Connecting the Dots in Smart Circular Manufacturing
Closed Loop Lifecycle Management

ICT4SM ict4sm.epfl.ch/

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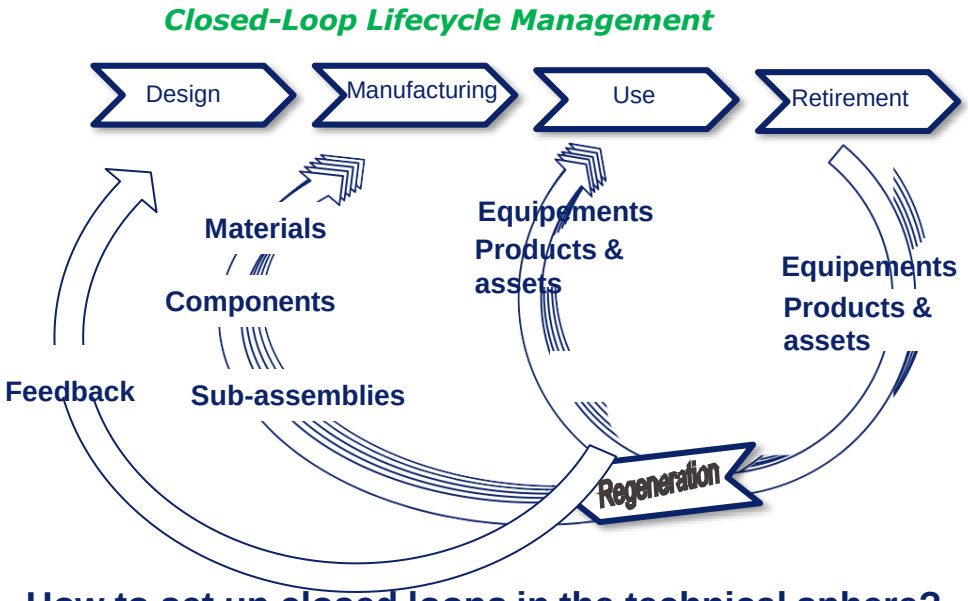
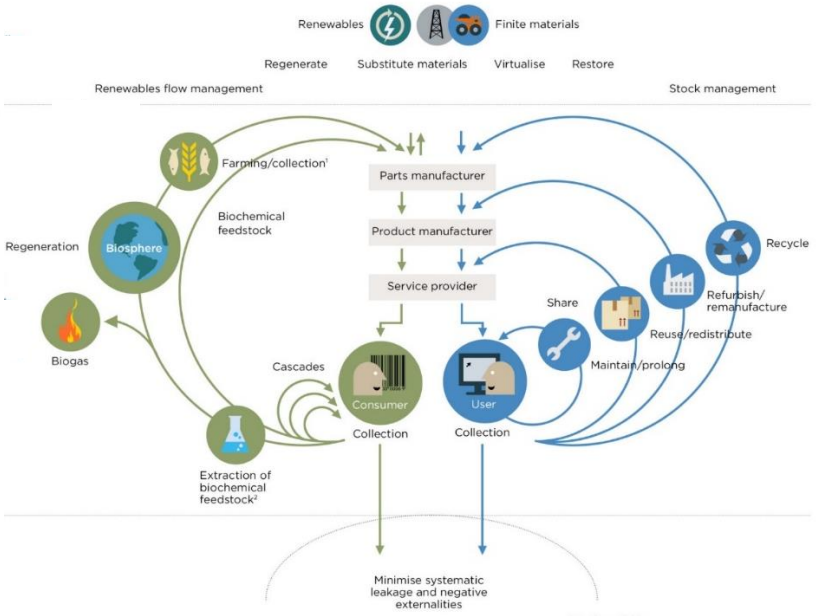
The new context: Circular Economy





How to set up closed loops in the technical sphere?

- Take into account several cycles of use
  - **Loops** (exploitation - regeneration - exploitation / manufacture)
  - **Types of products** (equipment, subassemblies, components, materials)

