

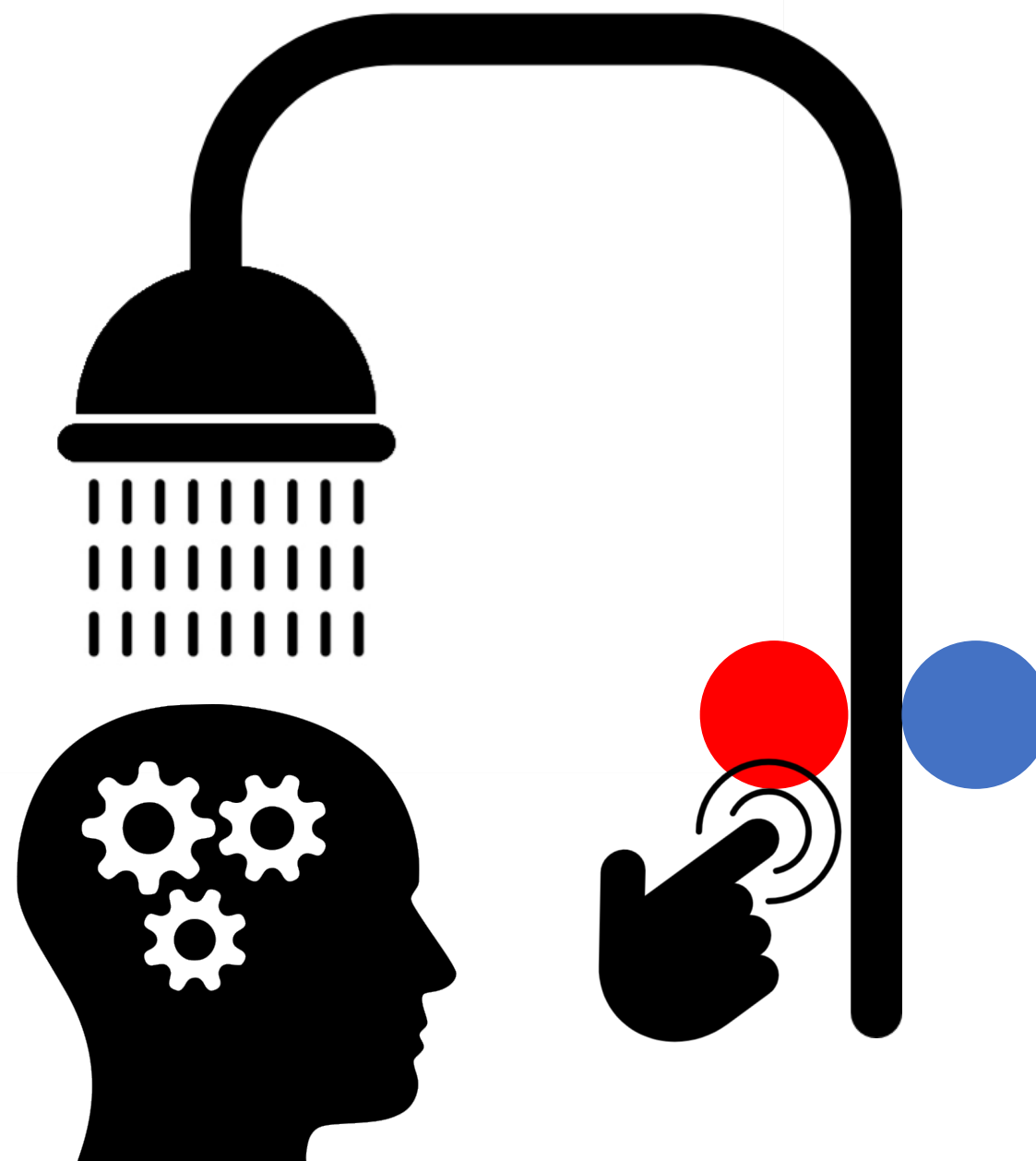
Control Systems

Alessandro Stecchi & Giampiero Di Pirro

INFN-LNF • Accelerator Division



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

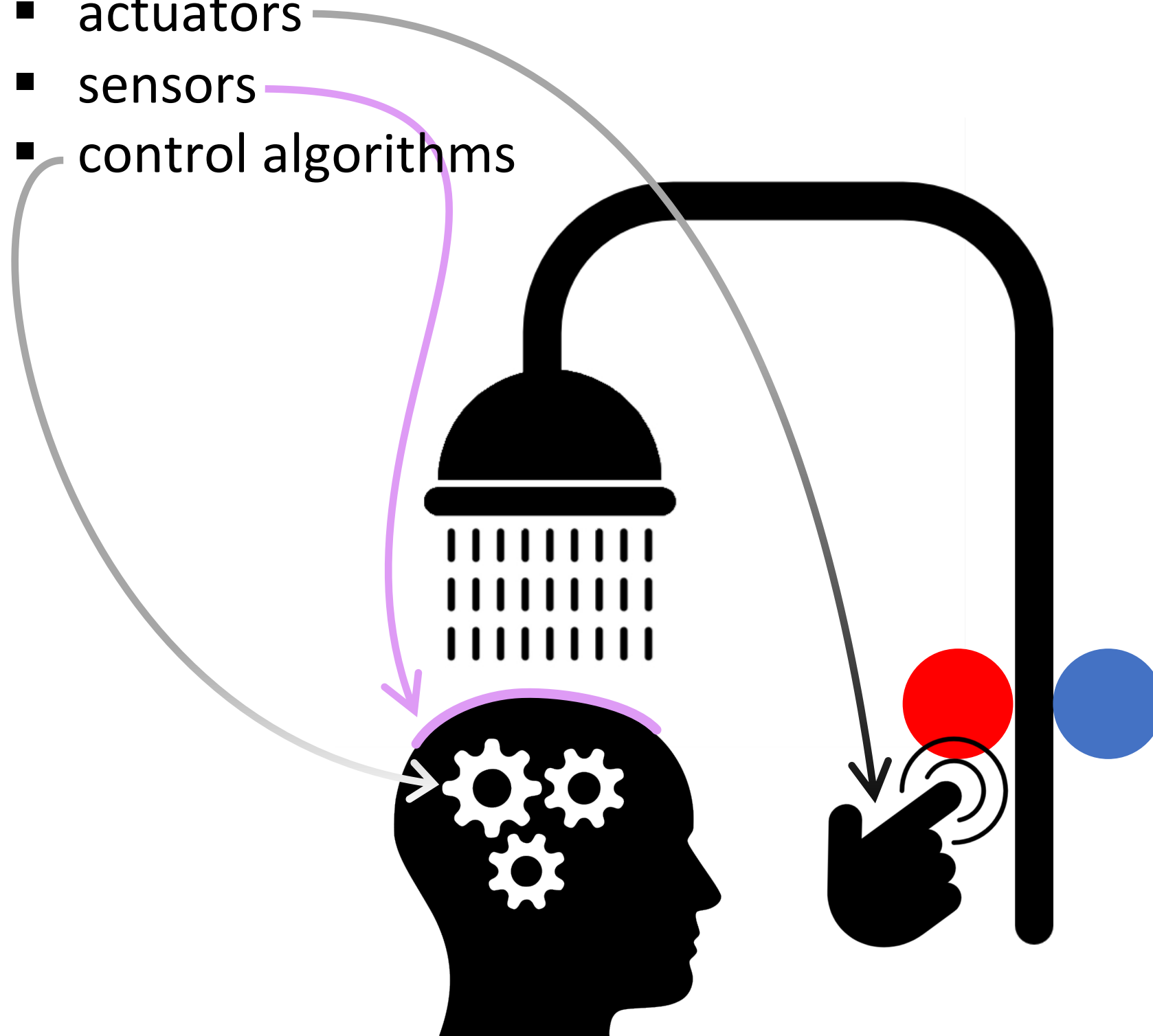
Action is based on initial **static information**.

Closed loop

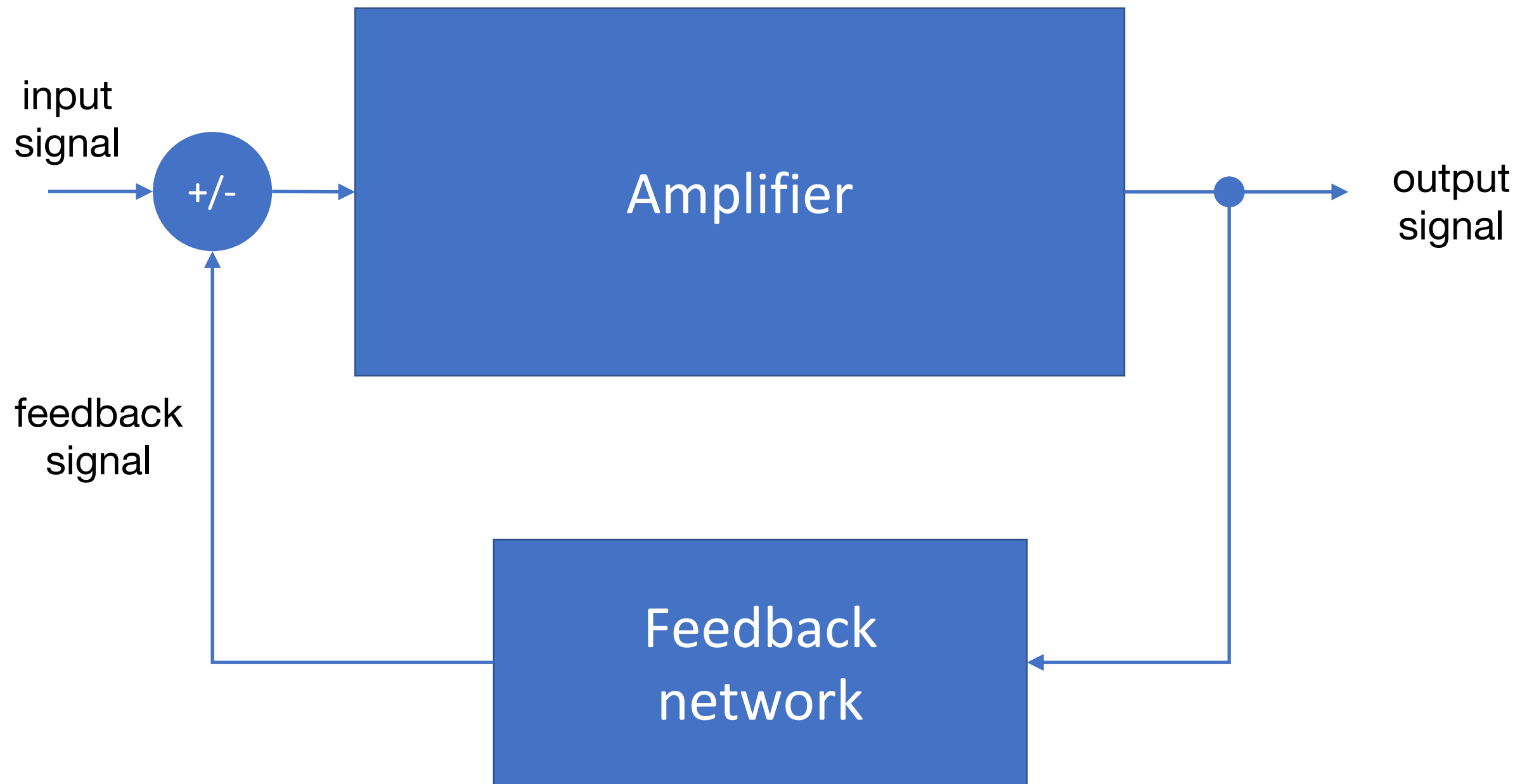
Action is based on **dynamic information** continuously read back from the controlled system.

