

# ACPS: Adaptive Cyber-Physical Systems in Industry 4.0

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Nowadays, with the rapid growth of connected objects and produced data involved in industrial processes, it is increasingly difficult to design and implement efficient cyber-physical systems (CPS) meeting business needs. As a consequence, architectures of CPS have to be able to integrate different heterogeneous actors (people, objects, data, services) coordinated by autonomous and self-adaptive processes capable of implementing the different business missions of a company. Moreover, with the emergence of Industry 4.0, interest in elastic services provided by cloud architectures is booming. Indeed, these architectures allow the smooth and scalable interconnection of interdependent systems in order to provide efficient solutions to facilitate the management of industrial processes. In this paper, we propose a generic architecture for Integration Platforms as a Service (iPaaS). This architecture offers key functionalities, namely integration and interoperability, but also self-decision support. One implementation based on open-source solutions and illustrating the benefits of this proposal in the area of the Agriculture 4.0 domain is proposed.

## Intro

Organizations are embracing digitalization and advanced technologies to transition into Industry 4.0, which brings a technological revolution and prompts businesses to reevaluate their models. Industry 4.0 involves the reorganization of the value chain and leverages real-time information communication to monitor and control physical systems using cyber-physical systems (CPSs). CPSs enable decentralized decision-making and collaboration between systems and humans. Integrating different digital technologies is crucial for successful deployment. The fourth industrial revolution extends beyond production processes and aims to revolutionize smart products and services. Designing and implementing smart cyber-physical systems that integrate IoT actors and enable intelligent coordination is essential. These systems should be adaptable, autonomous, and able to exchange information with other CPSs. This concept is known as cyber-physical systems of systems (CPSoS).

In this sense, we propose a flexible platform to manage cognitive processes in CPS able to integrate compliant data science approaches for decision-making in the area of the Agriculture 4.0.

## Problem statement

- ❖ Rapid growth of connected objects and produced data
- ❖ Heterogeneity of actors (things, data, people, processes/services)
- ❖ Performance and real-time needs
- ❖ Reduce manual supervision and control processes

How to design cyber-physical systems for Industry 4.0 integrating a generic model for cognitive processes and responding to real-time performance constraints as well as managing the heterogeneity of actors and activities ?

## Proposal

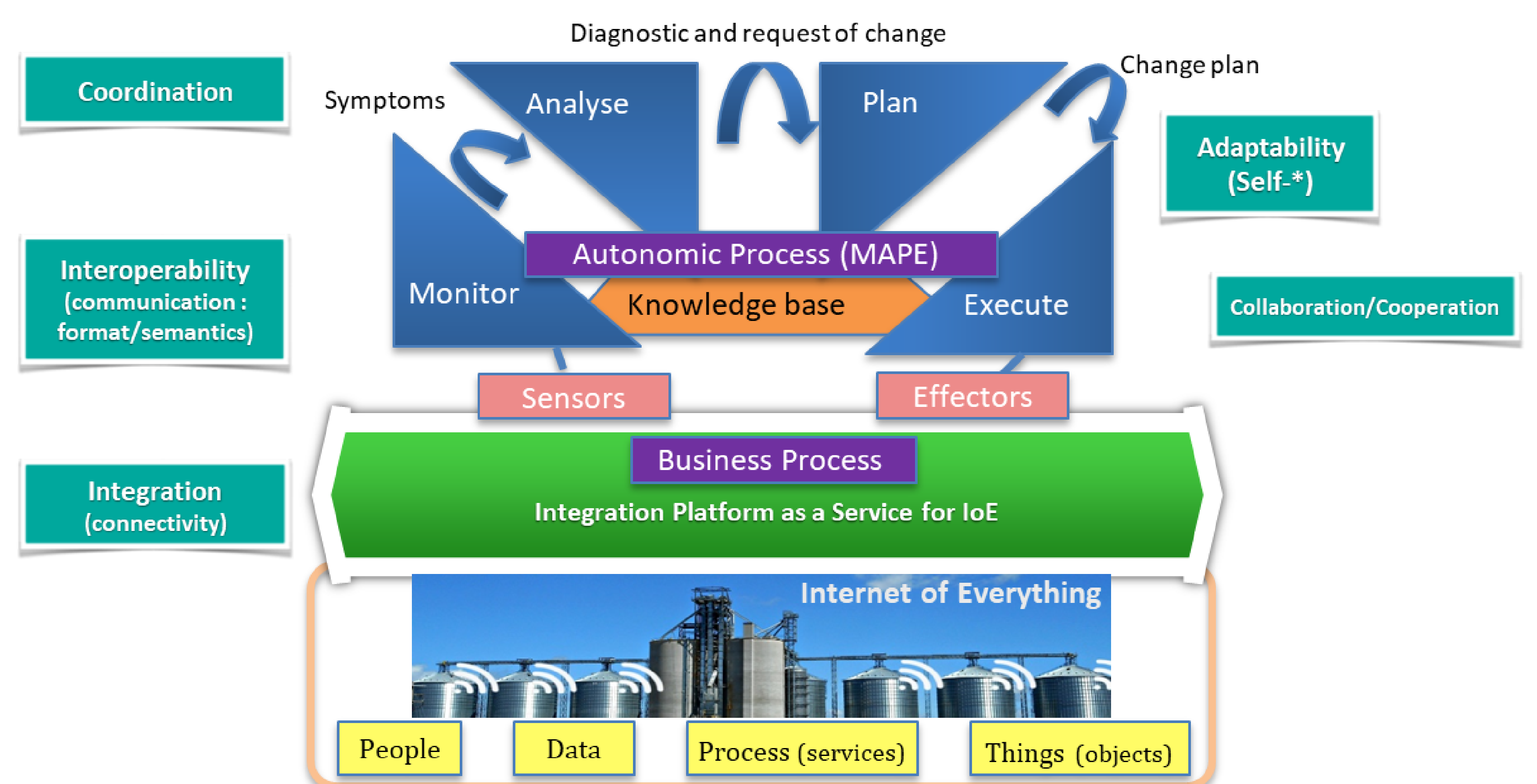
This work presents our architecture proposal which consists in designing a generic architecture for building cyber-physical systems capable of deploying autonomous processes, composed of Monitoring, Analysis, Planning and Execution (MAPE) phases and including knowledge bases, built using information provided by experts, to guide automated decision-making. The solution must consider the need to make these knowledge bases evolve to deal with new contexts, new objectives and constraints of industrial processes.