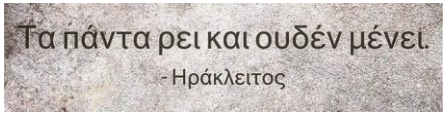
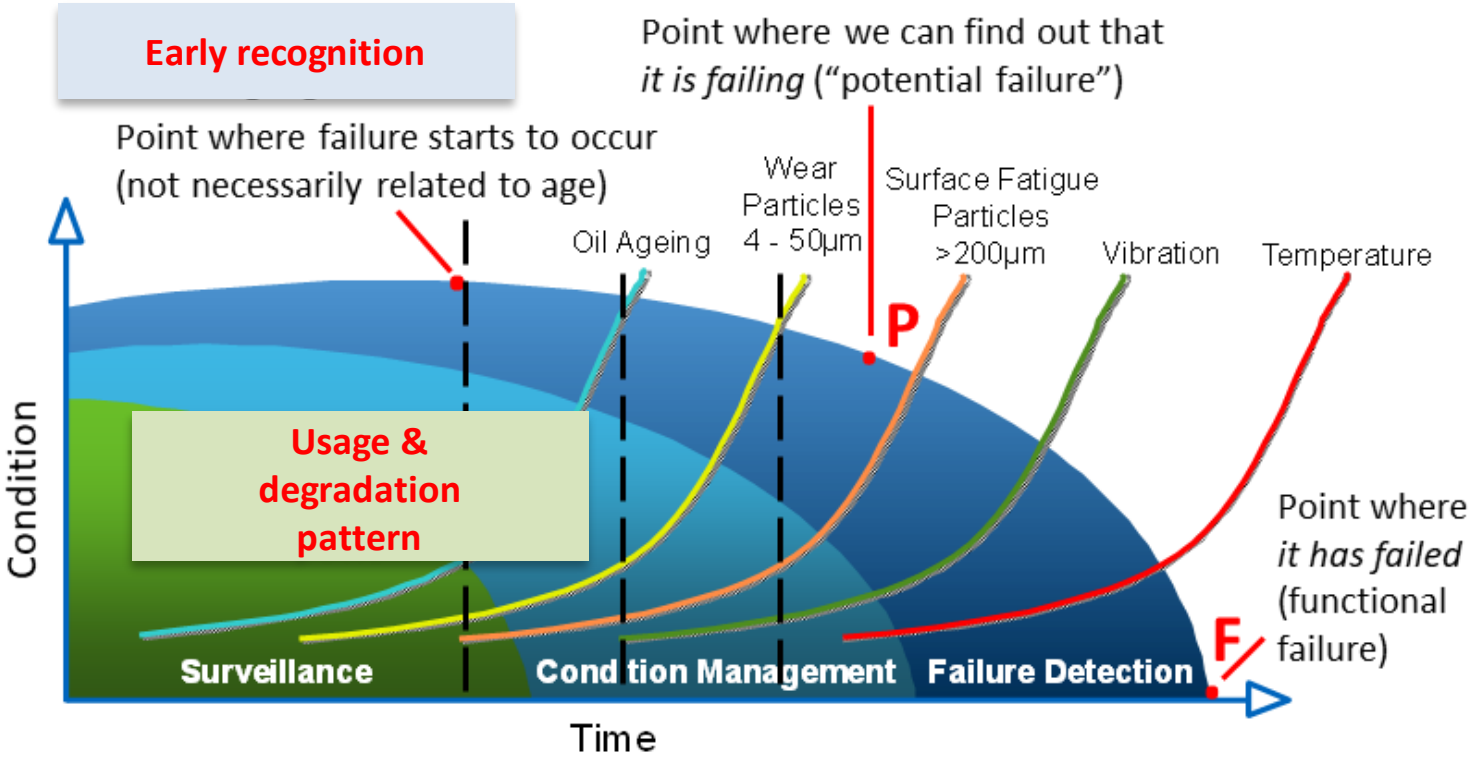


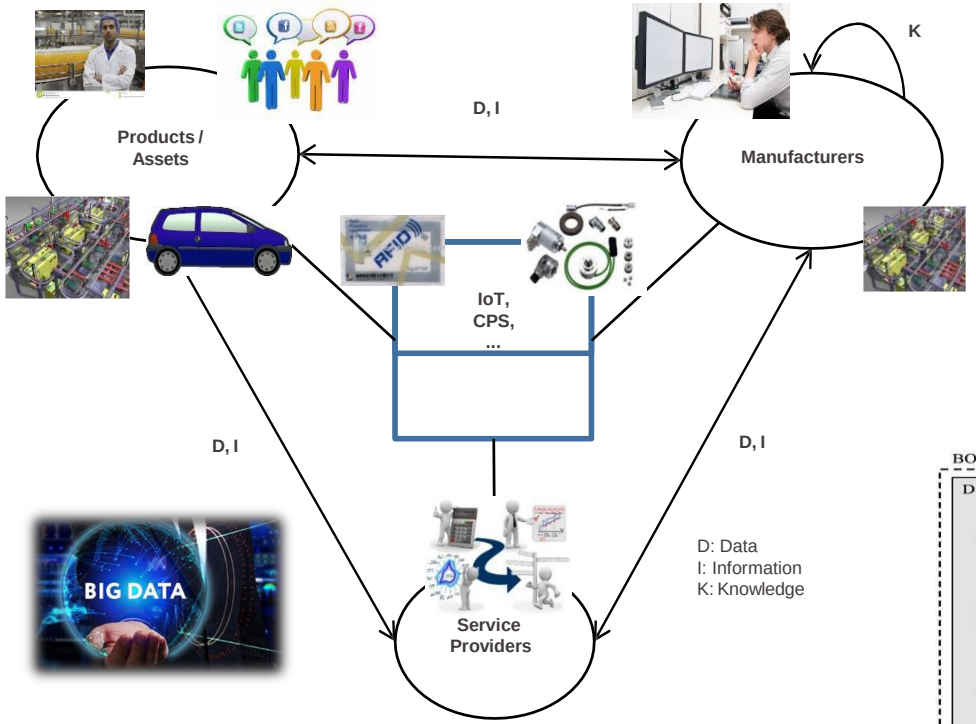
Figure adapted from PhD Thesis Laëtitia Diez, University of Lorraine