Key elements of a Control System:

- actuators
- sensors
- control algorithms



What physicists and engineers usually mean by *Control System*



Controls adopting "CPUs"

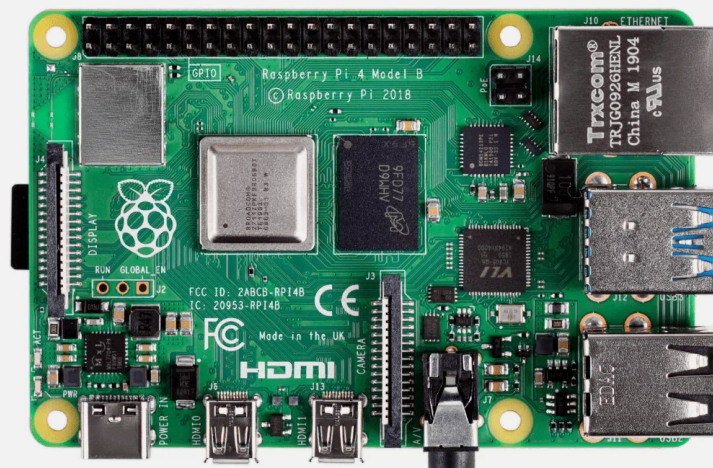


Computers $t \sim 1\text{-}10\text{ ms}$

PC



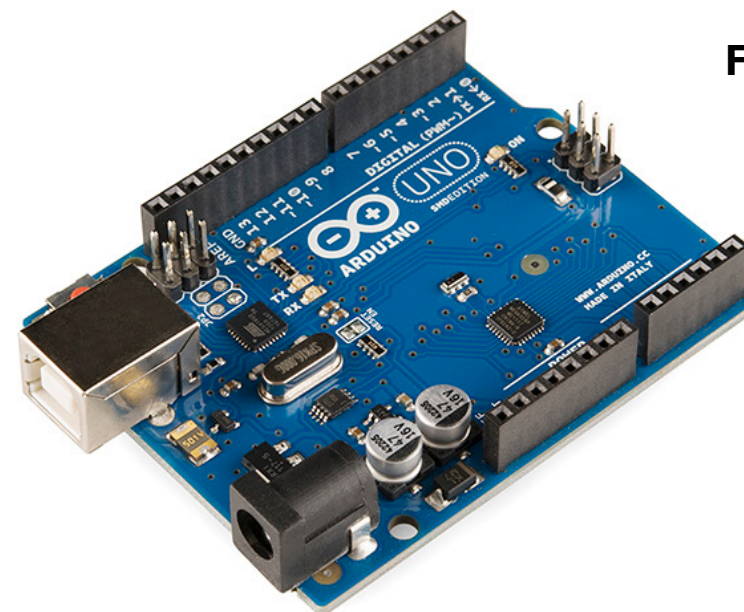
SBC: Single Board Computer



Embedded processor



**Virtual
Machines**



uP: microprocessor
 $t \sim 1\text{ ms}$



FPGA: Field Programmable Gate Array
 $t \sim \text{ns}$



ASIC: Application-Specific Integrated Circuit

Fields of application of control systems

Civil, Social

- home automation
- automotive, aeronautics
- building climate control
- agriculture
- medical equipment, radiotherapy, diagnostics
- telecommunications

Industrial

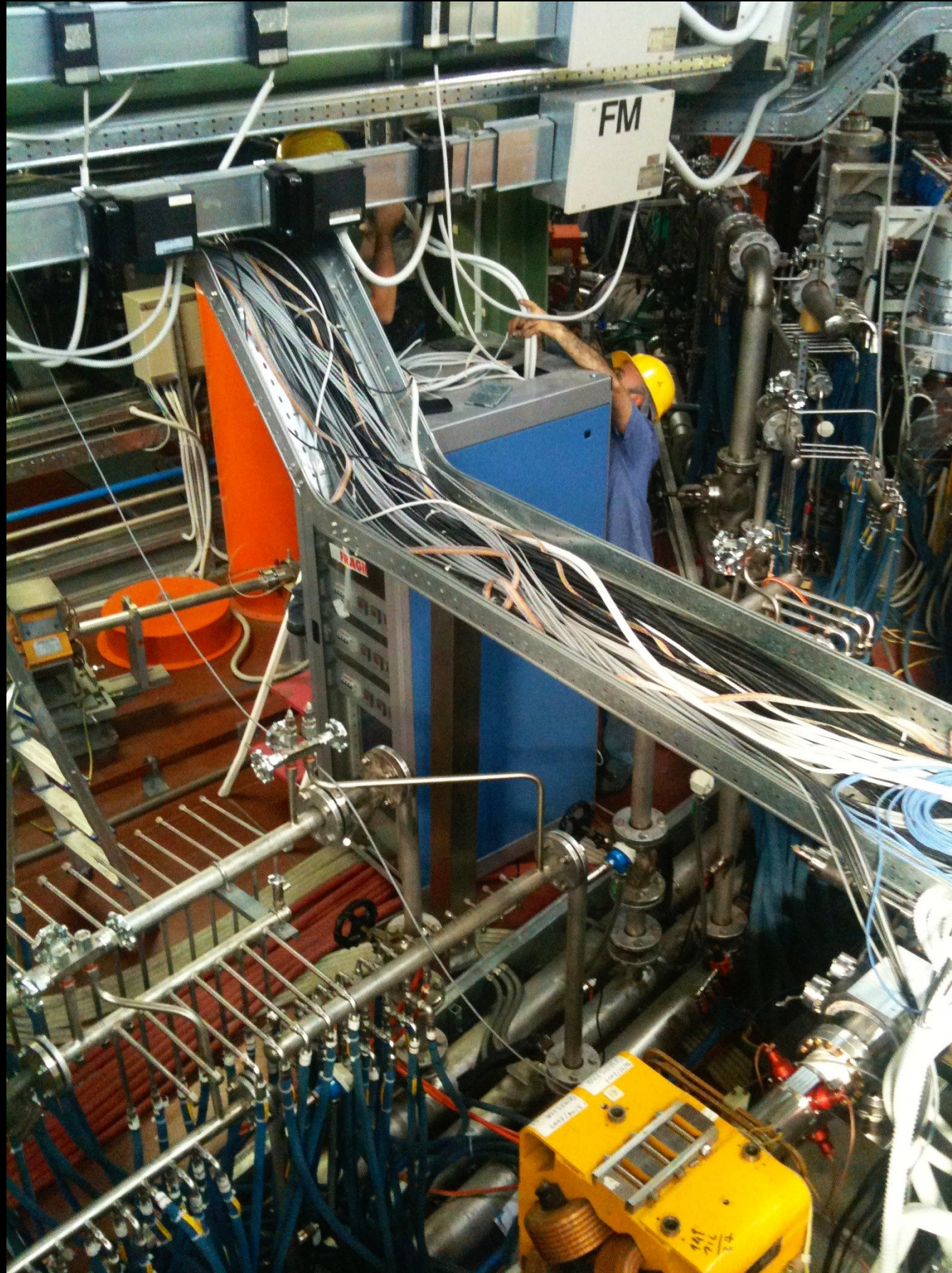
- production lines
- prognostics
- power plants

Scientific

- unmanaged rovers, space probes
- astronomy
- experimental apparatus, detectors, particle accelerators

Control Systems – of complex plants – employing computers (*and IT in general*)