The proposed architecture aims to address the challenges in designing cognitive cyber-physical systems by providing a comprehensive framework and practical mechanisms. It emphasizes the interoperability, cooperation, and coordination of diverse actors while optimizing system performance, adaptability, and responsiveness. The architecture focuses on managing heterogeneous actors through standardized communication protocols, adaptive interfaces, and data translation mechanisms to facilitate seamless information exchange. It promotes flexibility and customization of interactions between actors, accommodating their specific needs and constraints while ensuring overall system interoperability. The architecture also integrates advanced techniques such as machine learning and artificial intelligence to improve system performance, enabling real-time data utilization, learning from past experience, and making autonomous decisions.

## Conclusions/Future Directions

This work introduces a generic iPaaS architecture composed entirely of open-source solutions, demonstrating a cost-effective approach with potential for scalability. The architecture addresses requirements of integrability, interoperability, and extensibility. To optimize complex regression cases, the paper proposes enhancing data preprocessing techniques and implementing hyperparameter optimization using the Grid-Search technique. Additionally, the work explores using quantum machine learning methods for binary classification tasks, leveraging IBM quantum resources to achieve accurate results with minimal training. The architecture enables easy integration of a DDDSS (Data-Driven Decision Support System) for data cleaning, standardization, and suitable decision model selection. This collaboration of models enhances adaptability and robustness in future CPS (Cyber-Physical Systems). The potential inclusion of quantum decision models is also highlighted. Future work involves evaluating scalability and elasticity in a multi-tenant scenario.

## General Architecture Proposal



## Deployment, Evaluation & Results

Three evaluation tests were carried out to evaluate the feasibility of applying the quantum support vector machines QSVM model to solve binary classification problems to predict the number of burners in the drying process. This same problem was addressed using Support Vector Machine in its classical approach, and the performance of these two methods was compared.

Table 1. QML and CML test definition.

Tests	Feature Reduction (PCA)	Number of features	Number of Instances	Training	Testing dataset
Test 1	Yes	3	100	0.7	0.3
Test 2	Yes	3	3000	0.7	0.3
Test 3	Yes	7	3000	0.7	0.3

After deploying the QSVM model, the result obtained is not only promising for deploying quantum infrastructure solutions, but it is already a reality.

Table 2. QML and CML accuracy and running time results.

Approach	Test 1		Test 2		Test 3	
	Accuracy	Time (s)	Accuracy	Time (s)	Accuracy	Time (s)
QSVM	0.98	48.00	-	-	-	-
CSVM	0.73	0.001	0.77	0.08	0.99	0.1

We obtained extraordinary results, as in the first test, training the model only with a tiny part of the dataset; we were able to obtain an accuracy of 100% after being evaluated while its counterpart provides less efficient performance. The classical model must be trained with the complete dataset to provide similar results as the quantum model.

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