Industrial Smart Monitoring

CERN IoT Workshop

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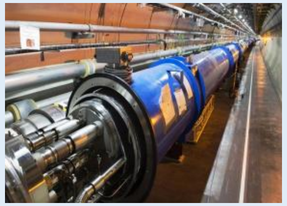
07/11/2017

Take advantage of control data

A multitude of Industrial Control Systems

Cooling & Ventilation



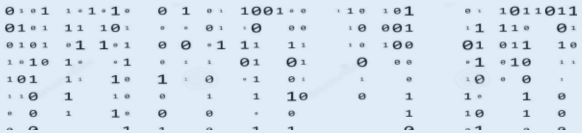
VACUUM

Cryogenics

GAS

Electric Grid

LHC Circuit, QPS, WIC,PIC, …



Storing +100 TB/year

Control Data analytics

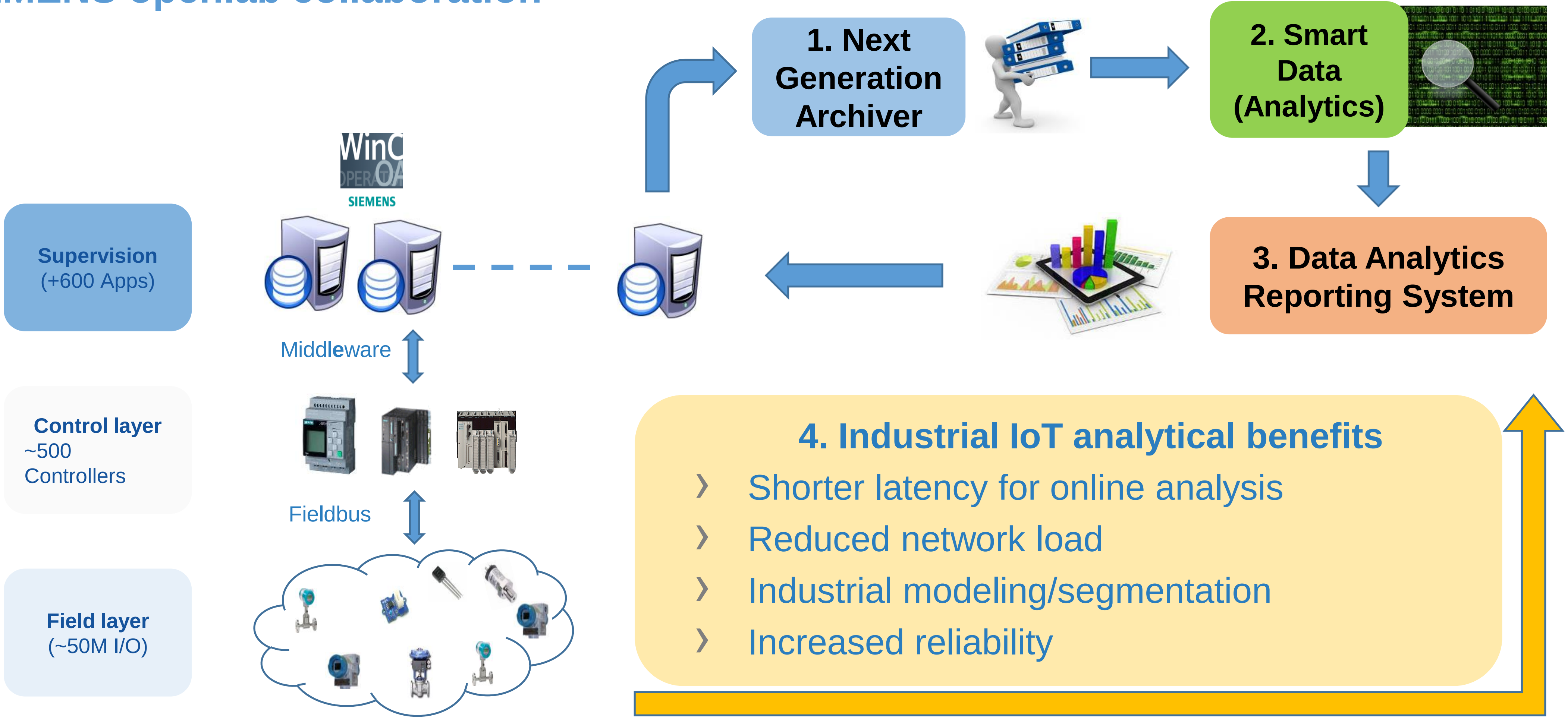
- Specific industrial analytics algorithms
  - Expert systems
  - Machine learning to deal with heterogeneous control systems

- Large-scale performance

- Take advantage of Big Data to improve:
  - ✓ Control system stability and efficiency
  - ✓ Reduce maintenance cost
  - ✓ Performances (even physic data quality)
  - ✓ Safety

Control monitoring: Ingestion, Analysis, Reporting

SIEMENS openlab collaboration



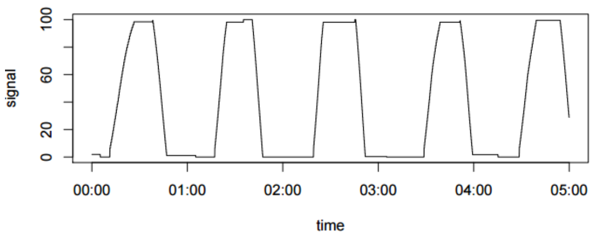
Enhance industrial monitoring with Smart Data

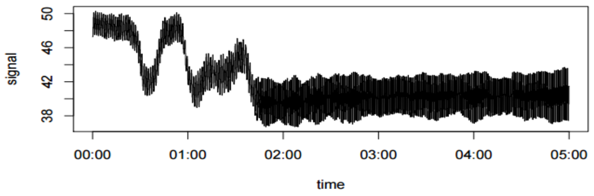
Extending the SCADA monitoring capabilities: some examples of analysis

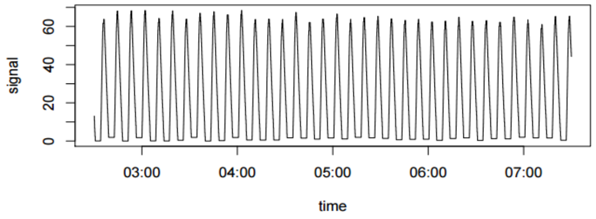
Anomaly detection

1. Detect anomalous oscillation:

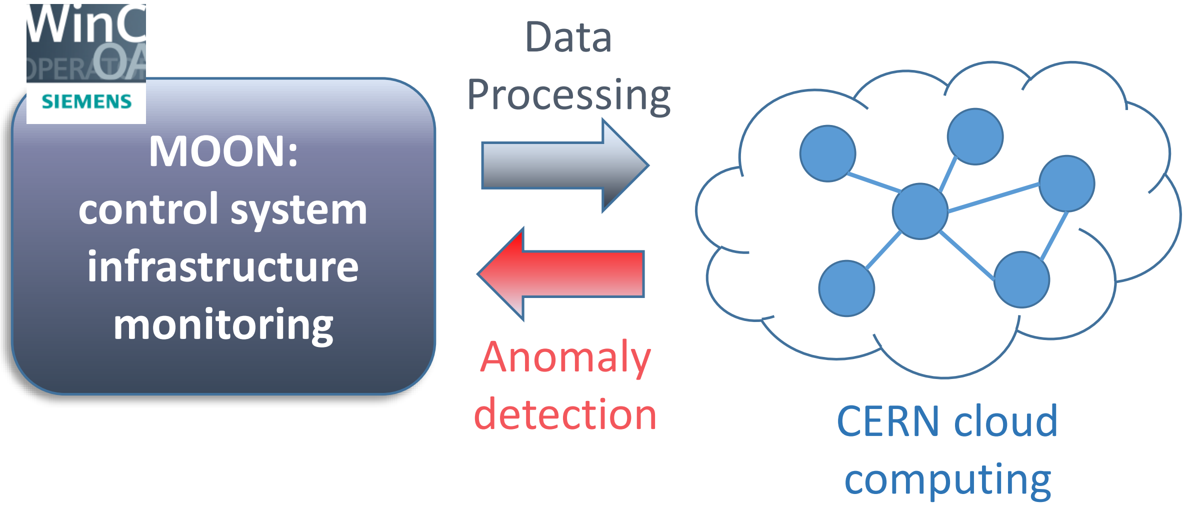
- Control system stability
- Increased communication load
- Maintenance (use of actuators)
- Performances (Physic time)