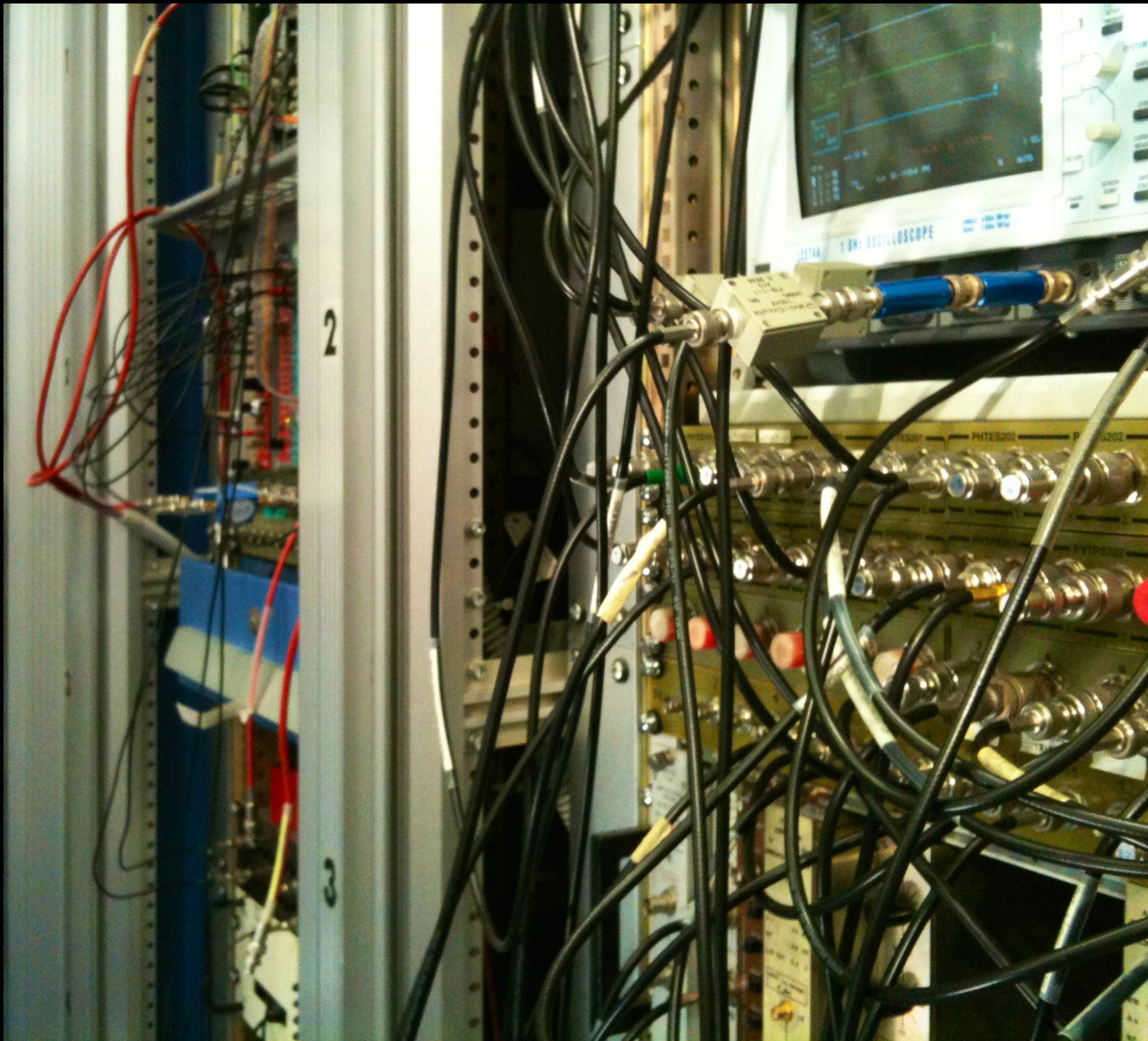
plant



plant → **sensors/actuators**



plant → sensors/actuators → **front-end**



plant → sensors/actuators → front-end → **control room**

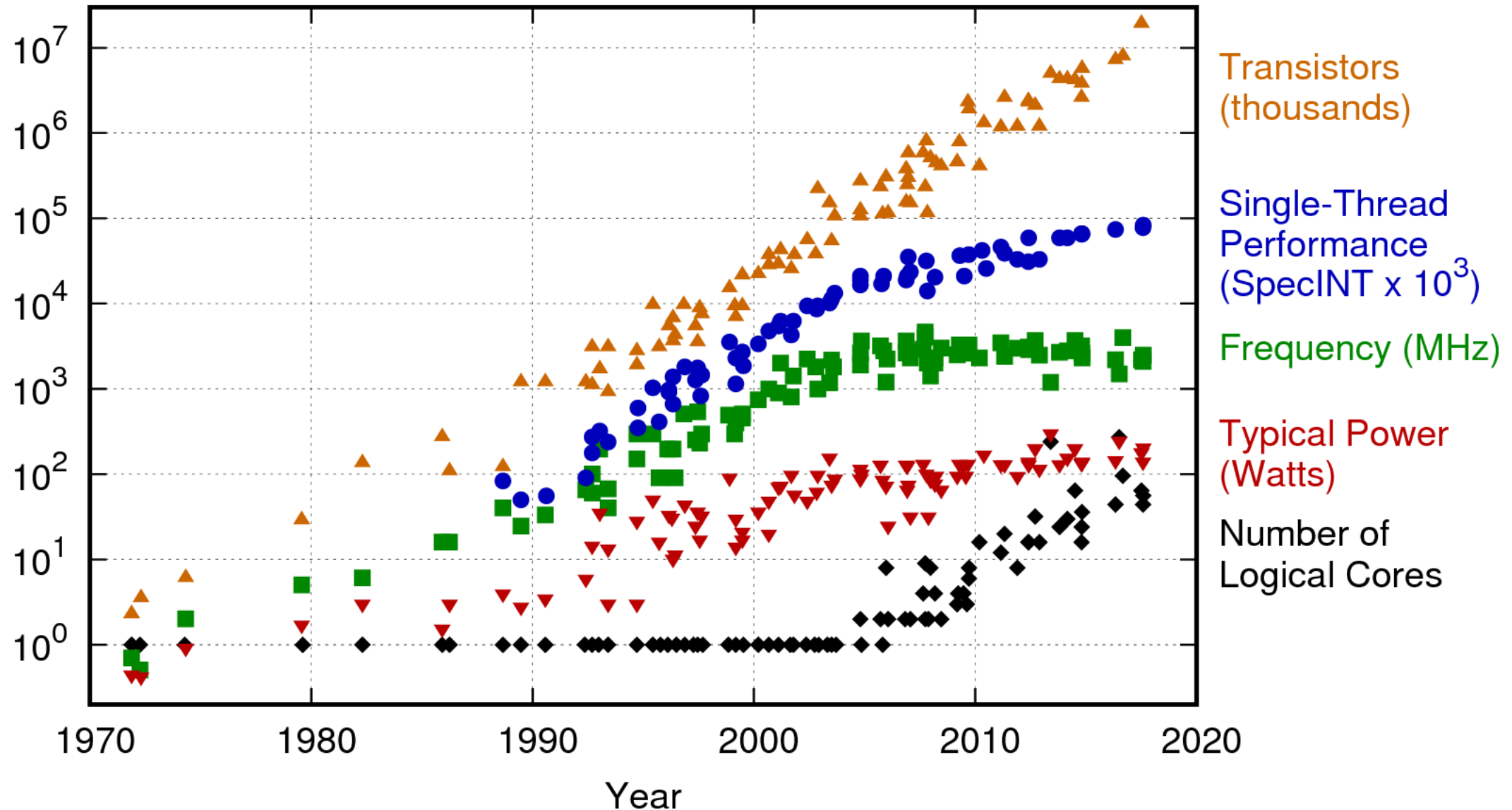


General characteristics

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

Technological growth

42 Years of Microprocessor Trend Data



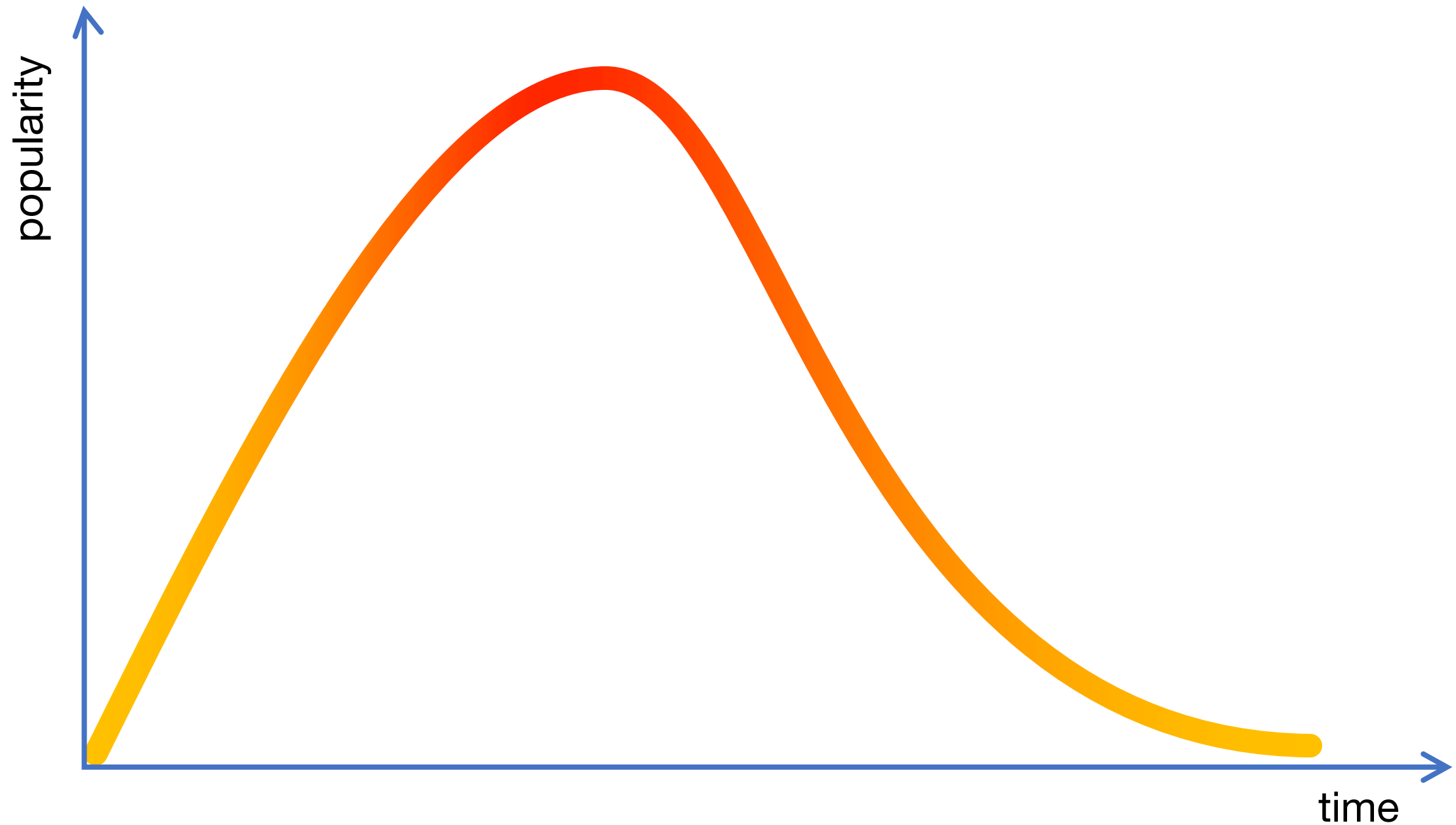
Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2017 by K. Rupp

Moore's law

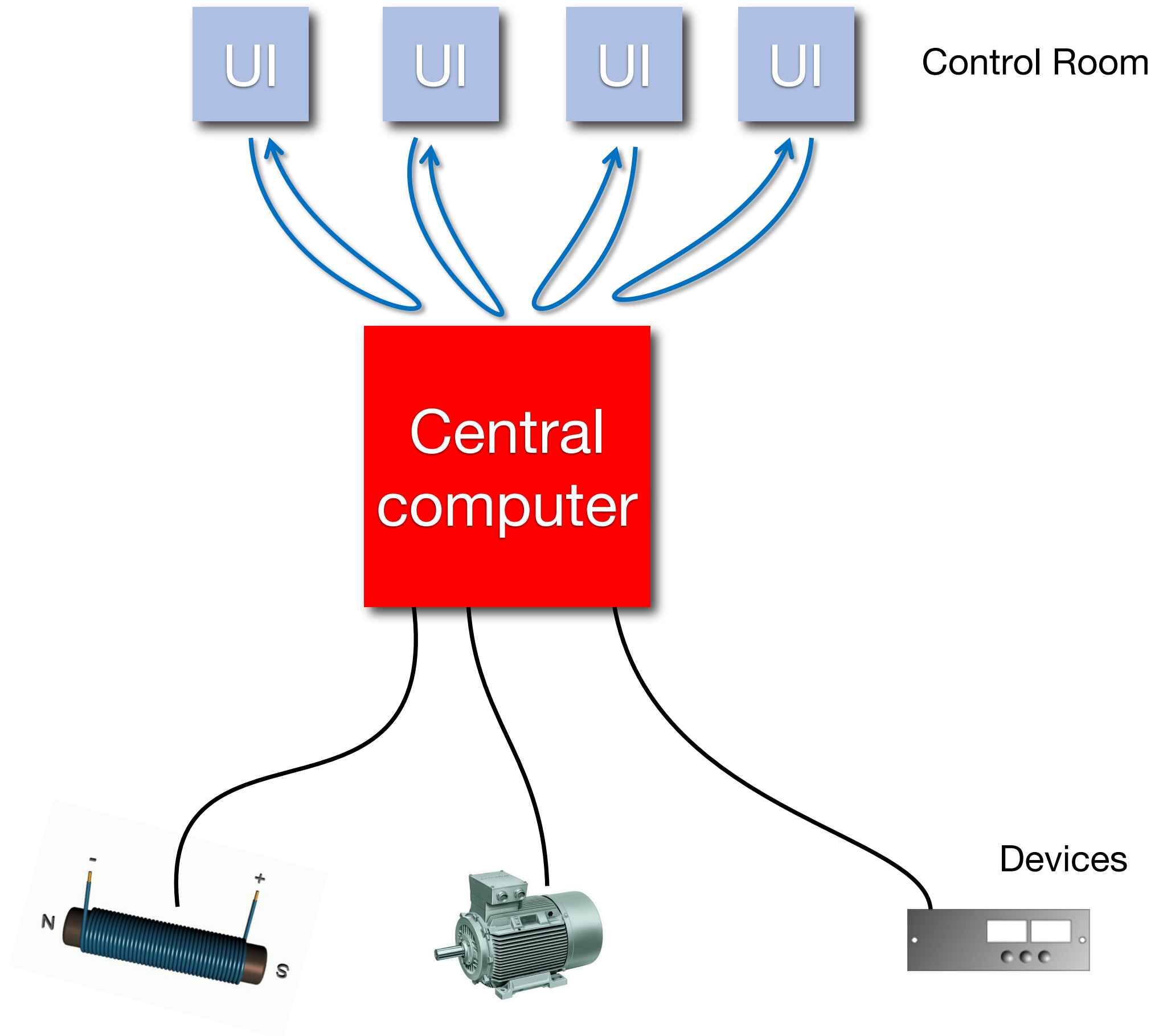
the number of transistors in processors doubles every 18 months

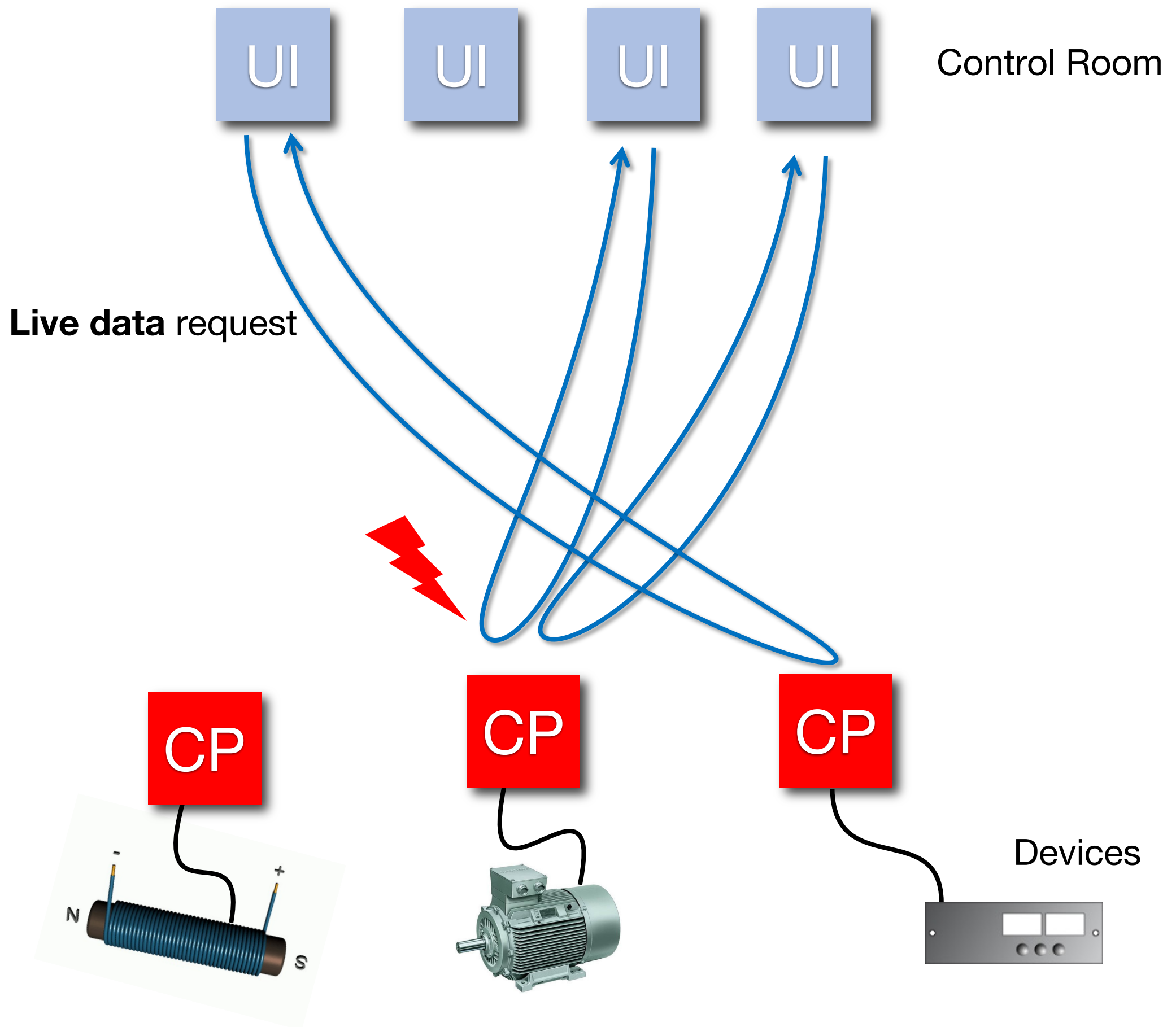
-> limits on reducing the size of transistors below which unwanted 'parasitic' quantum effects would occur in electronic circuits.

