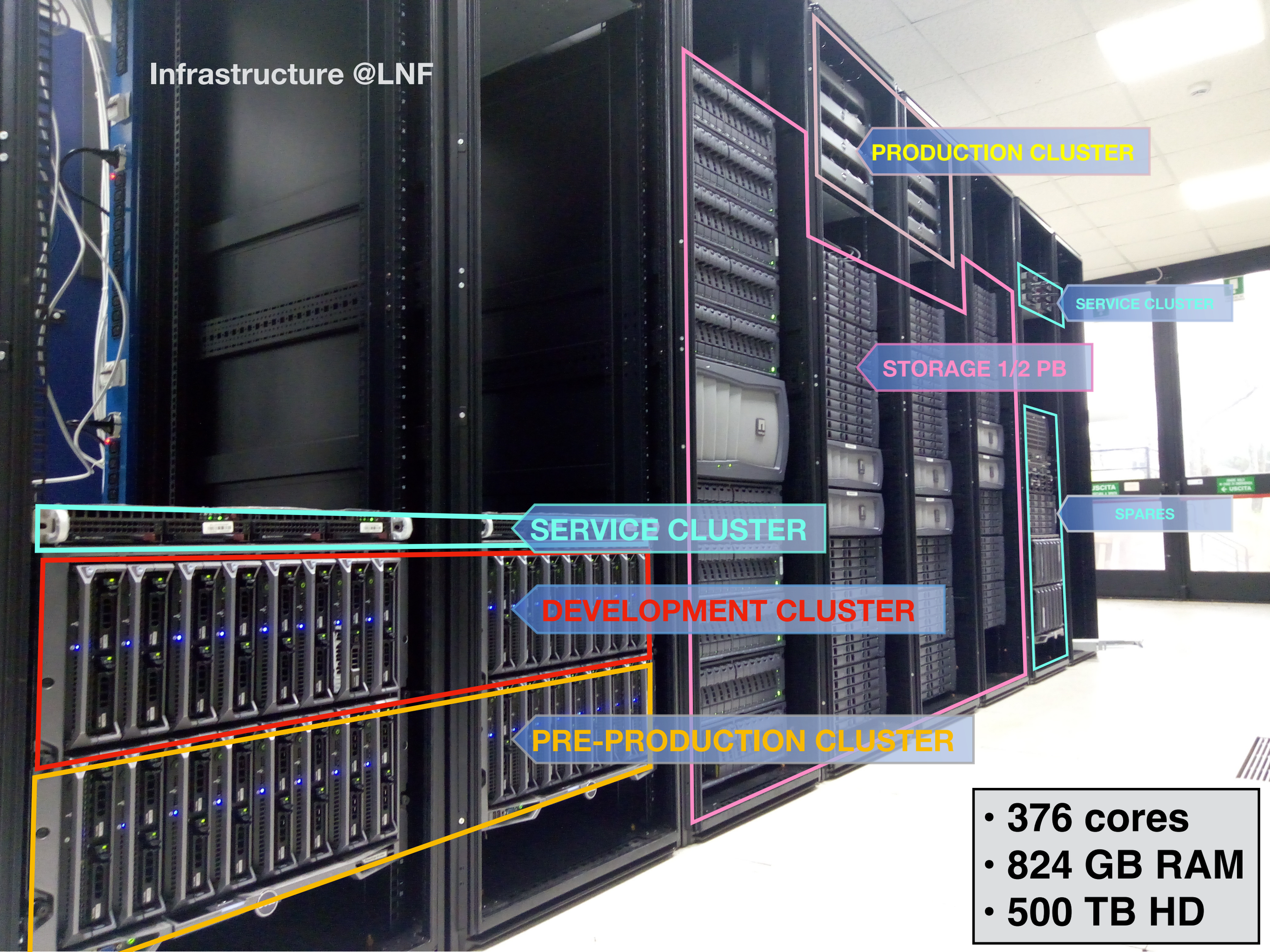
Courtesy of Giles Knap (Diamond)



Professionals

- Data scientist
- Software Developer, Software Engineer, DevOps
- System Manager
- Network Manager
- Systems Integrator

Infrastructure @LNF



- 376 cores
- 824 GB RAM
- 500 TB HD