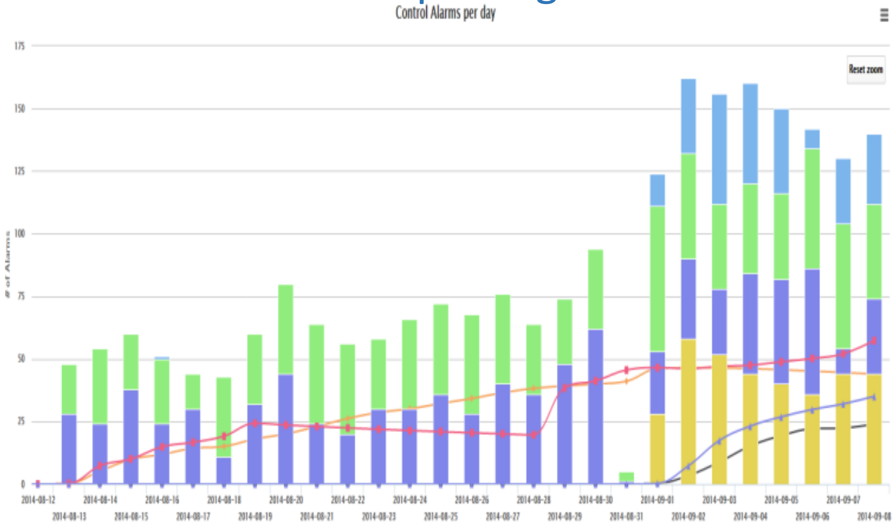




2. Detect system/hardware malfunctions

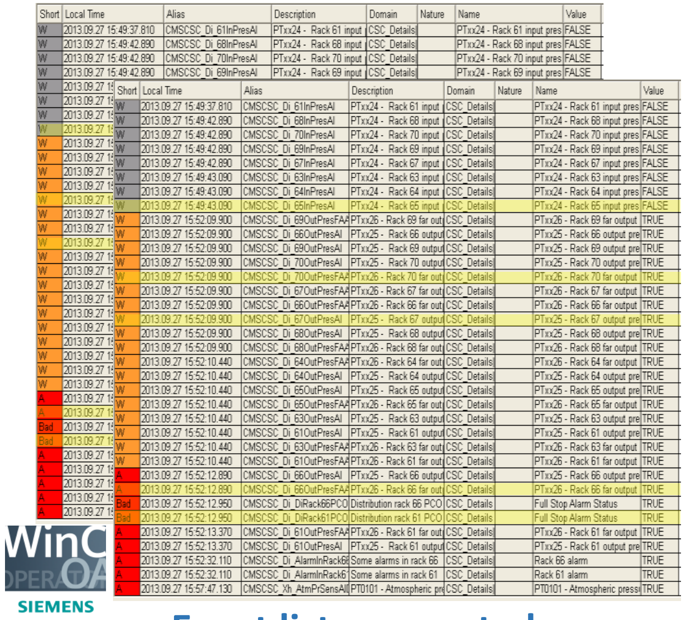


Web Reporting



Post-mortem analysis

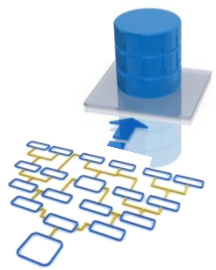
Root-cause analysis and fault prediction



Event lists generated by the same fault

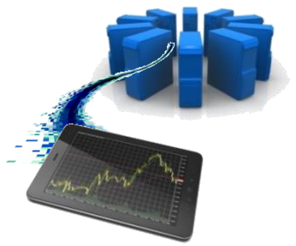
Data

Analyze



Identify and detect fault / abnormal pattern for Diagnosis and Prognostics based on domain knowledge

Learn



Provide experts with Root-cause and Gap Analysis using Rules and Patterns Mining

Diagnose

Forecasts, Trends and Early-Warnings to increase Operating Hours

Sequence: Confidence: 83.3 % / Appearance count: 5
CMSCSC_Di_62PRegAI | Alarm Unacknowledged | Rising
CMSC…

Sequence: Confidence: 100.0 % / Appearance count: 6
CMSCSC_Di_62PRegAI | Alarm Unacknowledged | Rising
CMSCSC_Di_62PRegAI | Position Status (HH-LL) | Rising
CMSCSC_Di_YC60995 | Auto Off/Close Request Status | Falling
CMSCSC_Di_YC60995 | Auto On/Open Request Status | Rising
CMSCSC_Di_YC60995 | Off/Closed Status | Falling
CMSCSC_Di_YC60995 | On/Opened Status | Rising
CMSCSC_Di_YC60995 | Output Order Value Status | Rising