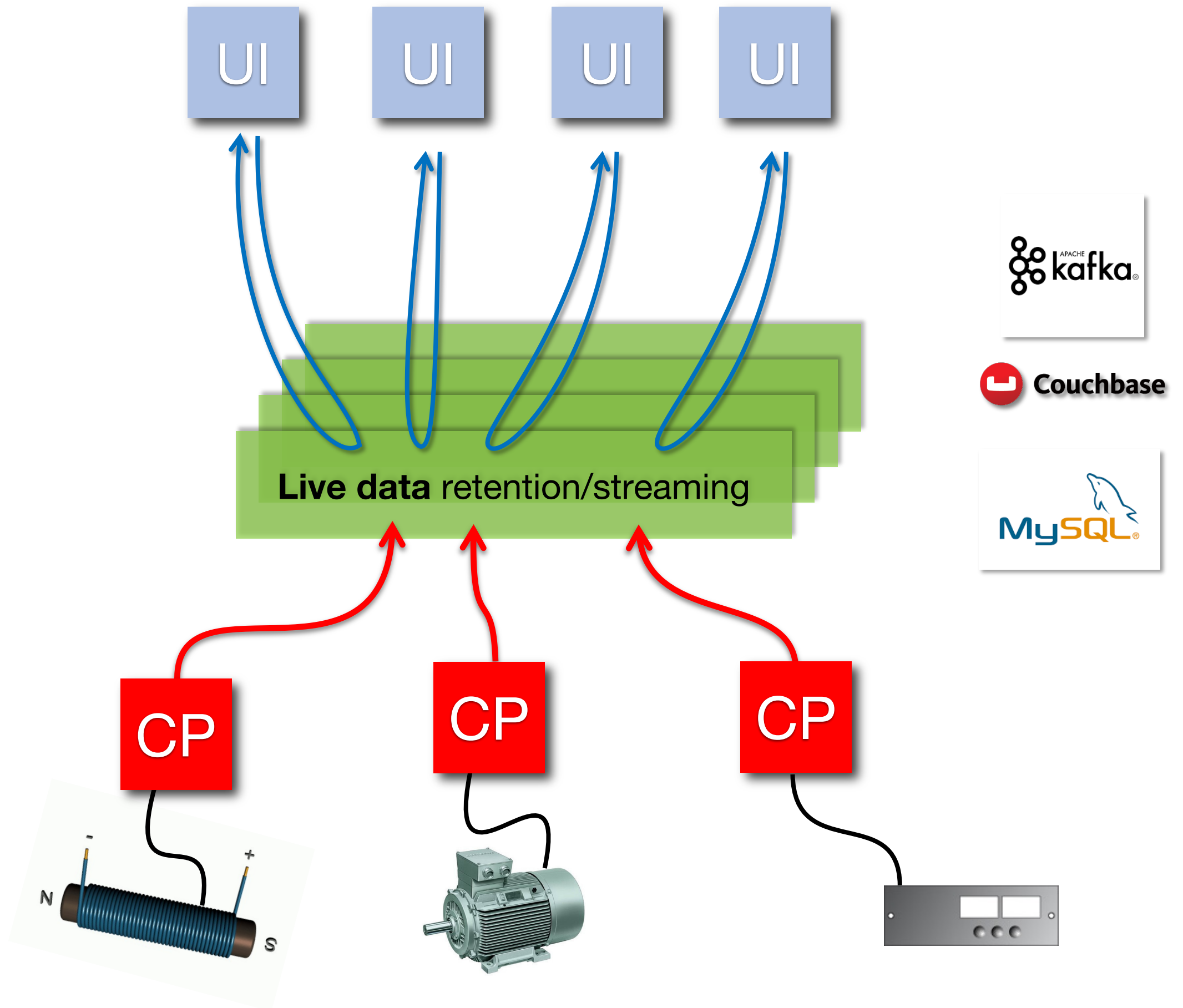
Obsolescence of standards

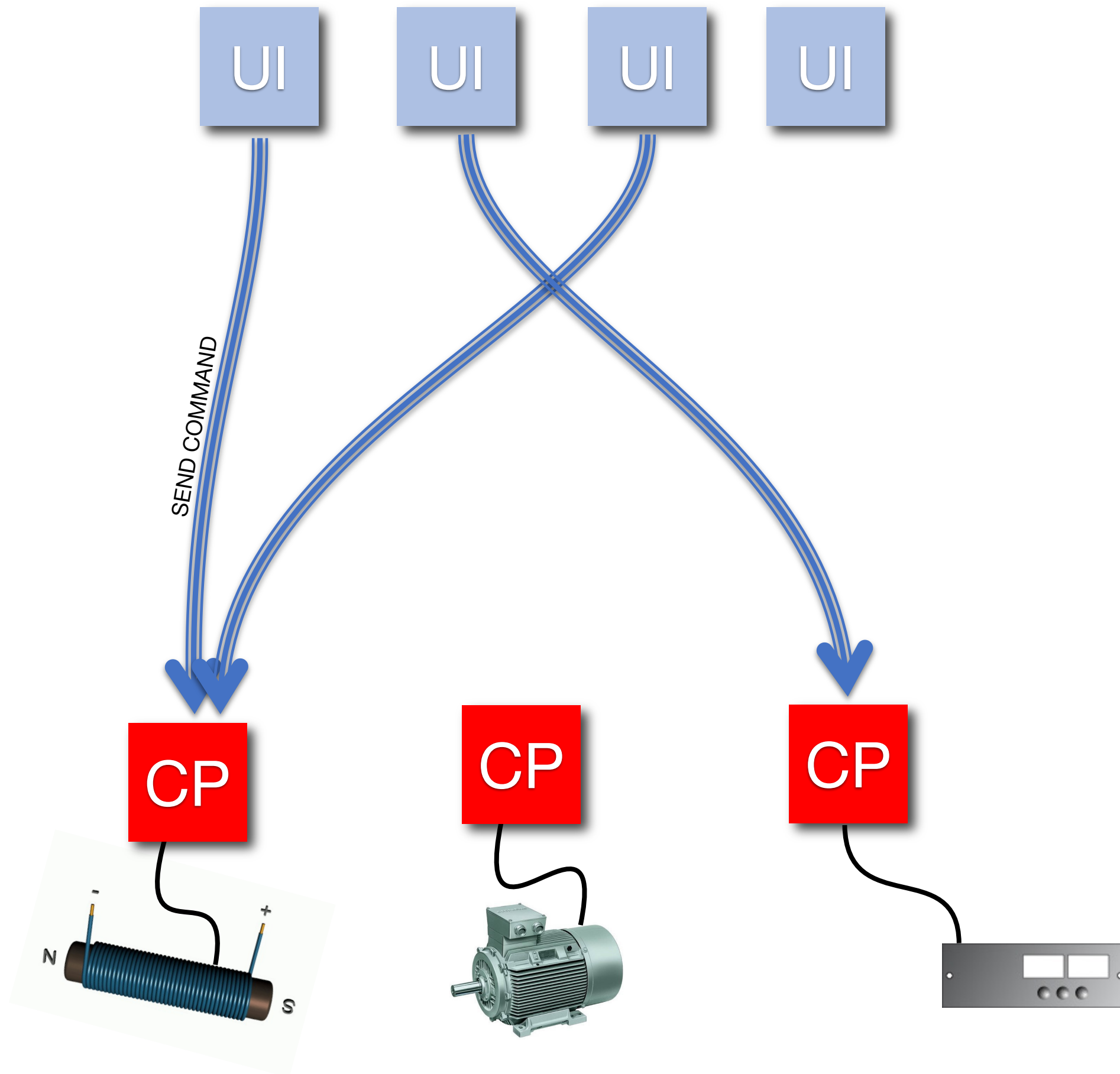


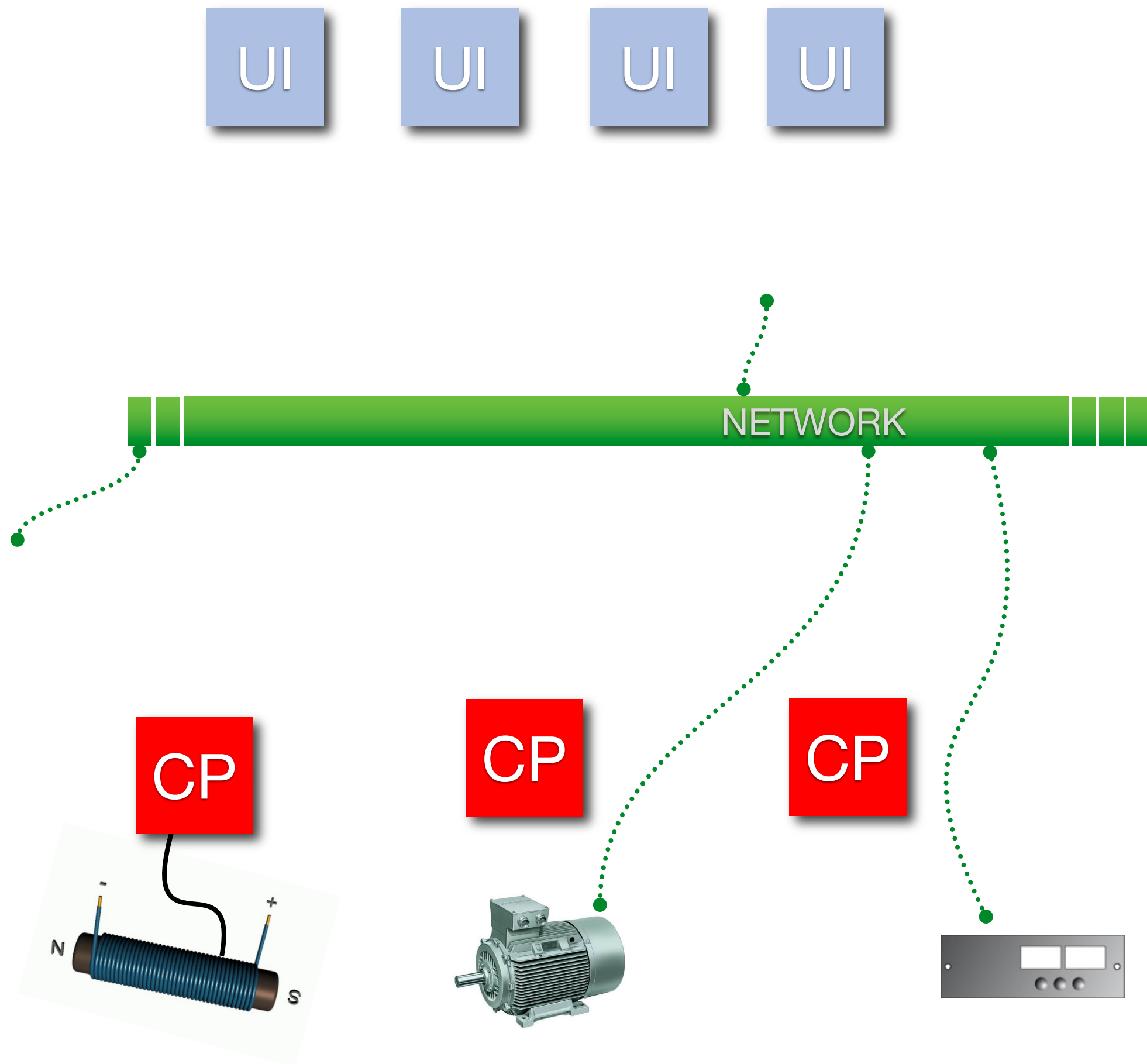
The lesson is: a system has to be as **independent** as possible from hardware standards and specific software products.