The problem: Degradation and Failure

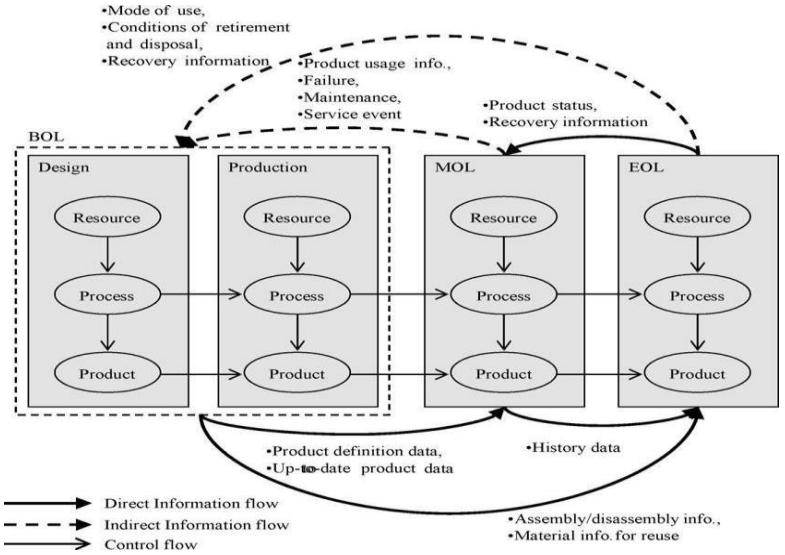


Refer to: Moubray, J., 1997. Reliability Centred Maintenance. Butterworth Heinemann, Oxford, UK.