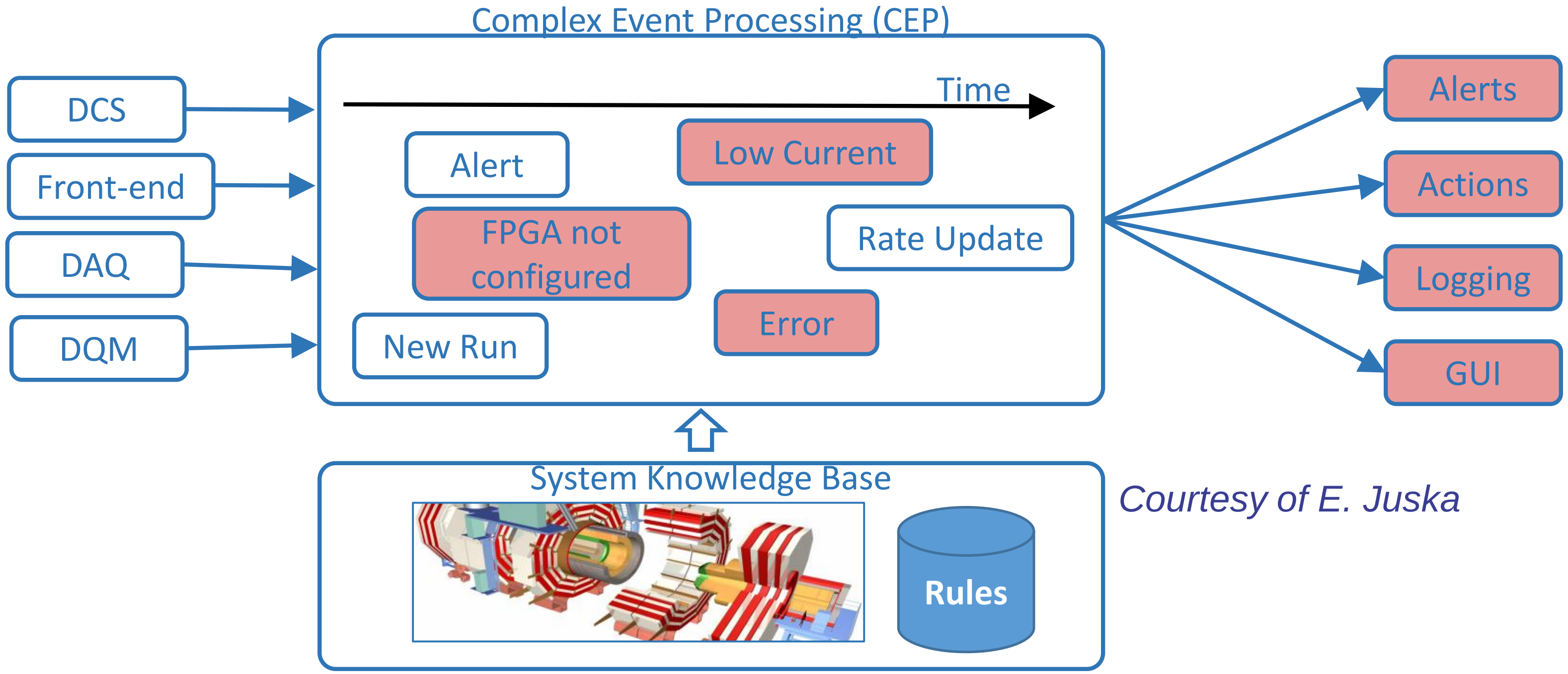
Pattern AA B A A B → **Alarm**

X T C D F A A E D N D B K D F A A B K D

Expert systems

1. Formalization of experts’ knowledge

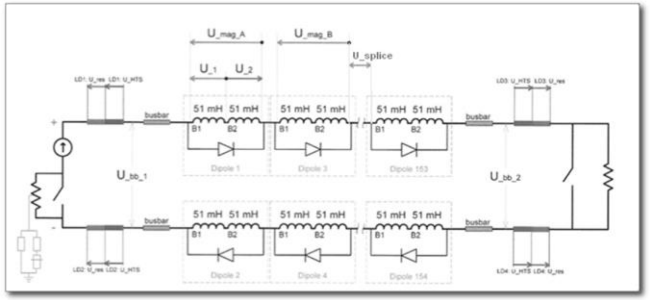
- Orchestrate complex systems by combining huge datasets (ex: automatize the operator routines)



Courtesy of E. Juska

2. Predictive maintenance

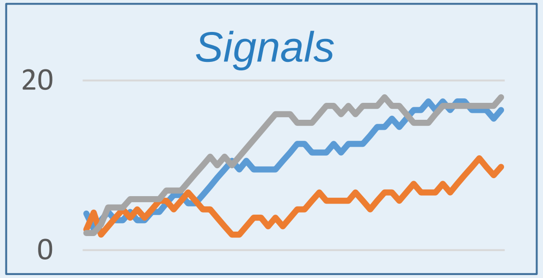
- LHC Circuits monitoring:
  - Detect anomalous/aging hardware
  - DSL for the rules definitions
  - Distributed environment for rules assessment



Knowledge Discovery

Extract system/subsystem interdependency

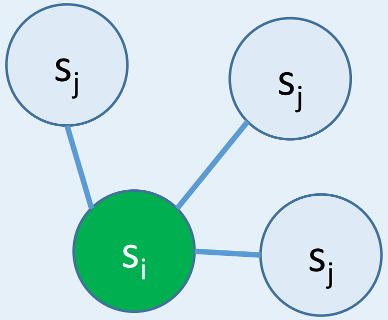
Correlation and K-NN



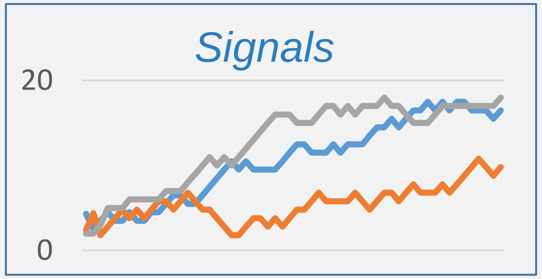
Pearson Correlation Index

$$d_{ij} = -\ln|a_{ij}|$$

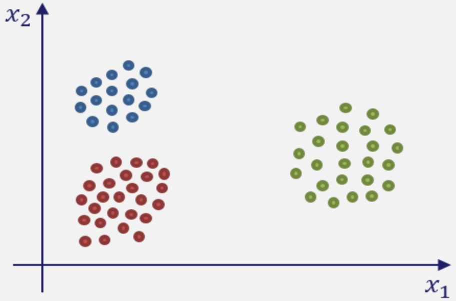
$$E(d_i) = \sum_{j=1}^{k} d_{ij} * P(j|i)$$



Stochastic clustering

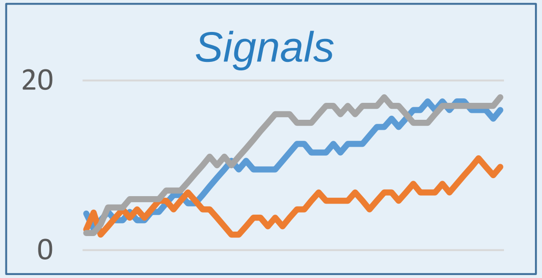


K-Mean & Davies-Bouldin index



$$P(X_j = k) = \binom{n}{k} * P(g_j)^k * \left(1 - P(g_j)\right)^{n-k}$$

Experts' knowledge



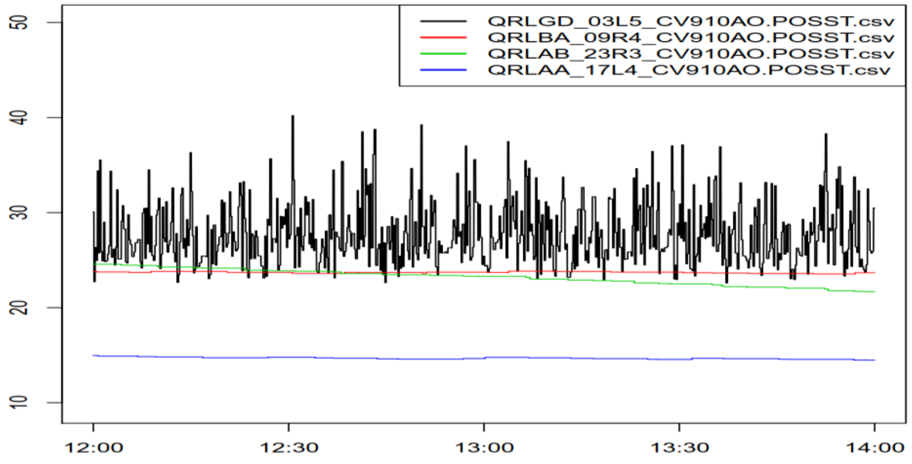
- Statistical indexes:
  - Cluster and single signals derivatives
  - β = tolerance factor.

$$\begin{cases} x_i = x_{i-1} + \dfrac{dt}{\nabla Tf + dt}(x_i - x_{i-1}) \\ tw^{-1}\left(\sum_{tw} \nabla xi \; - \; \nabla X\right) > \beta, \\ X = \{xi \in Cluster\}, tw = time\ window \end{cases}$$

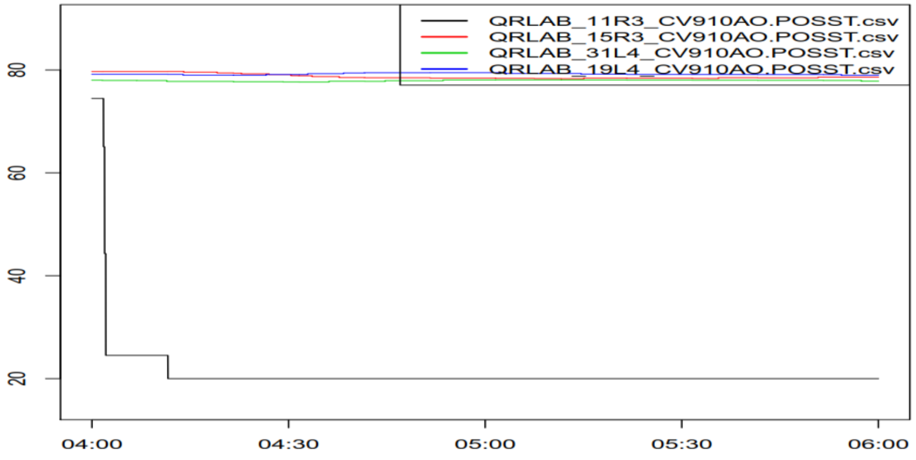
Signals Correlation and K-NN in action!