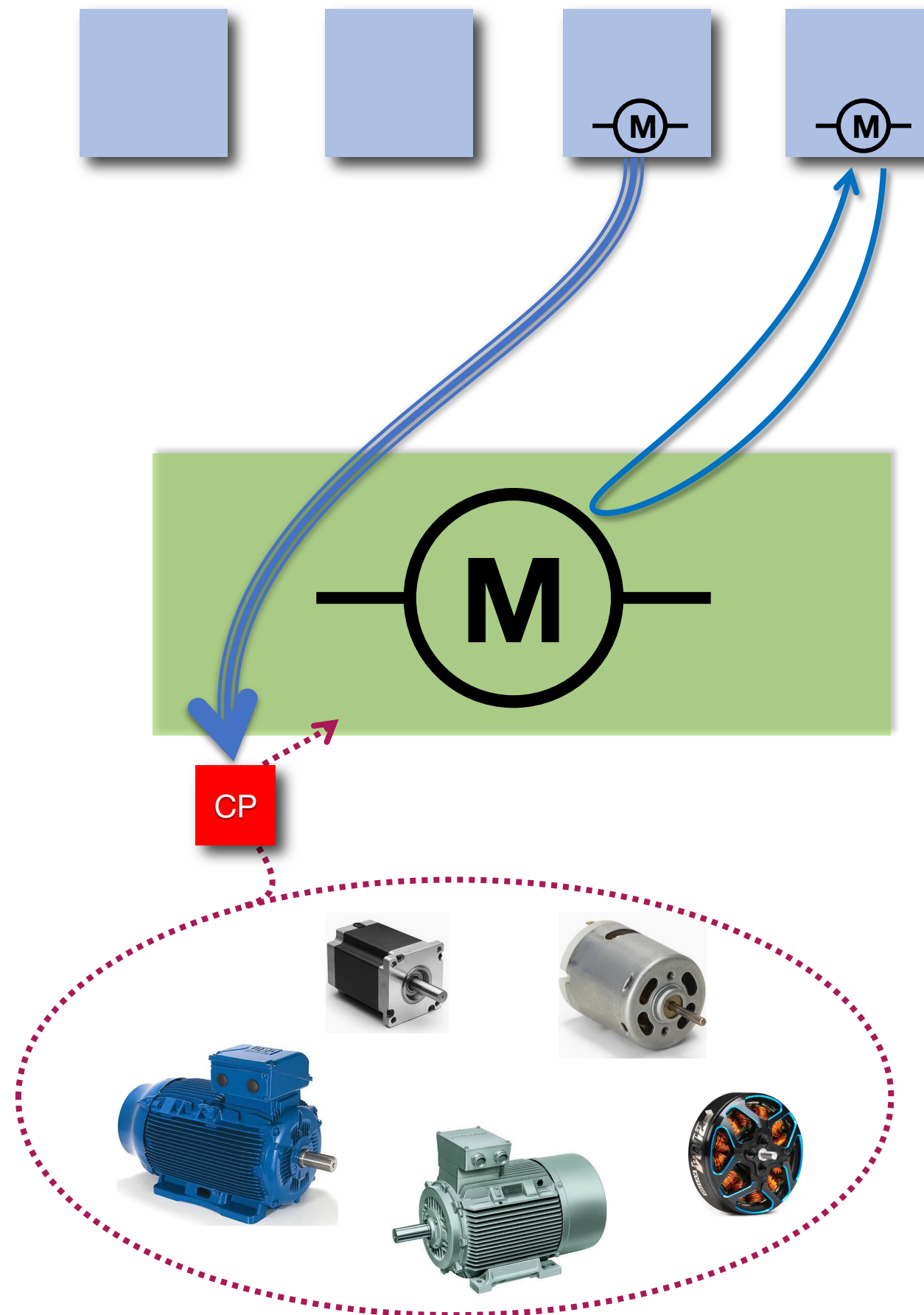




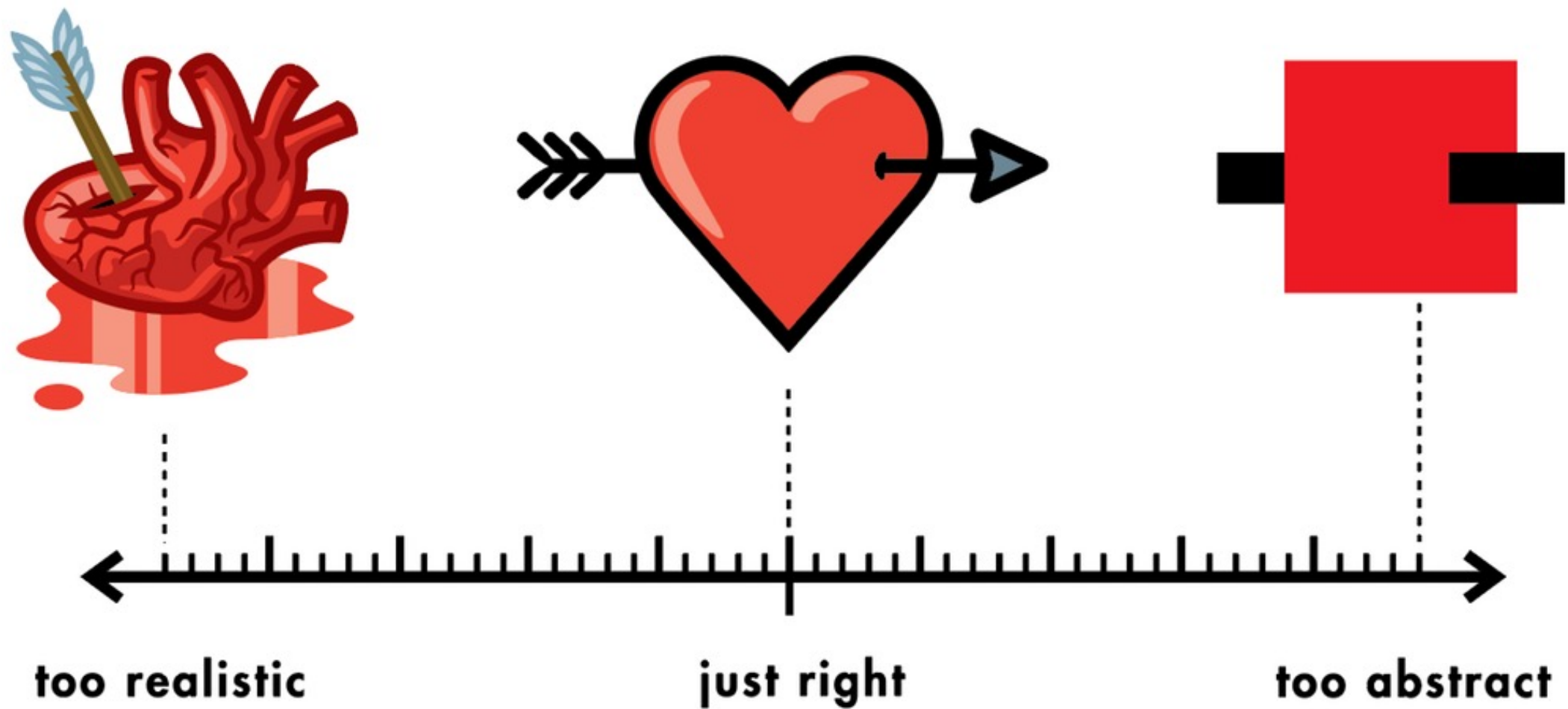


Abstraction



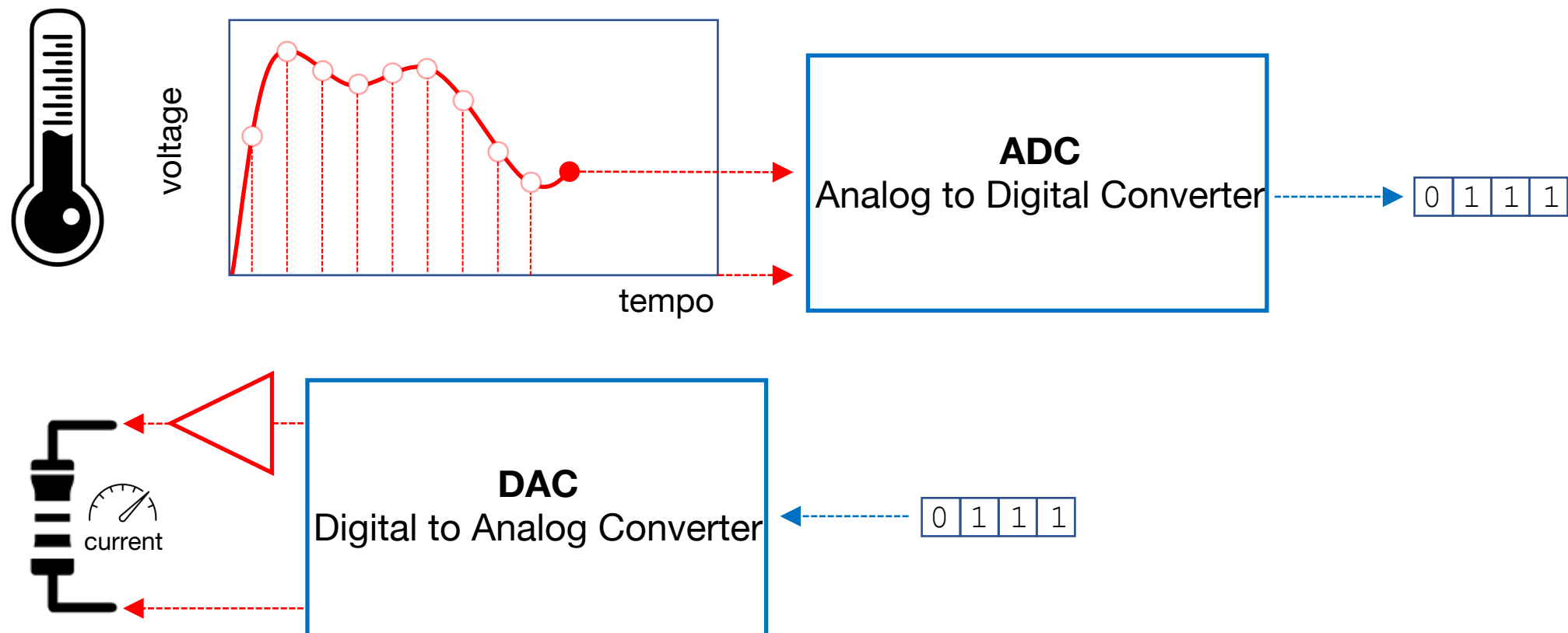


THE ABSTRACT-O-METER



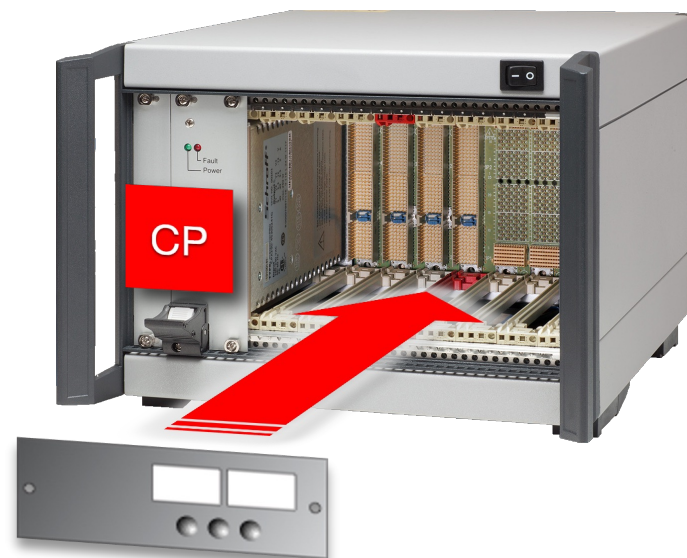
- **acquisition/actuation**

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



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

Embedded devices



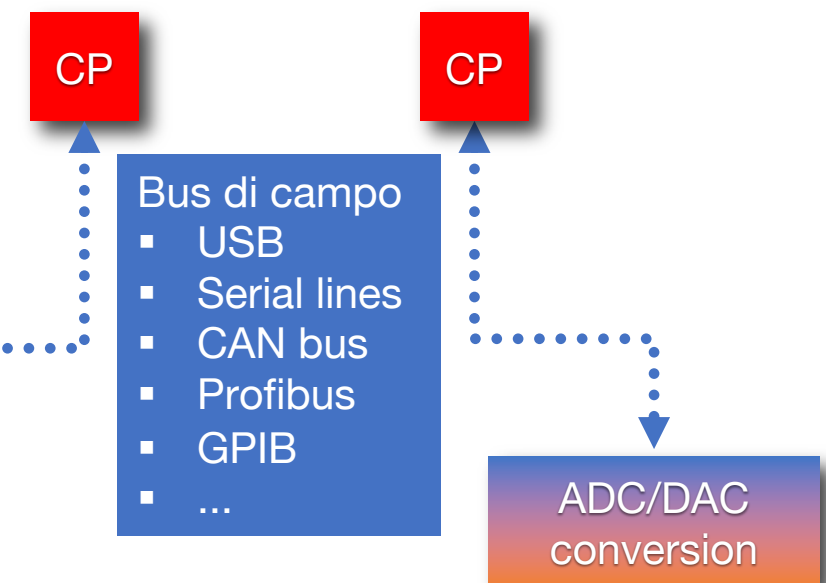
Intelligent devices



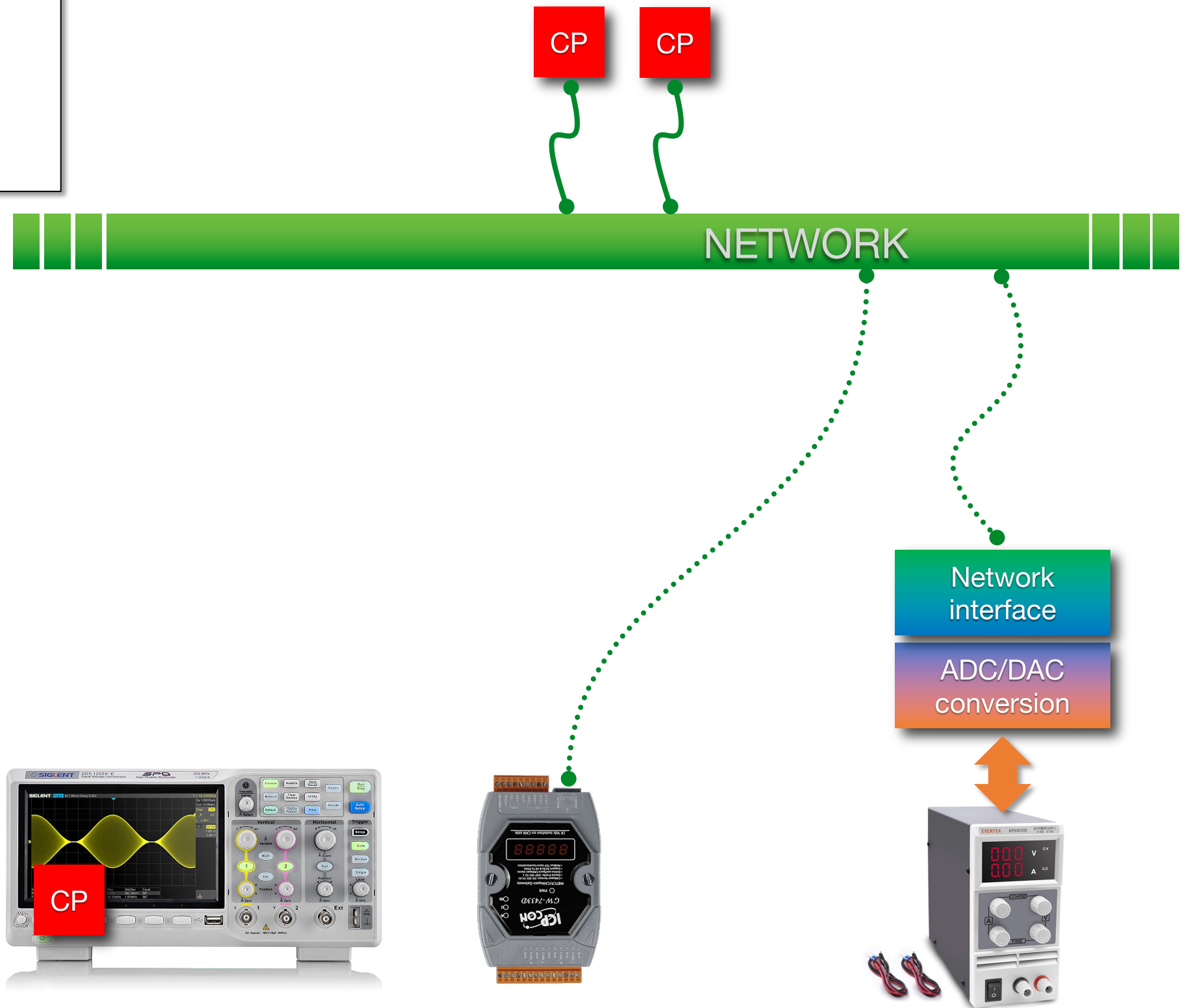
Digital devices



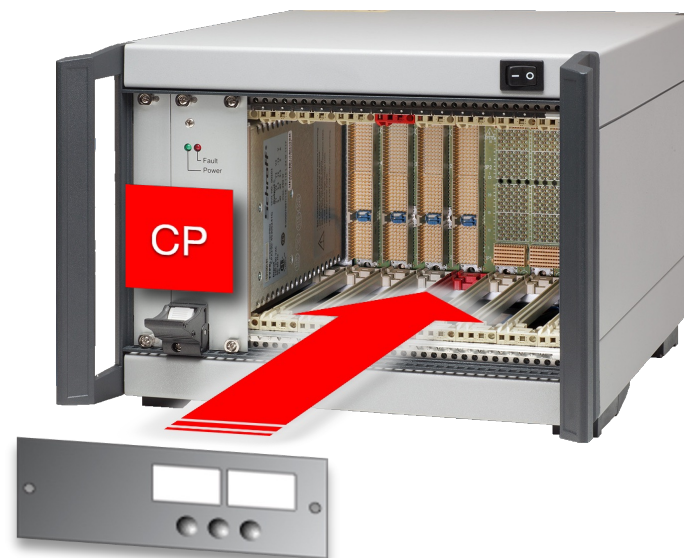
Analog devices



- acquisition/actuation
- **communication**
- storage
- presentation
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Embedded devices



Intelligent devices



Digital devices



Analog devices



- acquisition/actuation
- communication
- **storage**
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- analysis / correlation
- historization

average size (@DAFNE)
~ 650 byte



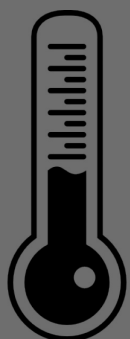
```
{
float64 temperature_read;
char    units;
boolean status;
....
}
```

```
{
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



Dante Alighieri (1265–1321)

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 ogni calle.

→ ▪

The Divin Comedy
~0.5 Mbyte

DAFNE ~1.4 Mbyte

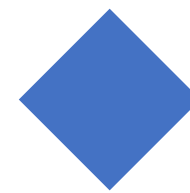
Relational
database →



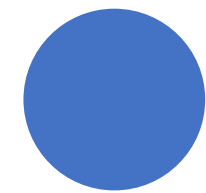
```
{  
float64 temperature_read;  