It is all about Big Life Cycle Data Transformations

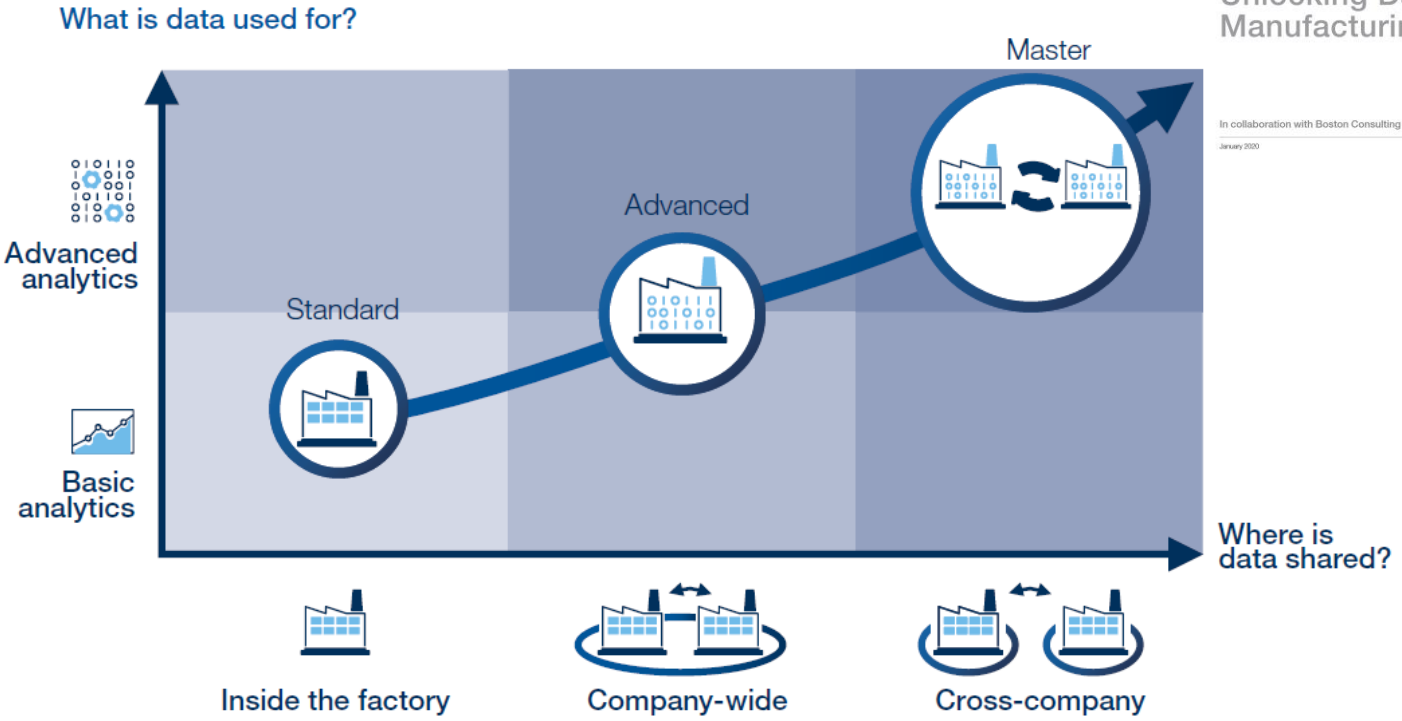


- Closed-Loop Life cycle Data-Information-Knowledge Transformations
- Semantic Model-Based Systems Engineering for Industrial Data Analytics