Detection of different anomalies in Cryogenics

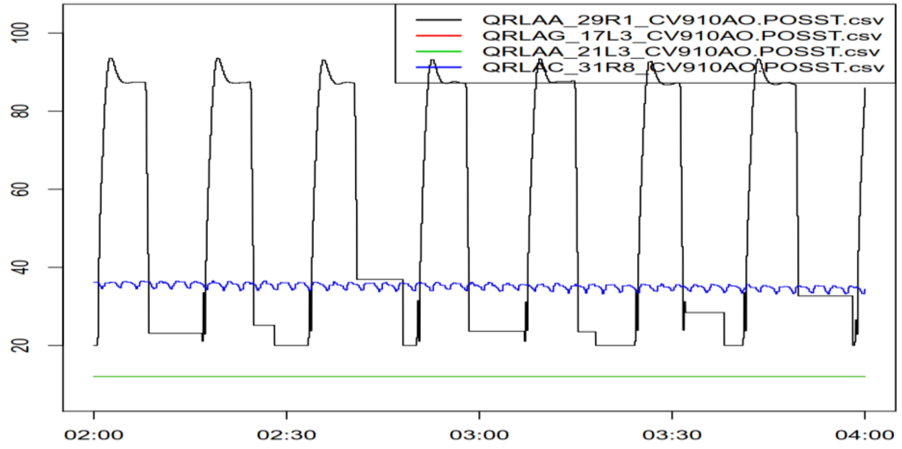
Flipping fault detection



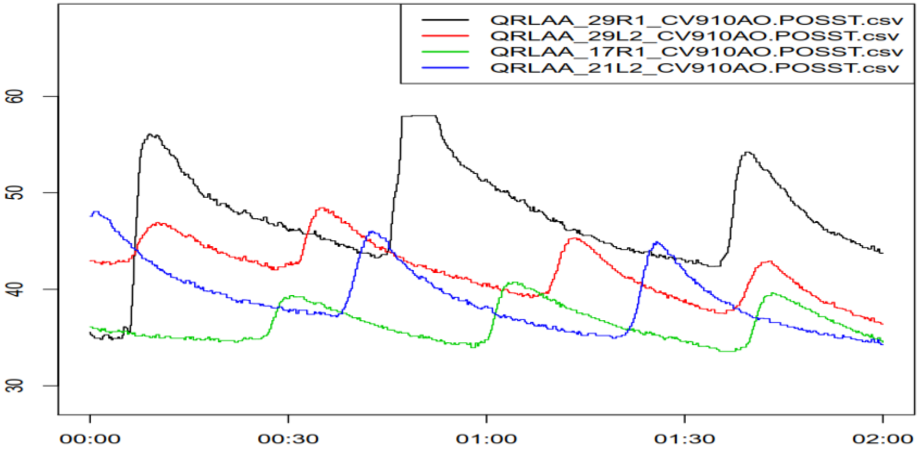
Signal offset detection



Oscillation detection

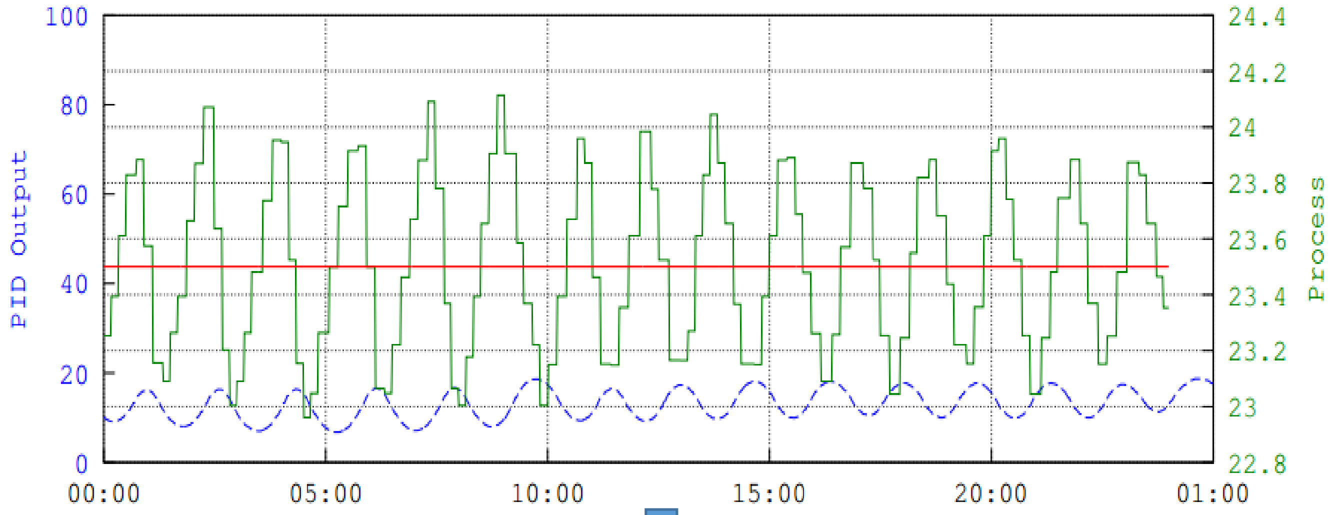


Faulty amplitude detection

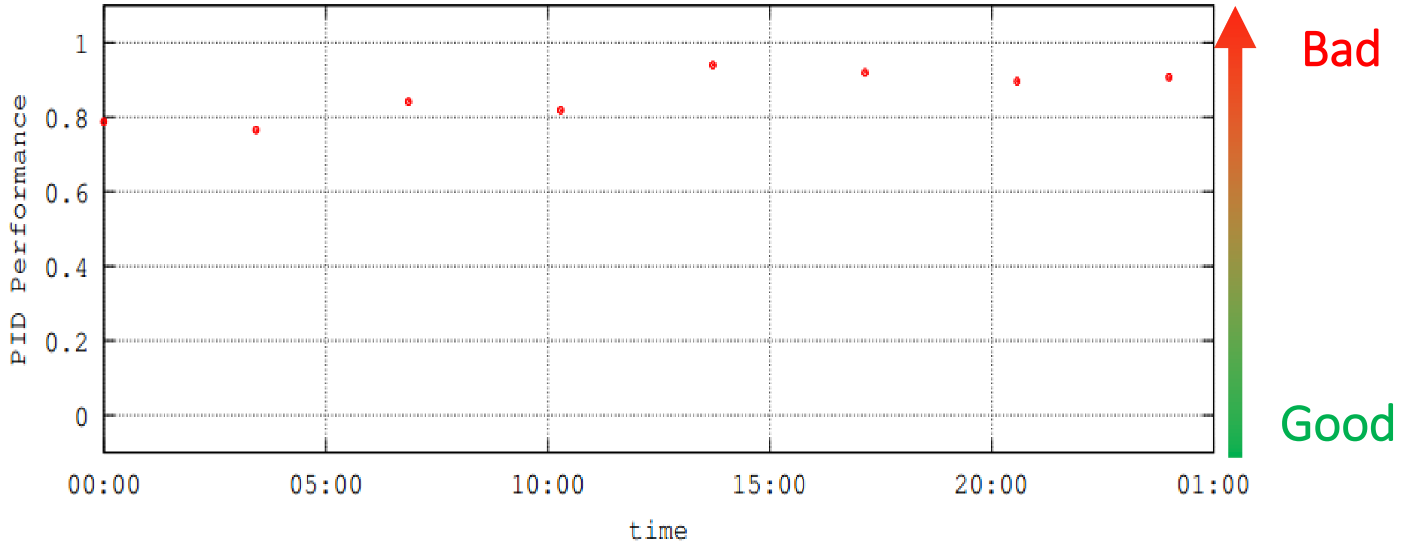


Evaluate system performances

- **PID anomaly detection:**
  - Learning each PID model from the historical data
  - Extraction of similar PID models
  - Comparison of PID behaviours:
    - on the single PID level
    - similar PID