char    units;  
boolean status;  
....  
}
```



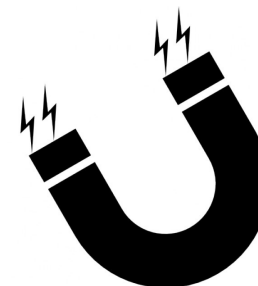
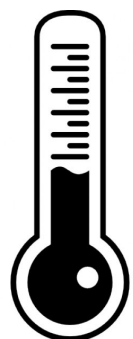
```
{  
float64 current_read;  
float64 current_set;  
char    units;  
boolean error;  
....  
}
```



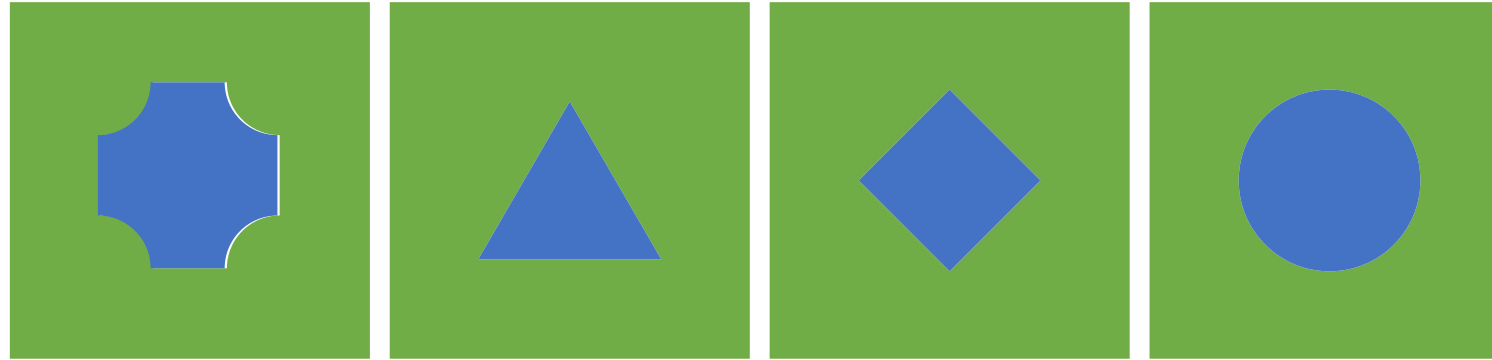
```
{  
float64 mag_field_read;  
float64 mag_field_set;  
int     polarity;  
....  
}
```



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



Relational
database →

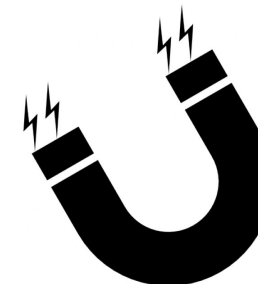
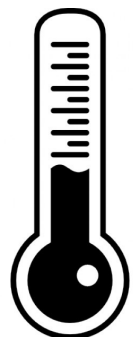


```
{
float64 temperature_read;
char    units;
boolean status;
....
}
```

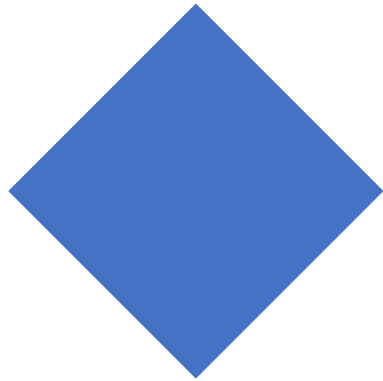
```
{
float64 current_read;
float64 current_set;
char    units;
boolean error;
....
}
```

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

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



Serialization: *self-describing* data vs *formatted* data



```
BEGIN OF DATA  
  here it is described a rhombus;  
  each side measures 100 mm;  
  the orientation of the diagonal is 0 deg;  
  blah blah...;  
END OF DATA
```

Most popular *self-describing* data formats

XML

```
<note>
  <to>Andrew</to>
  <from>Jane</from>
  <heading>Reminder</heading>
  <body>Don't forget me this weekend!</body>
</note>
```

YAML

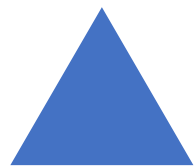
```
note:
  to: Andrew
  from: Jane
  heading: Reminder
  body: "Don't forget me this weekend!"
```

JSON