LinkedDesign ZFactOr ZBre4k Boost 4.0 BIG DATA FOR FACTORIES QUALITY

Data Sharing for Manufacturing



WORLD ECONOMIC FORUM
COMMITTED TO IMPROVING THE STATE OF THE WORLD

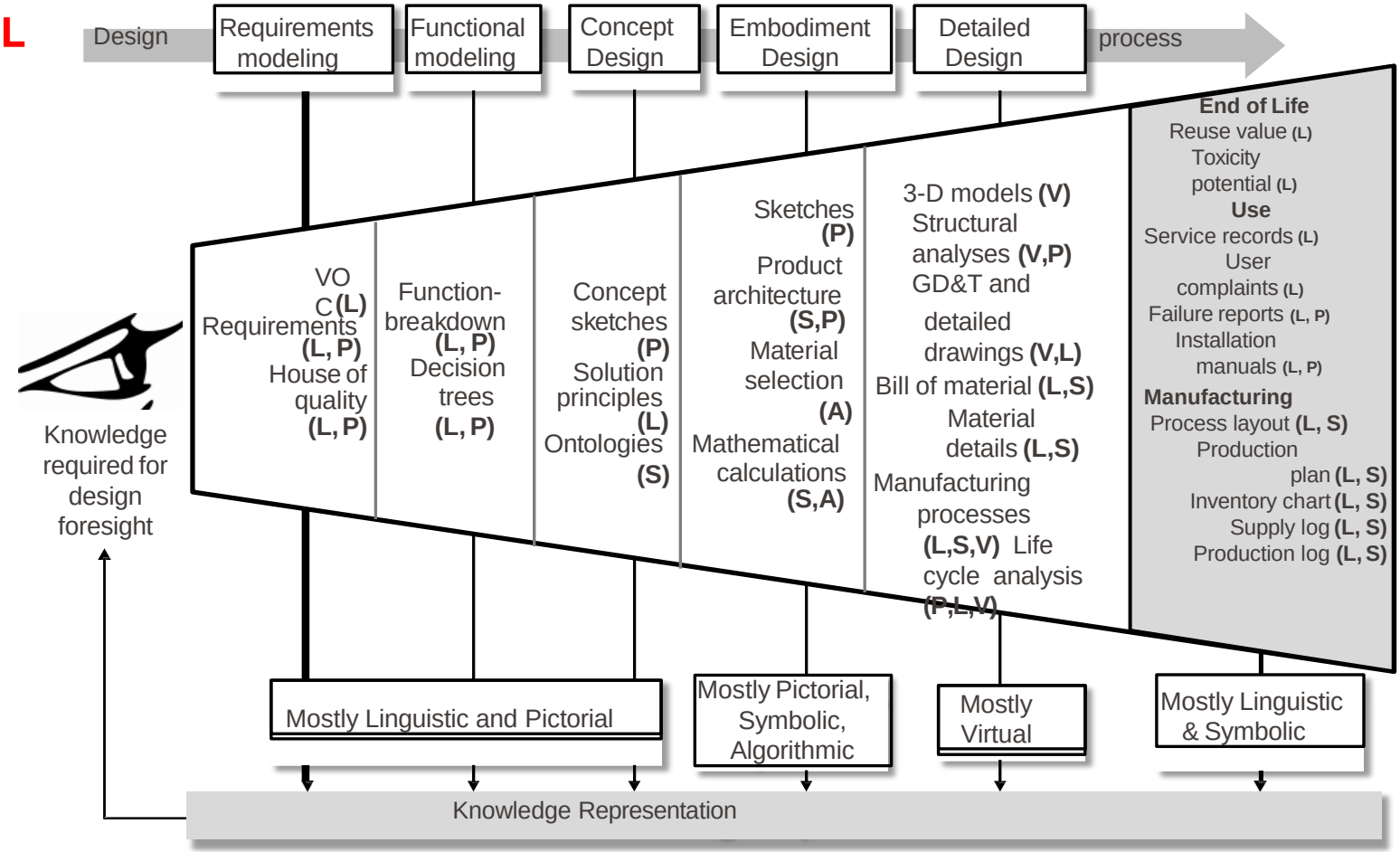
White Paper

Share to Gain:
Unlocking Data Value in Manufacturing

In collaboration with Boston Consulting Group

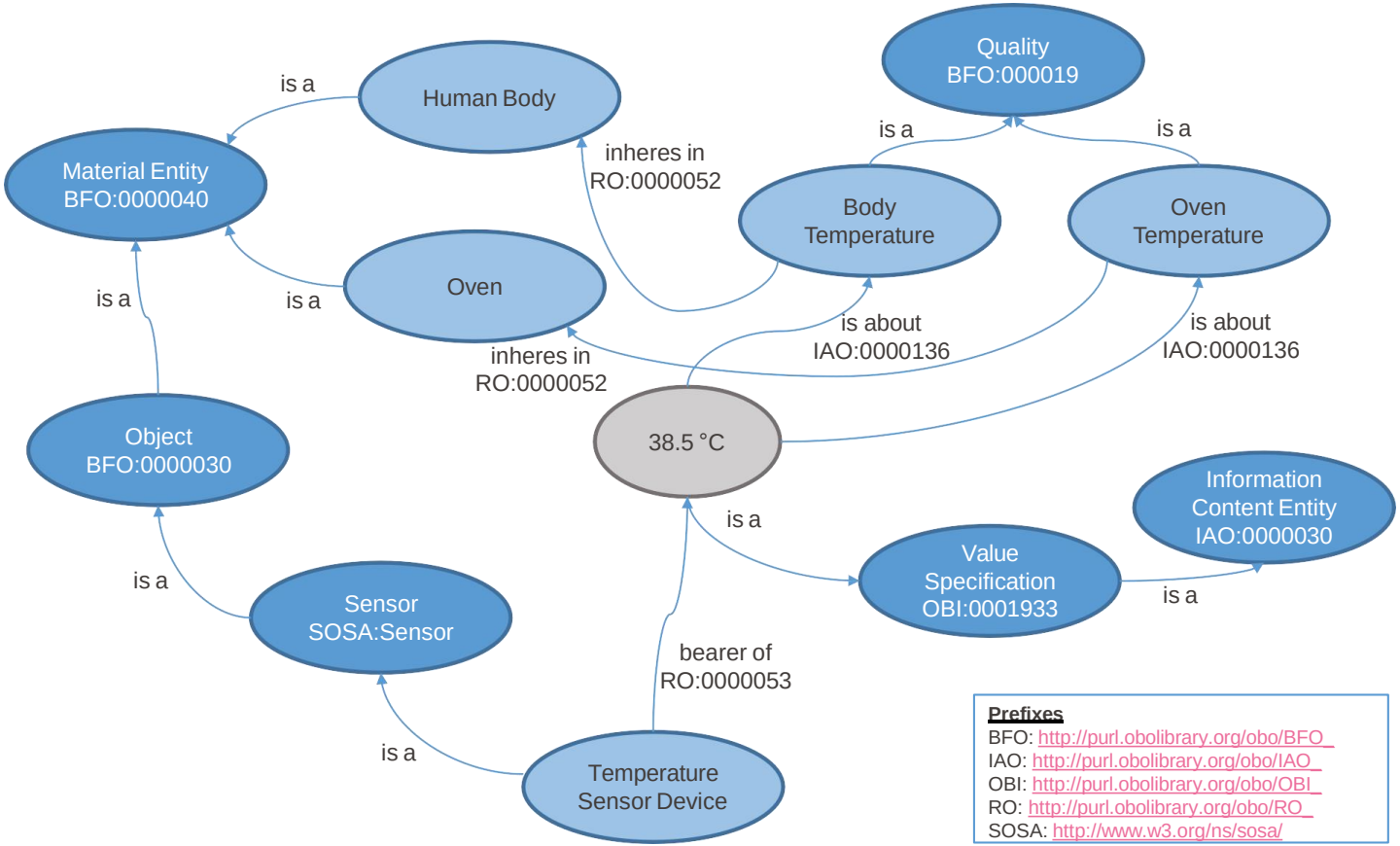
January 2020