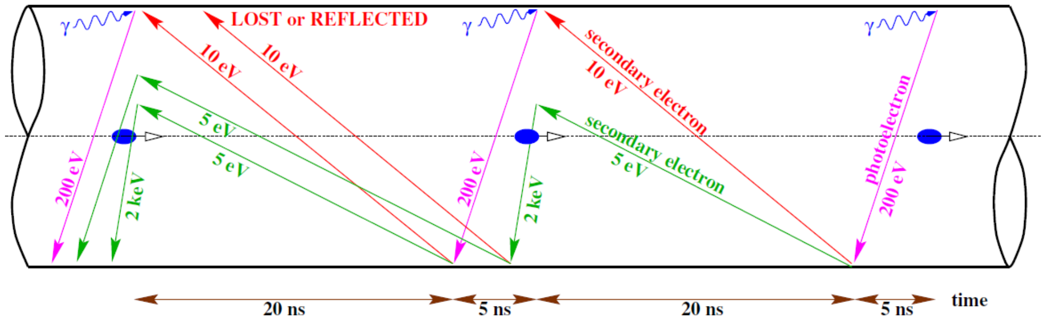
- **Efficiency of control process:**
  - Comparison of PID performances
  - Time/actions taken/energy consumed to reach steady points
  - Stability of the controlled variable

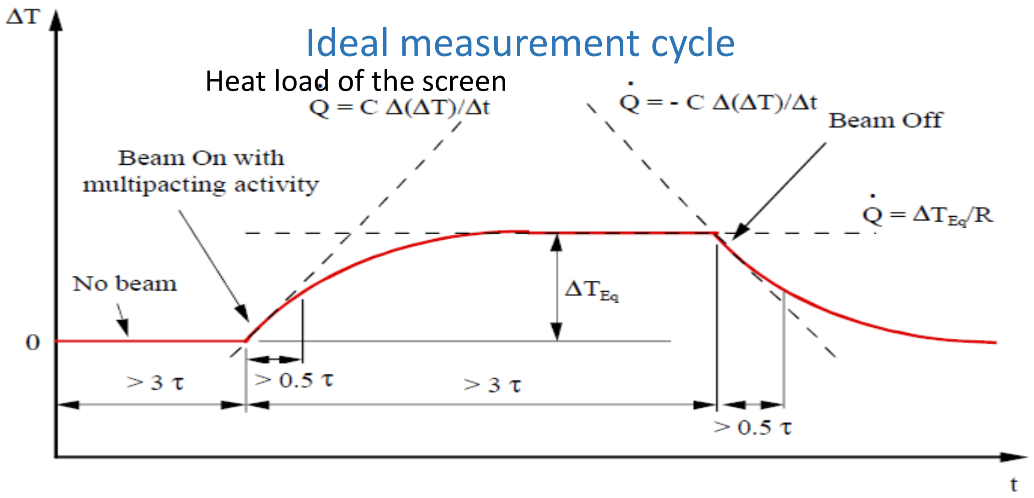


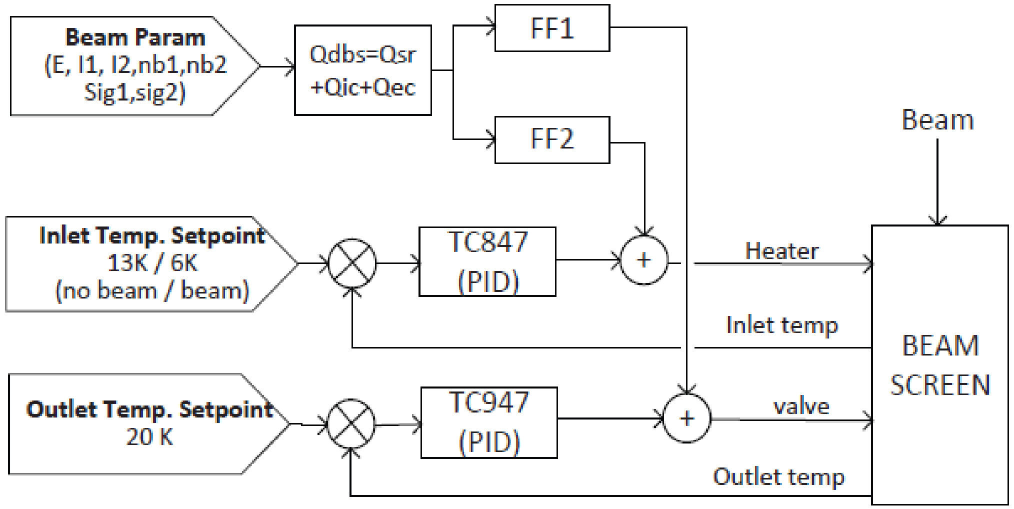
Modelling

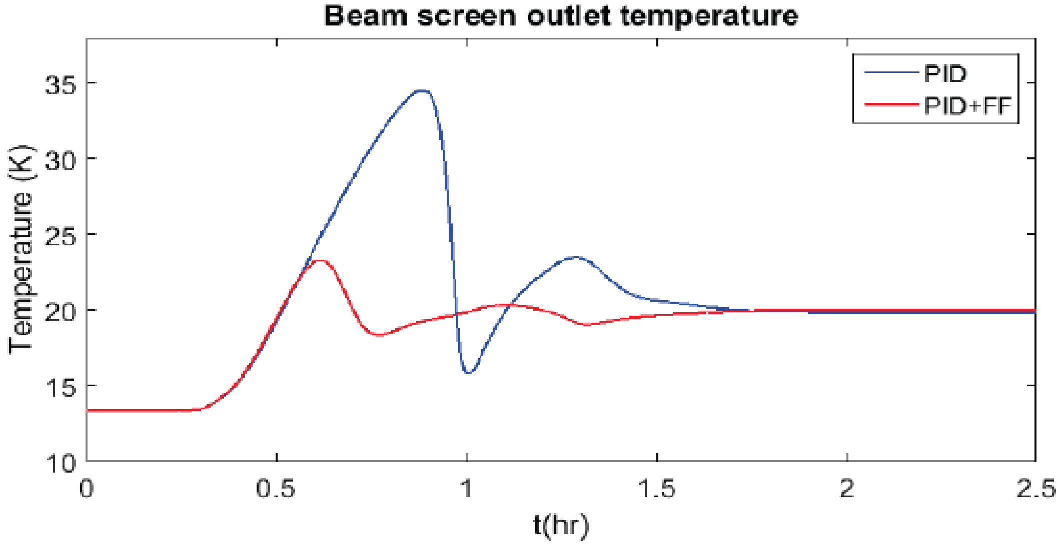
(BE-ICS-PCS)

- **Electron cloud heat load estimation**
  - Interference with the control system









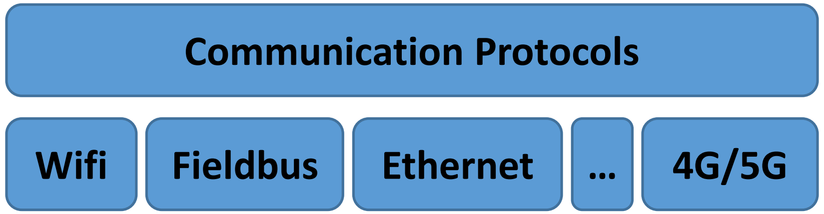
Industrial IoT analytical model

Industrial IoT analytical requirements for CERN control systems

Data ingestion

Make data available for analytics

- **Online ingestion**
  - Collection of data streams in real time
  - Time window to operate over the data
  - Distribute the data to multiple analyzers
- **Offline ingestion**
  - Data lake and not separated storages
  - Archive huge dataset
  - Distributed environment & data locality

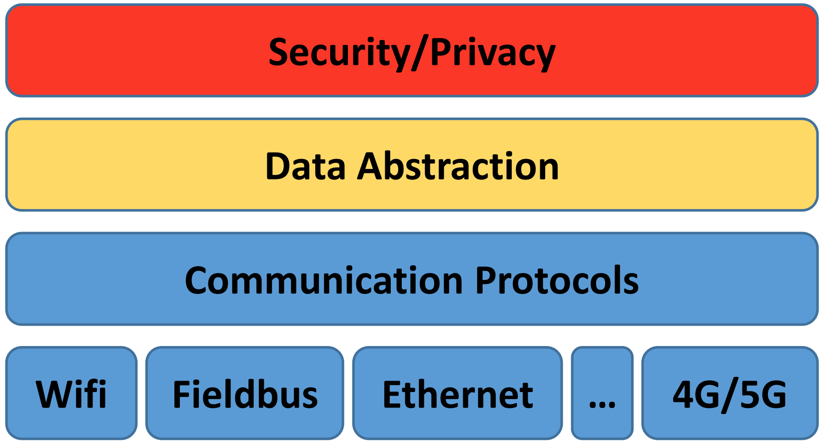


- Ingestion from field devices and SCADA
- Multi-protocol support
  - Application specific requirements
- Time synchronization
- Reduced impact on ICS
  - Network load across the nodes/SCADA
  - Not invasive fieldbus communication
  - Latency among nodes