```
{
  "note": {
    "to": "Andrew",
    "from": "Jane",
    "heading": "Reminder",
    "body": "Don't forget me this weekend!"
  }
}
```

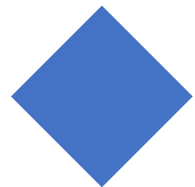
Non relational database

Key	Value



my_data

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



my_other_data

.... another descriptive sequence

e.g. BSON serialization

\0x16\0x00\0x00\0x00

\0x02

hello\0x00

\0x06\0x00\0x00\0x00world\0x00

\0x00

total document size

0x02 = field data type is string

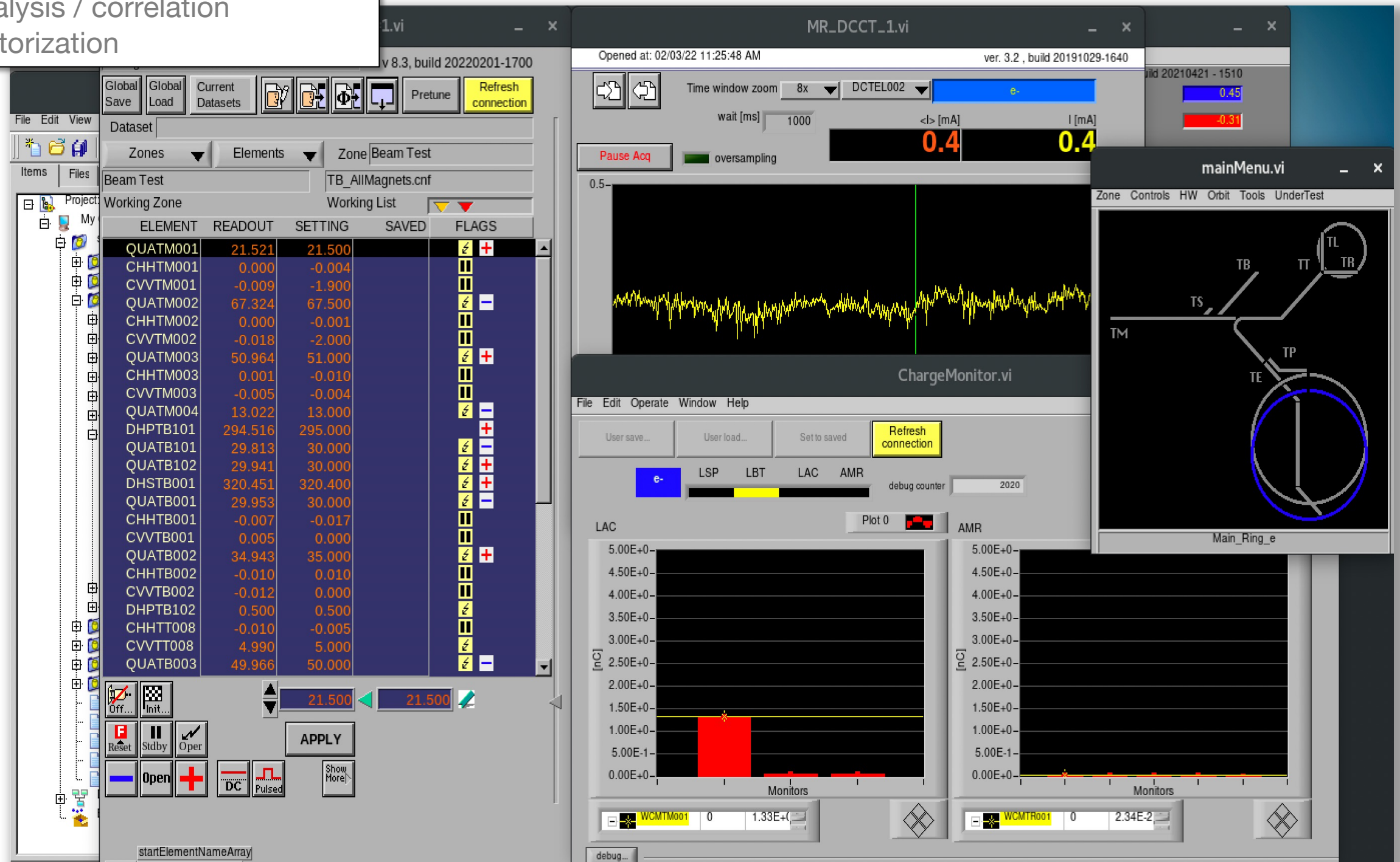
field name

field value (size of value, value, terminator)

type EOO ('end of object')

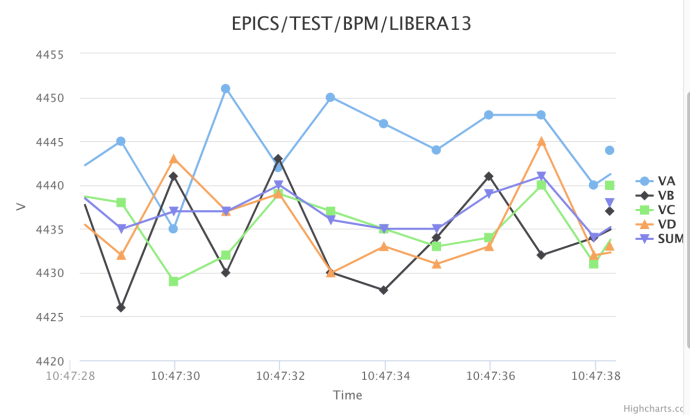
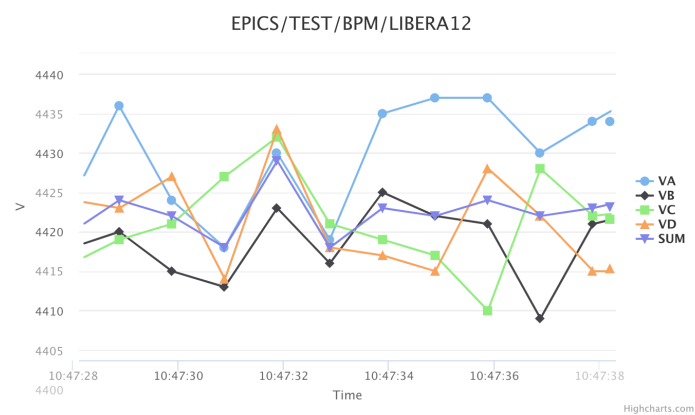
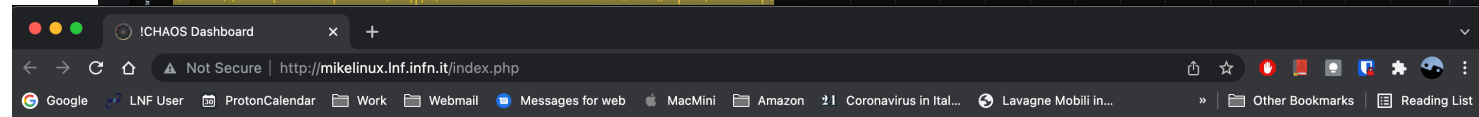
- acquisition/actuation
- communication
- storage
- **presentation**
- analysis / correlation
- historization

User Interface

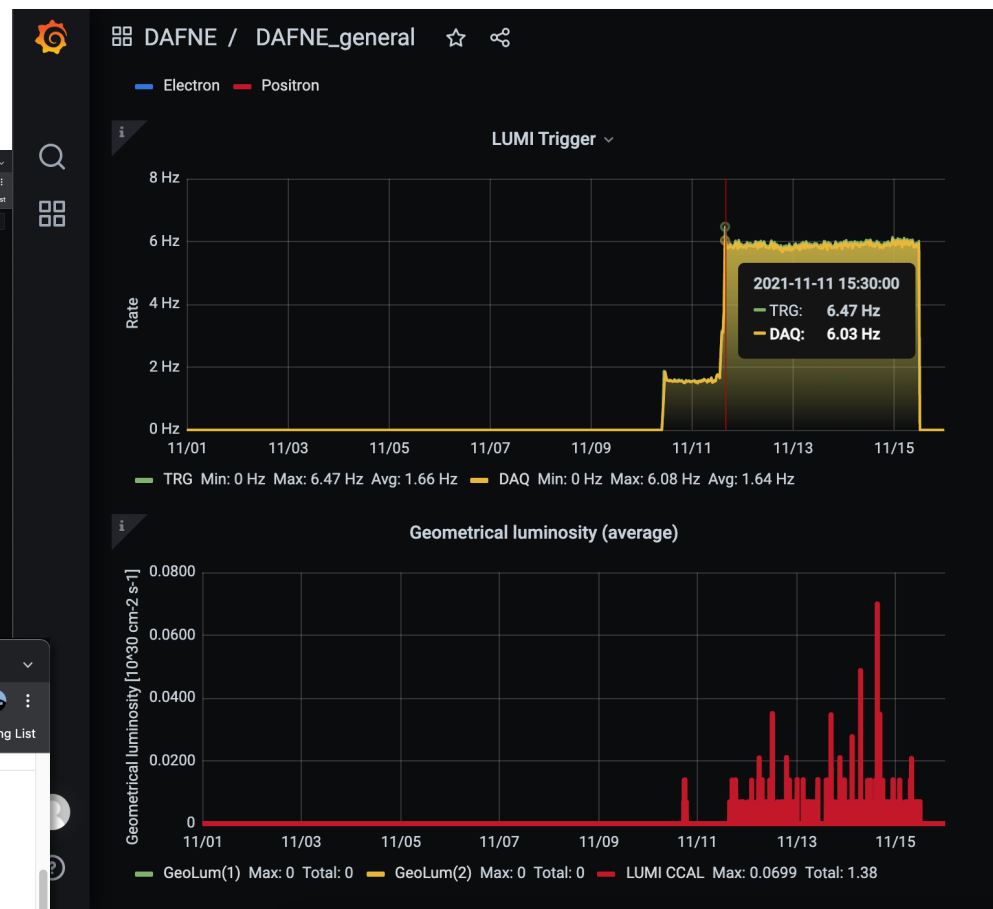
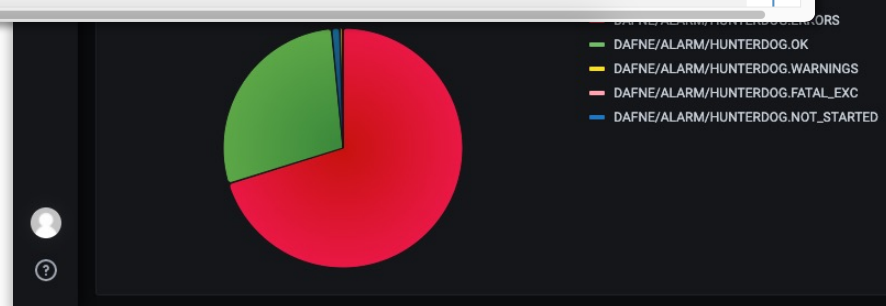


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User Interface

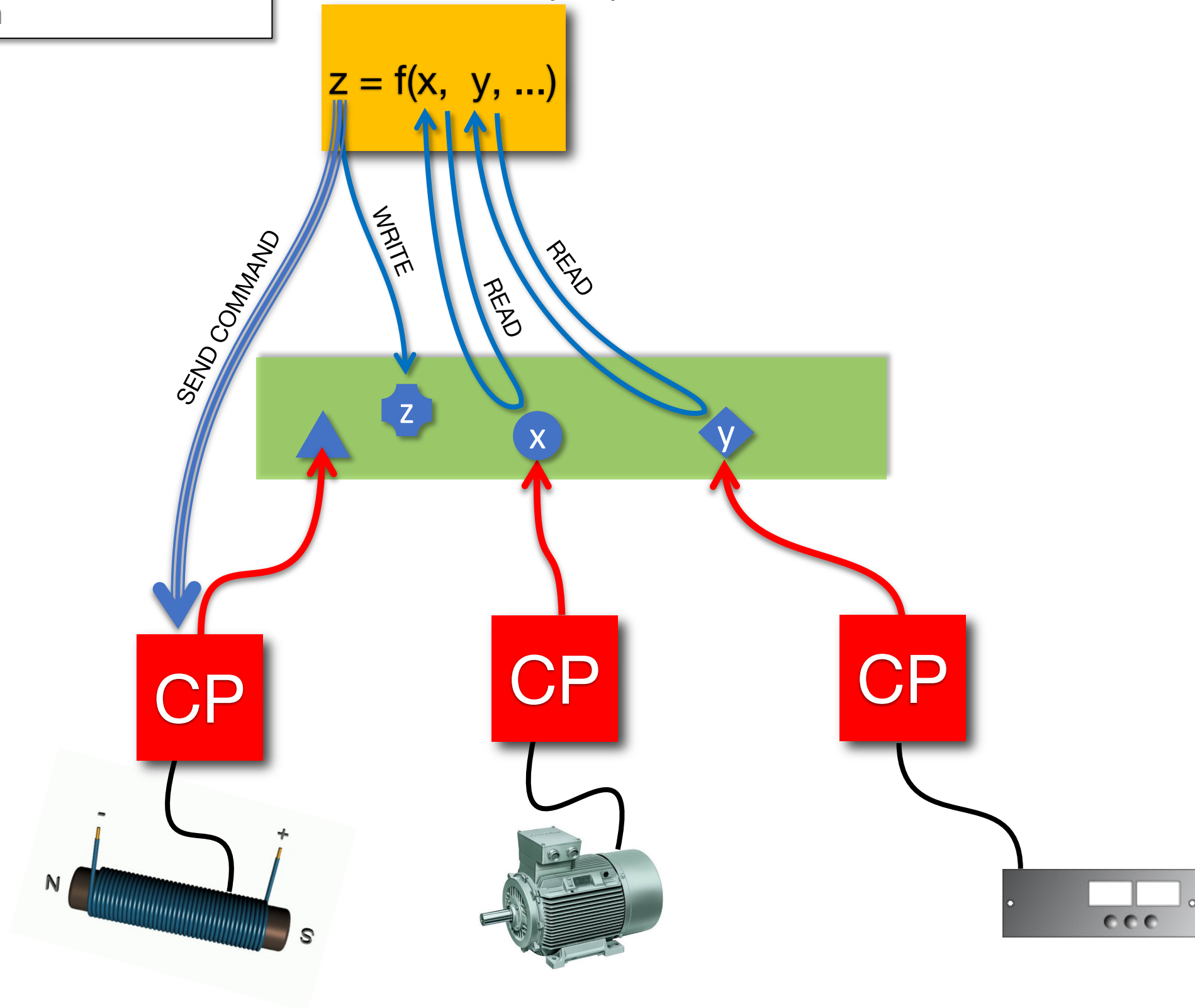


Sel	Element	Status	X	Y	VA	VB	VC	VD	SUM	Samples/Trigger	Alarms dev/cu
☐	EPICS/TEST/BPM/LIBERA01	 	0.000	0.000	667	862	1166	1093	3788	0	No Trigger
☐	EPICS/TEST/BPM/LIBERA02	 	0.000	0.000	777	508	950	873	3110	0	No Trigger
☐	EPICS/TEST/BPM/LIBERA03	 	0.000	0.000	591	481	705	650	2428	0	No Trigger