http://www3.weforum.org/docs/WEF_Share_to_Gain_Report.pdf



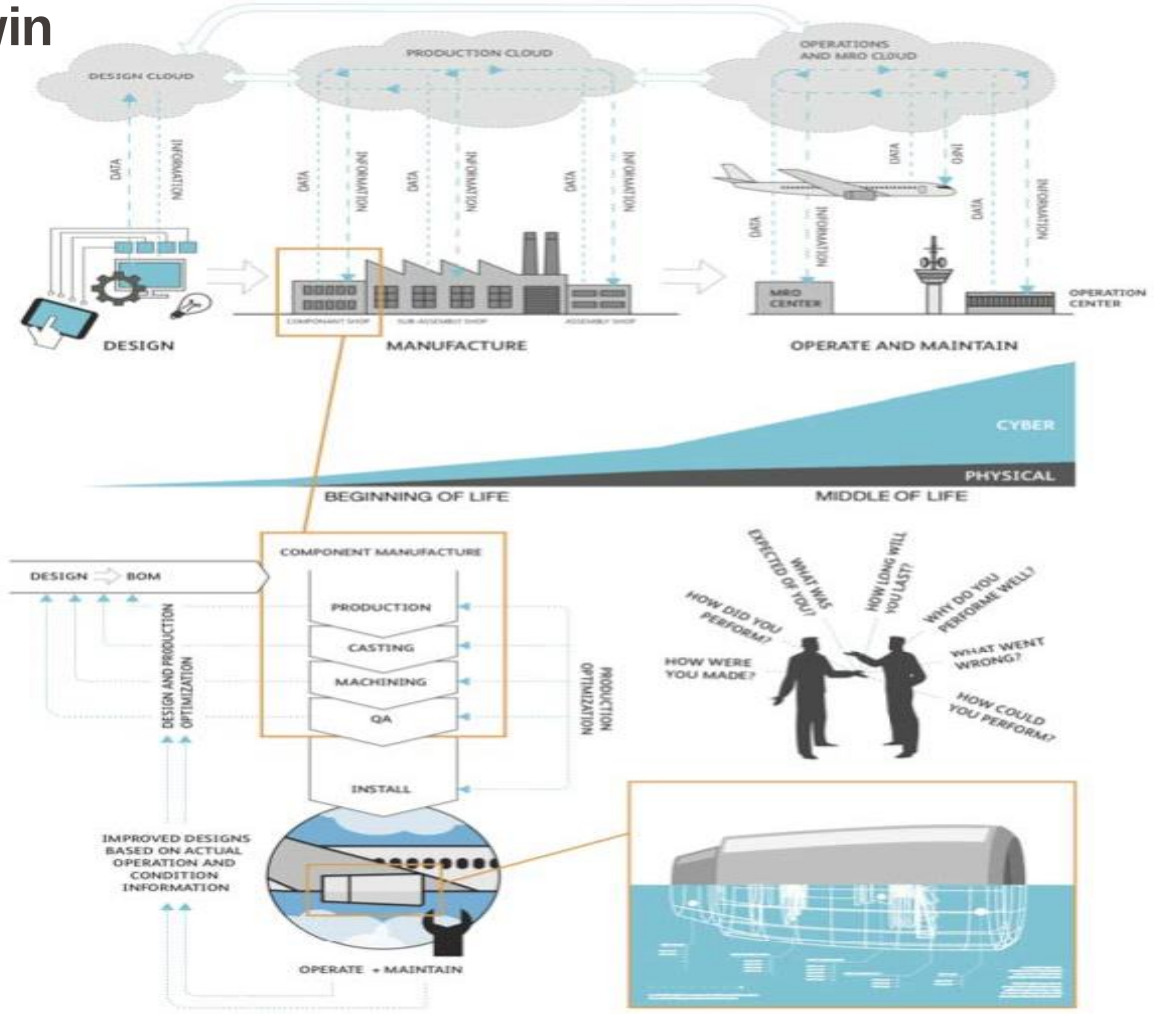
Senthil Chandrasegaran, Karthik Ramani, Ram D. Sriram, Imre Horvath, Alain Bernard, Ramy Harik, Wei Gao
The evolution, challenges, and future of knowledge representation in product design systems
Computer-Aided Design Volume 45, Issue 2, February 2013, Pages 204-228.