Data abstraction and Security

Data modelling for analytics

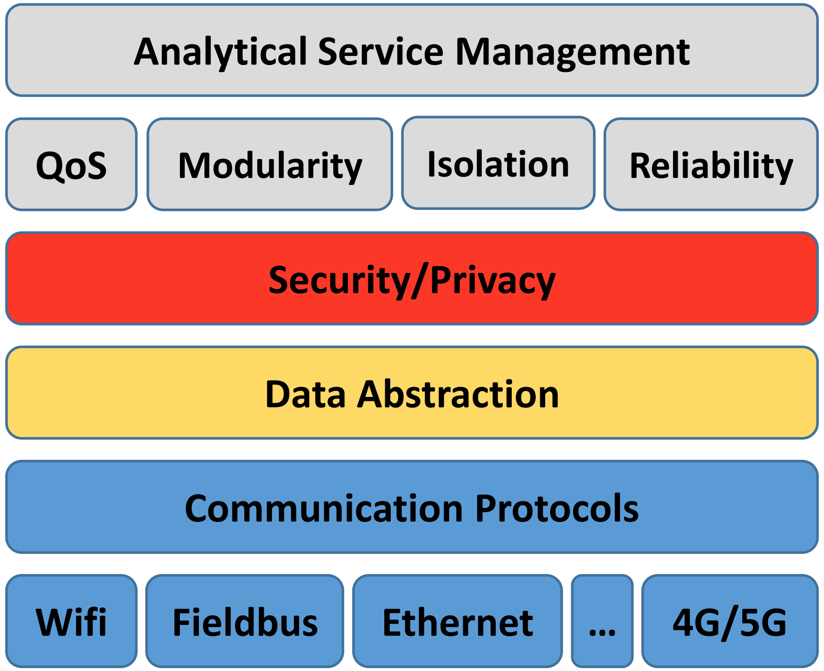
- **Security and privacy**
  - Data encryption
  - Securing the communication among nodes
  - Anonymizing the data before sending them to public cloud



- **Homogenous data modeling**
  - Consistent references across control systems
  - Different data types: process measurements, control alarms, logs
  - Different measurement units (ex: temperature in C/K)
- **Data validation**
  - Data quality embedded in the model
    - By code like in OPC
    - By comparing neighbors' values
  - Operations in the model
- **Data resolution**
  - Information reduction to run analysis and storage capabilities

Analytical service management

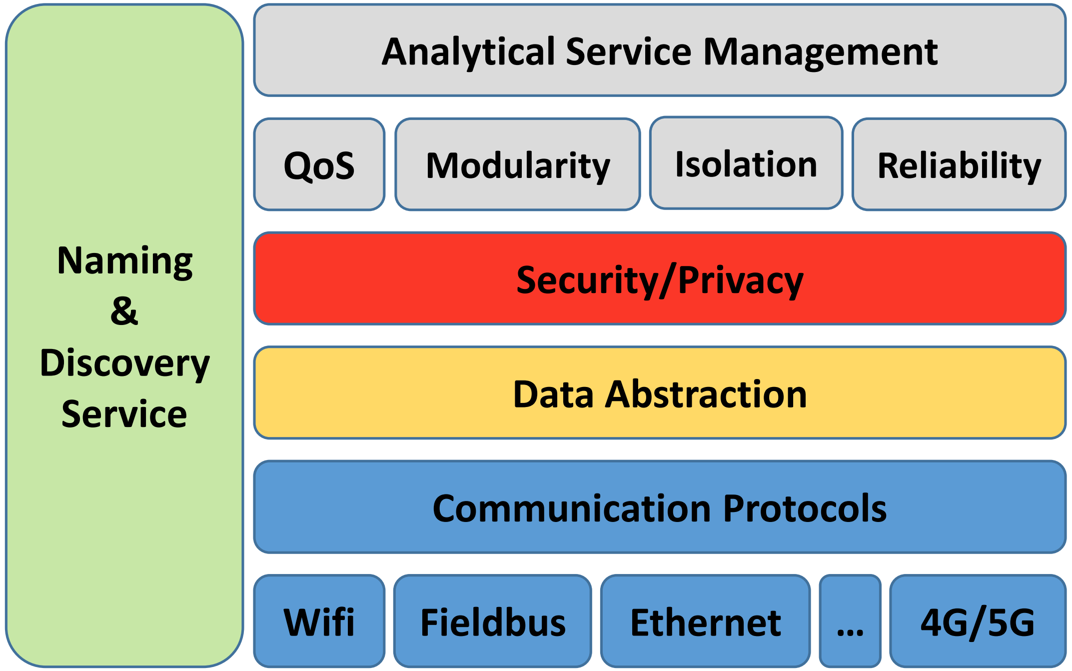
Key features for control analytics



- **Quality of Service**
  - Set different analytical priorities and service levels
- **Modularity and Isolation**
  - Add/replace IoT devices
  - No single point of failure
  - Detect and isolate fault/crash
- **Multi-platform support**
- **Reliability**
  - Check the service status
  - Maintain the network topology during the transmission of anomalies
  - Do not disrupt the control process
- **Analytical optimization**
  - Workload allocation based on devices resources, topology, special HW, data sources proximity, latency, network usage …

Naming and discovery service

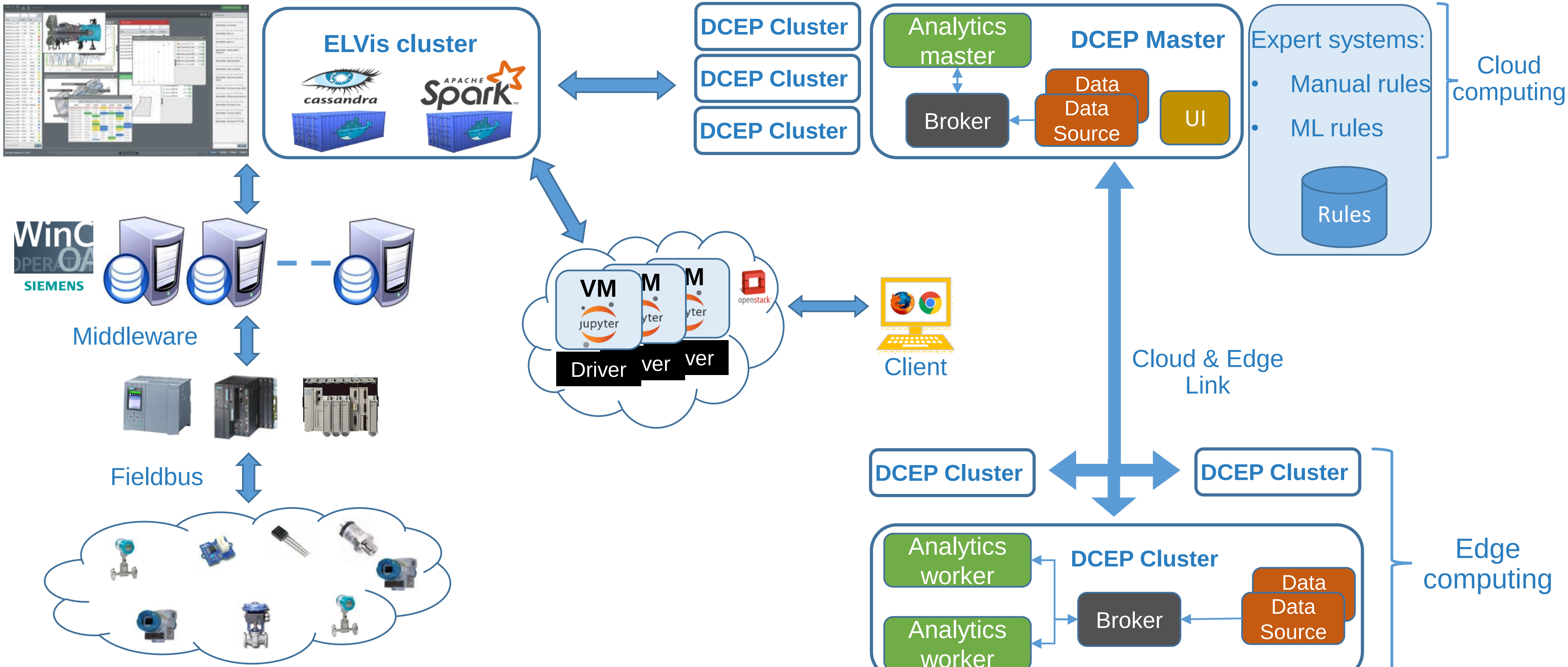
Description of control resources



- **Dynamic device registration**
  - In line with the control system structure
  - Sensors description
  - Available resources
  - Dynamic configuration
- **Service discovery**
  - Services endpoints
  - Permitted operations
  - Event subscription
  - Dynamic update due to device mobility