☐	EPICS/TEST/BPM/LIBERA05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

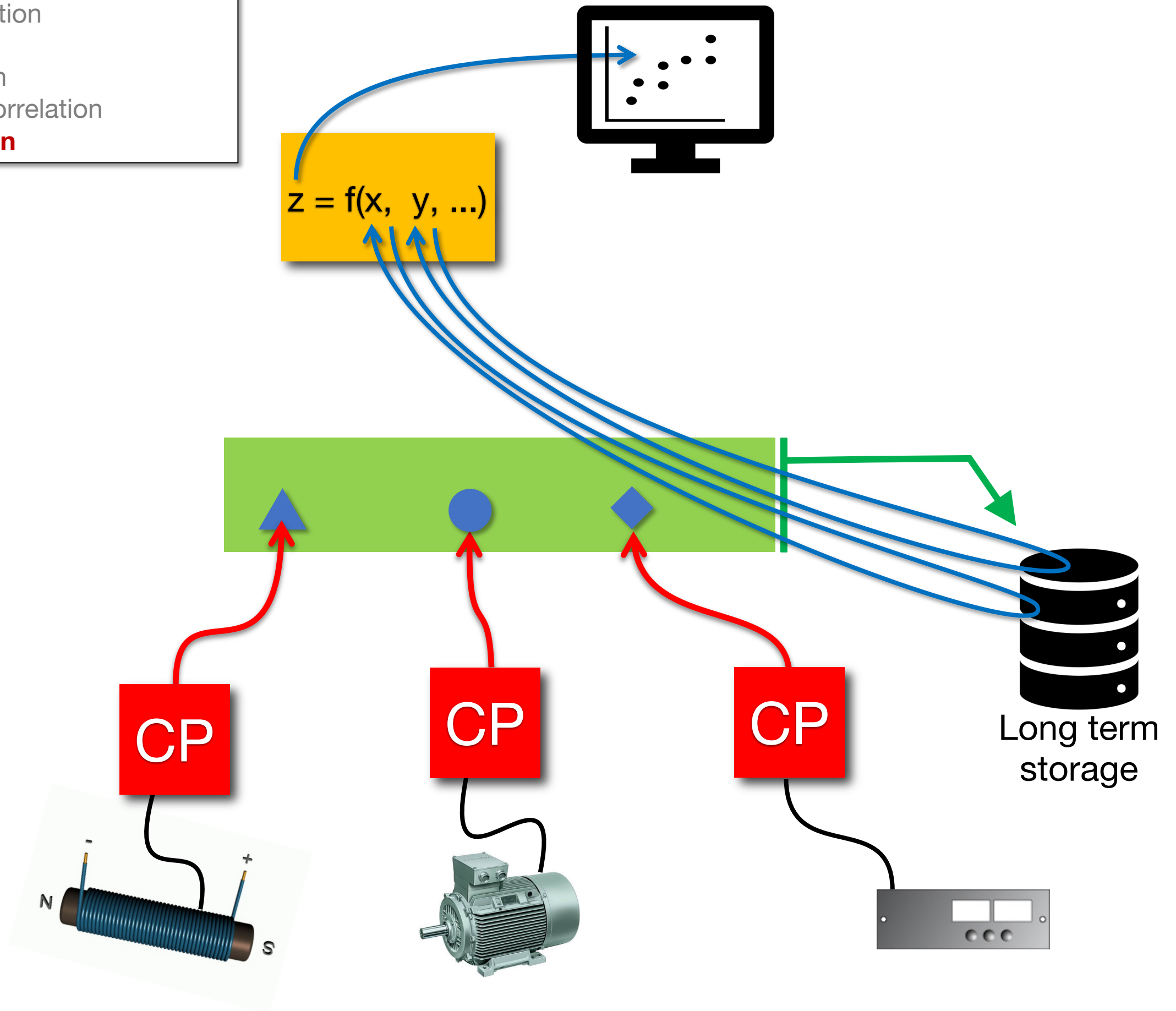


- acquisition/actuation
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- **analysis / correlation**
- historization

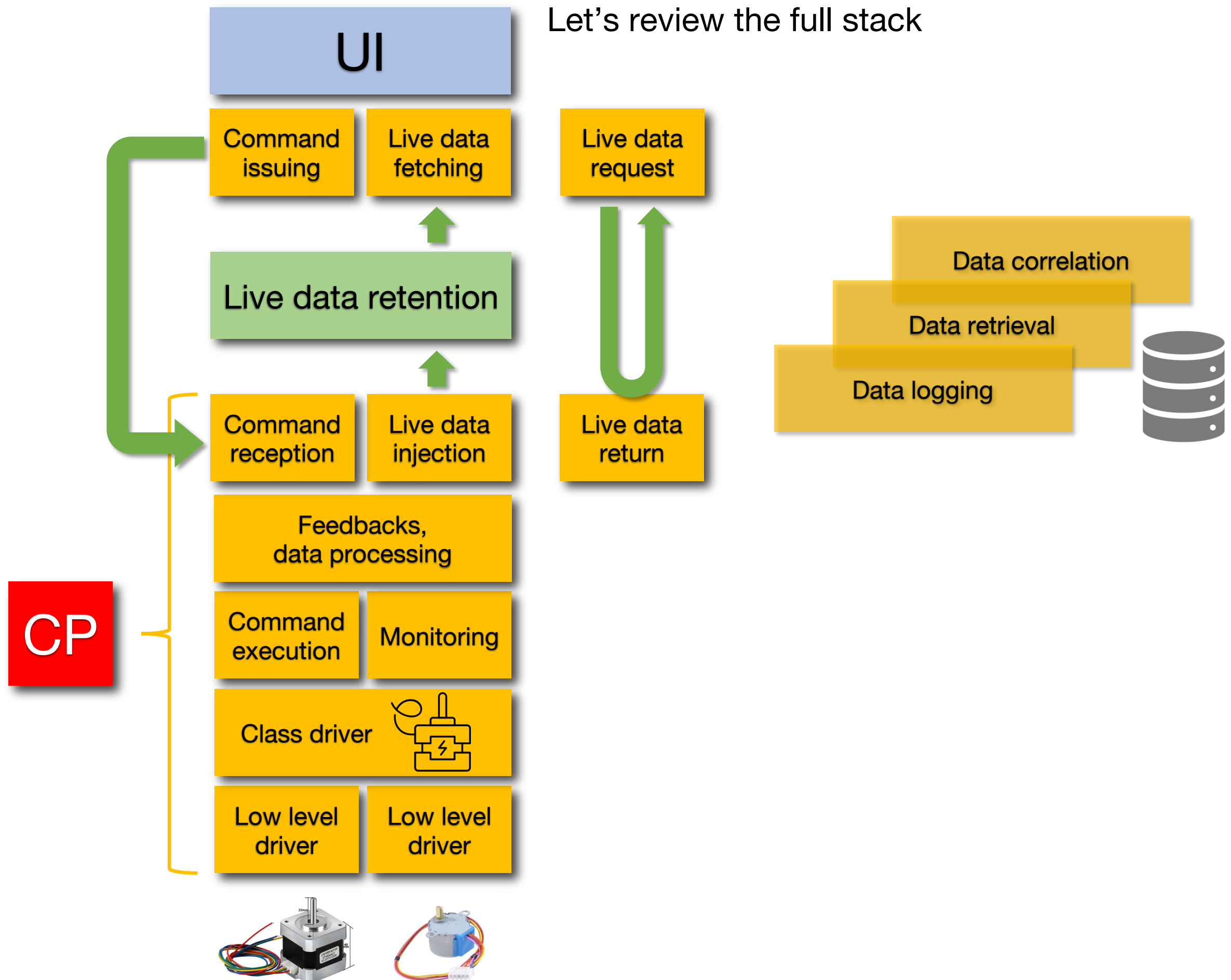
Correlation and analysis processes



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

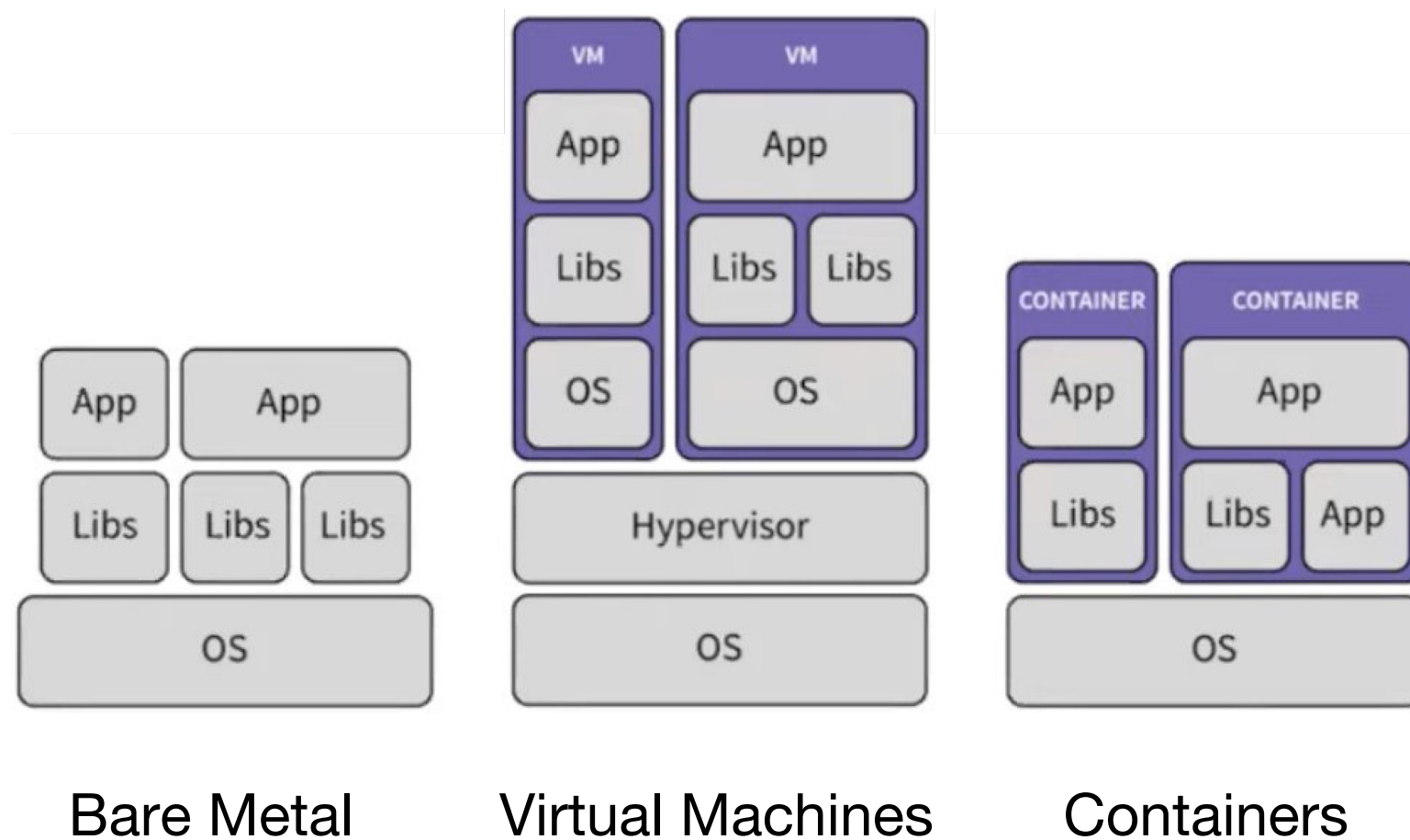


Let's review the full stack



IT interesting topics

- Big data
- AI
- Virtual machines, Containers/Dockers/Orchestrators



Courtesy of Giles Knap (Diamond)

Infrastructure @LNF

PRODUCTION CLUSTER

SERVICE CLUSTER

STORAGE 1/2 PB

SPARES

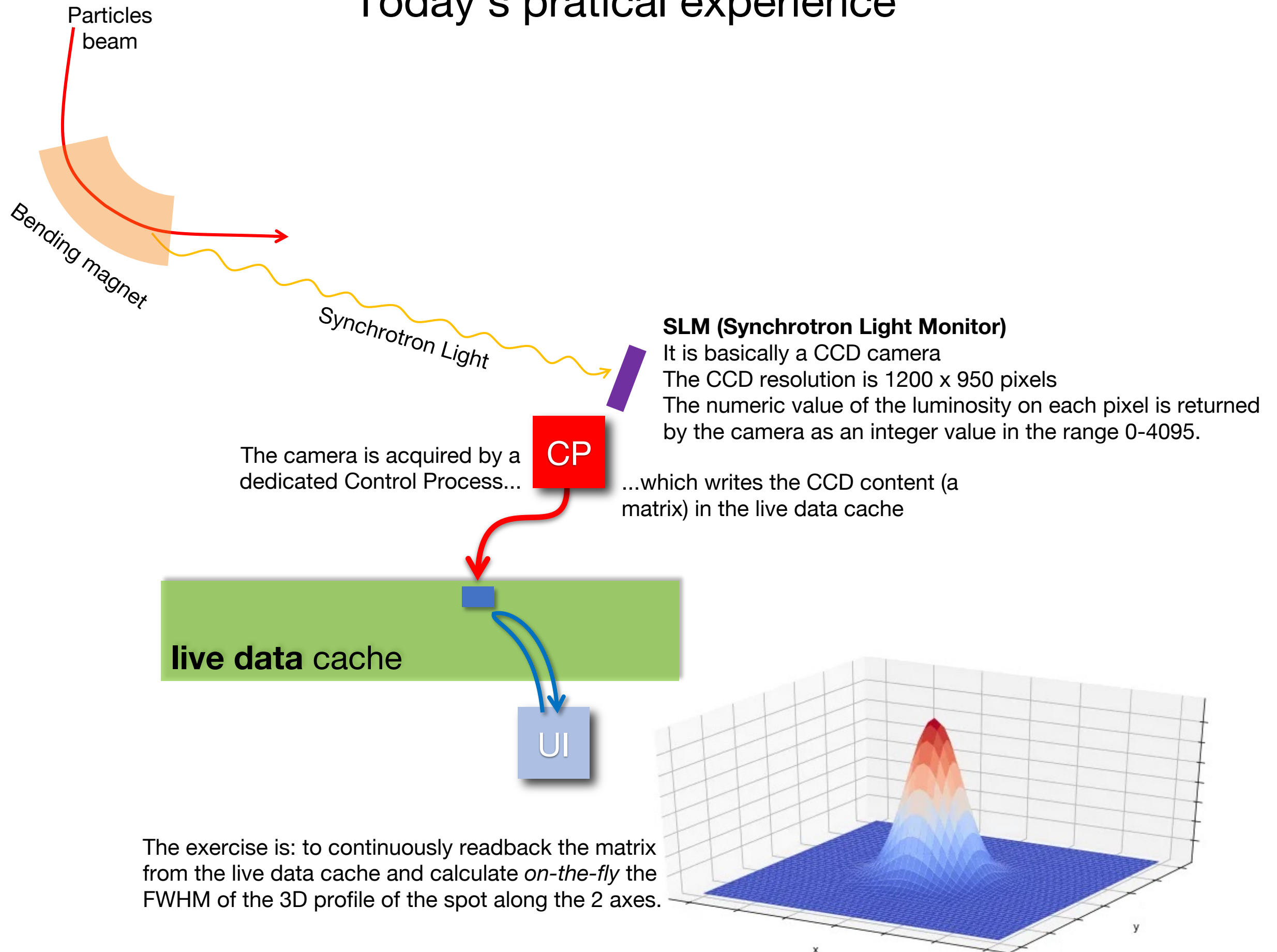
SERVICE CLUSTER

DEVELOPMENT CLUSTER

PRE-PRODUCTION CLUSTER

- 376 cores
- 824 GB RAM
- 500 TB HD

Today's practical experience




```
$ shutdown -h now █
```

```
The system is going down for halt NOW!
```

```
[ OK ] Stopped Presentation.
```

```
[WARNING] Everyone is very tired.
```

```
systemd[1]: Unmounting tutor Alessandro...
```

```
[ OK ] Unmounted tutor Alessandro.
```

```
systemd[1]: Unmounting all Seminar Attendees...
```

```
[ERROR ] Unmount of all Seminar Attendees failed with the message:  
"Practical experience is still pending."
```

```
systemd[1]: Shutdown aborted.
```

```
$ █
```