Capturing the Meaning of Data



Prefixes
BFO: http://purl.obolibrary.org/obo/BFO_
IAO: http://purl.obolibrary.org/obo/IAO_
OBI: http://purl.obolibrary.org/obo/OBI_
RO: http://purl.obolibrary.org/obo/RO_
SOSA: http://www.w3.org/ns/sosa/

Digital Twin

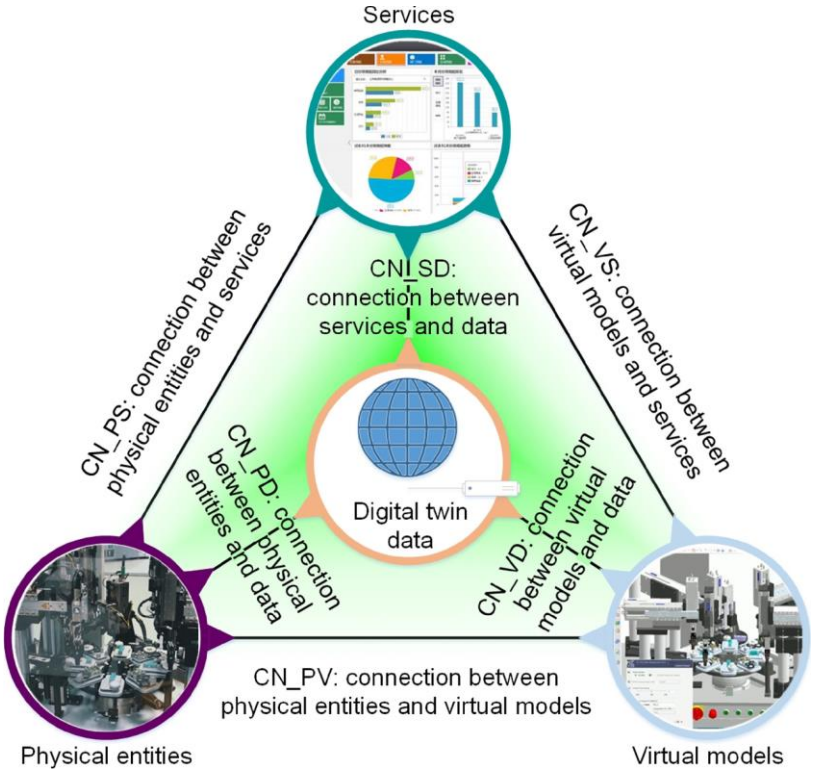


Source: DigitalTwin InnoSWISS project

Digital Twin - Concept

- "*A Digital Twin is a **virtual instance** of a **physical system** that is **continually updated** with the latter's performance, maintenance, and health status **data** throughout the physical system's life cycle.*"[*a]

- Key elements:
  - Physical entities
  - Virtual instances
  - DT data
  - Services
  - Connections

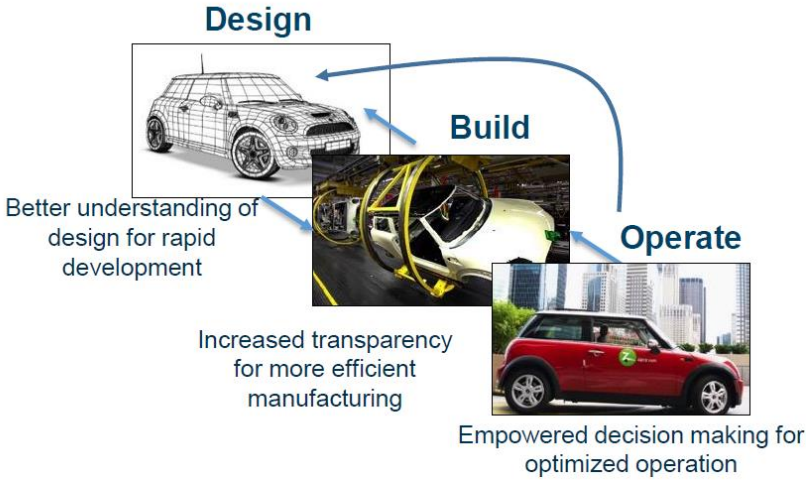


Five-dimension digital twin model [*b]

[*a] *Madni et.al., Leveraging digital twin technology in model-based systems engineering, Systems, 2019*
[*b] *Qi et.al., Enabling technologies and tools for digital twin, Journal of Manufacturing Systems, 2019*

DT Challenges

- High complexity of modern industrial systems
- Heterogeneous DT models corresponding to
  - related systems, subsystems and components
  - different lifecycle phases
  - different stakeholders, protocols and standards
- Lack of unified platform for integrating all relevant DT models