Smart Data for Industrial Control Systems

Combining cloud and edge computing into a single framework



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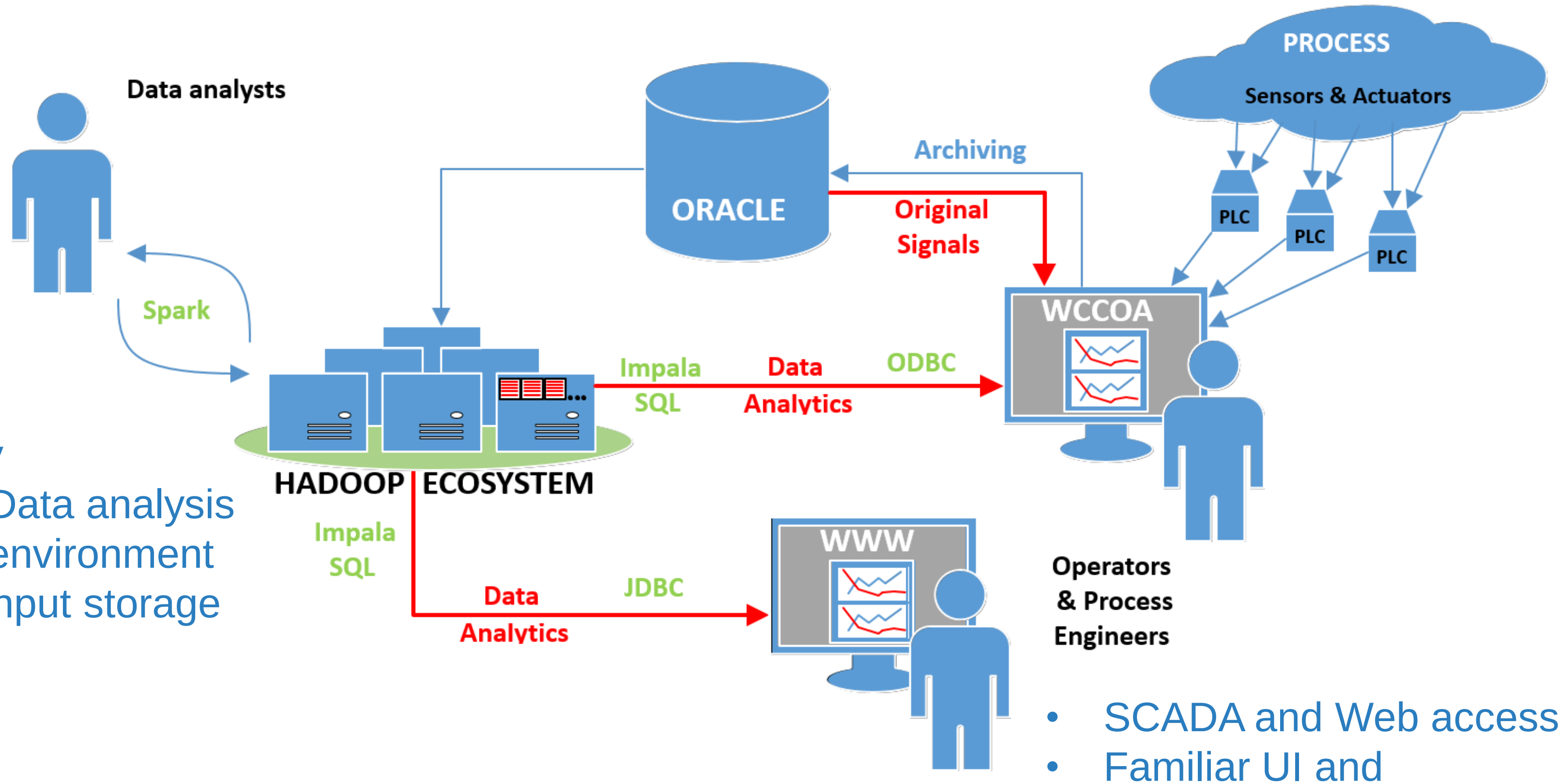


- Data locality
- API for Big Data analysis
- Distributed environment
- High throughput storage

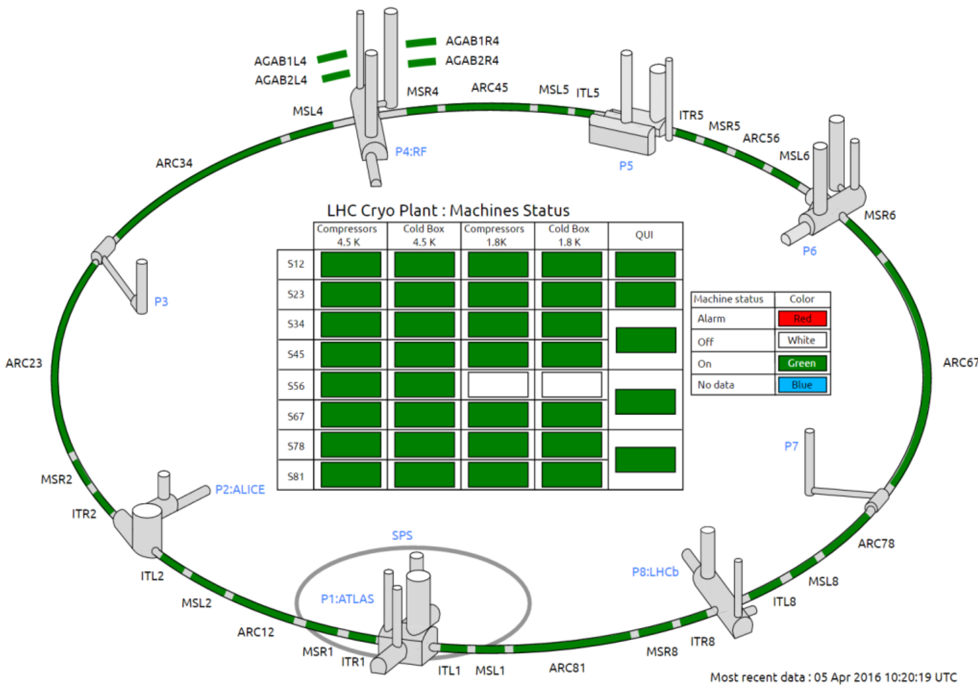
- SCADA and Web access
- Familiar UI and functionalities
- Rapid prototyping

Data Analytics Reporting for Industrial Control Systems

Display analytics results on the operator's screen and web-frontend.

Big data visualization for control

(Courtesy of B. Copy and J. Hamilton)

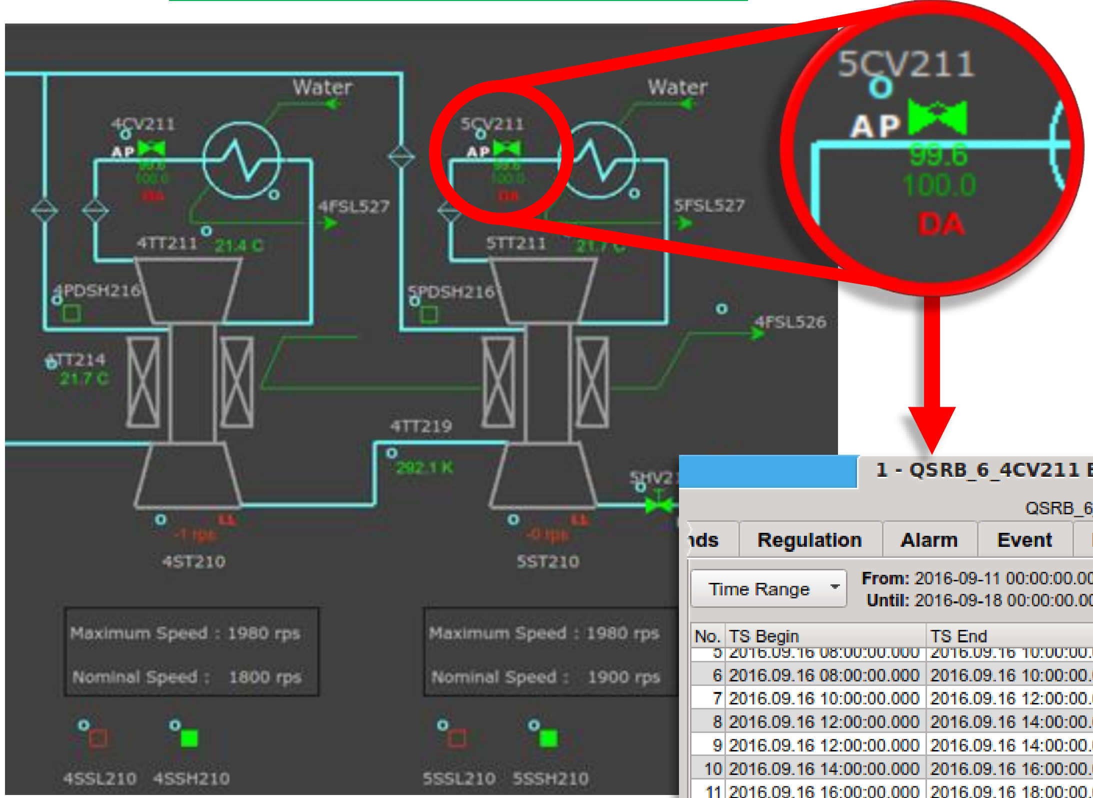


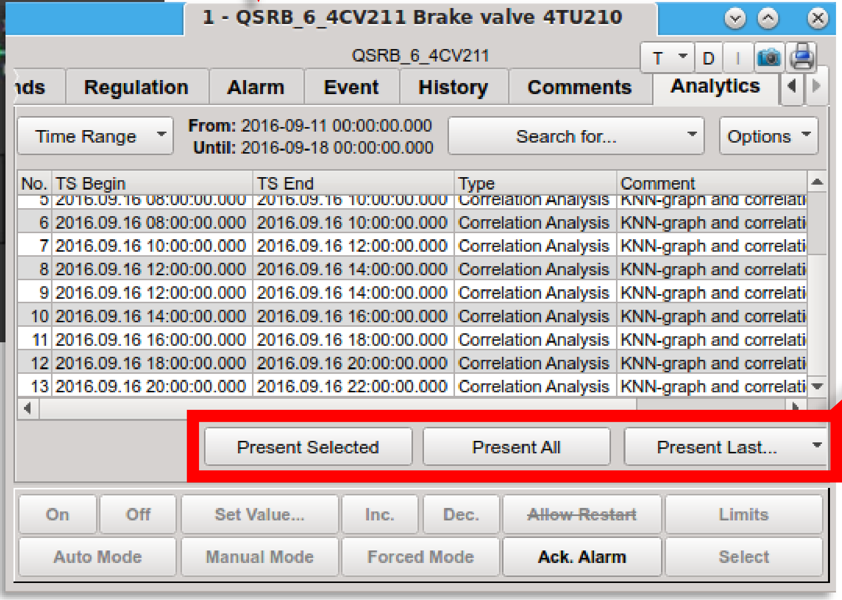
Features:

- Faster data extraction
- Database query protection mechanism
- Data distribution
- User friendly navigation
- Easy to access
- Multiple sources
- Multiple output formats (Charts, Table, Text)
- Similar to the Atlas DDV (DCS Data Viewer)

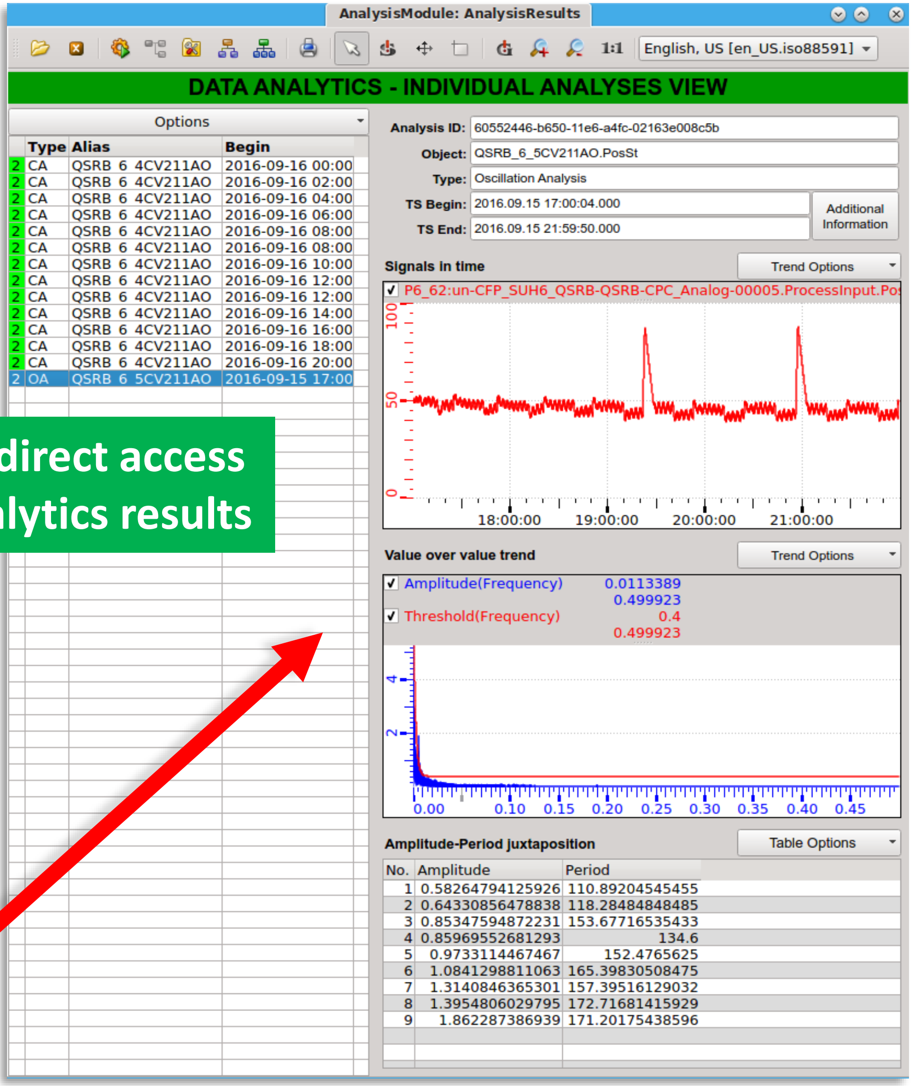
Data Analytics Reporting System for WinCC OA

Attract operators attention





Easy and direct access to the analytics results



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Conclusions

- **Main idea: combine cloud and edge computing in a single analytical framework**

- **Siemens involvement:**
  - New collaboration with an IoT group
  - Existing collaboration with the cloud computing group

- **Initial phase**
  - Requirements definitions
  - Initial prototype of the analytical framework
  - Integration with CERN control systems

Thank you!

CERN BE-ICS

https://be-dep-ics.web.cern.ch/