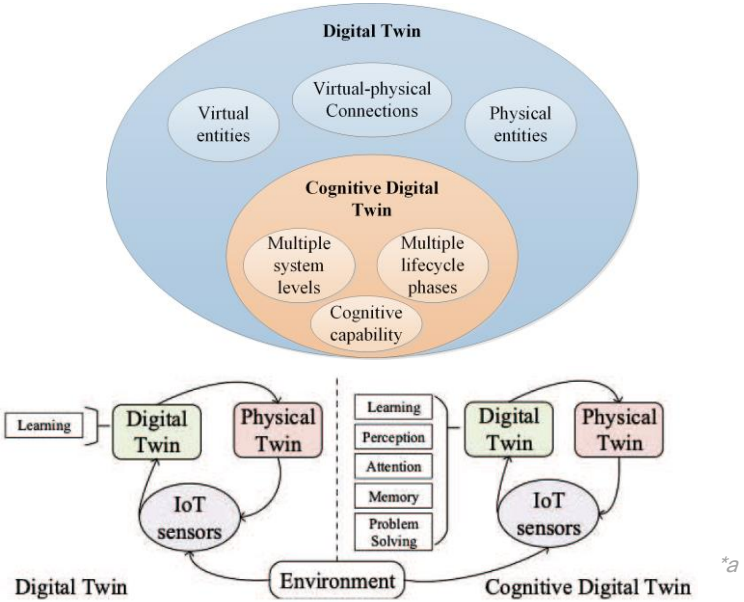


- *Fariz Saracevic, IBM, Cognitive Digital Twin, Bosnia Agile Day 2017*
- *https://www.nytimes.com/2017/05/03/magazine/a-look-inside-airbuss-epic-assembly-line.html*

Cognitive Digital Twin

- *Cognitive Digital Twin (CDT) is a **digital representation** of a physical system that is augmented with certain **cognitive capabilities**; comprises a set of **semantically interlinked digital models** related to different **lifecycle phases** of the physical system including its subsystems and components; **evolves continuously** with the physical system across the entire lifecycle; and support to execute **autonomous lifecycle activities**.*

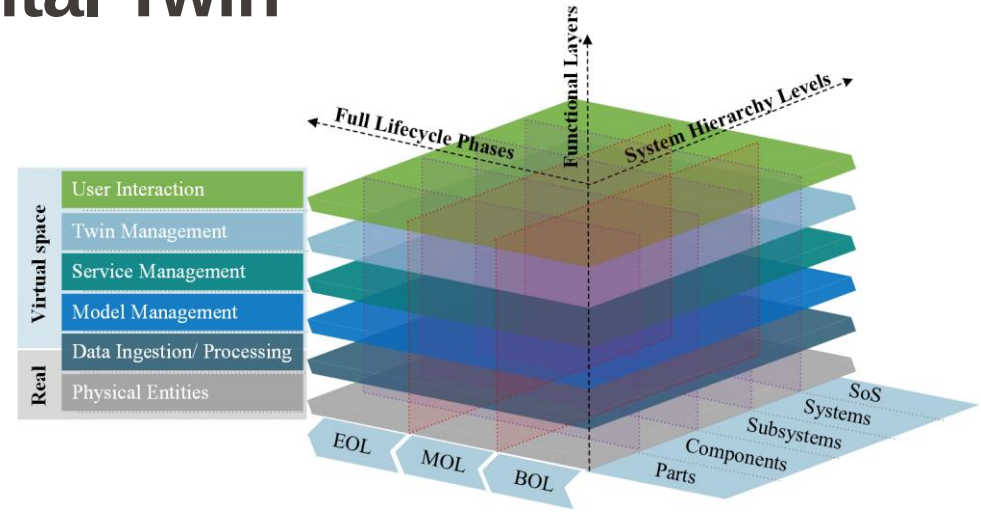
- **Characteristics** :
  - Based on Digital Twin
    - CDT is a subset of DT
  - Cognitive capabilities
    - attention, perception, comprehension, memory, reasoning, prediction, decision-making etc.
  - Autonomy capability
    - conduct autonomous activities without human assistance or minimum level of human intervention
  - Cross lifecycle phases & cross system levels
  - Continuous evolving
    - Multi-levels and multi-lifecycle phases interaction

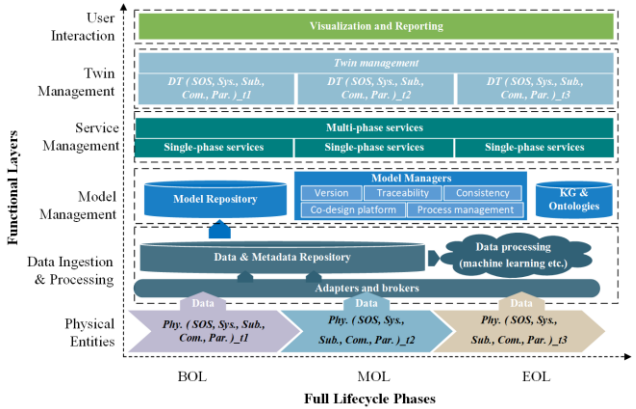


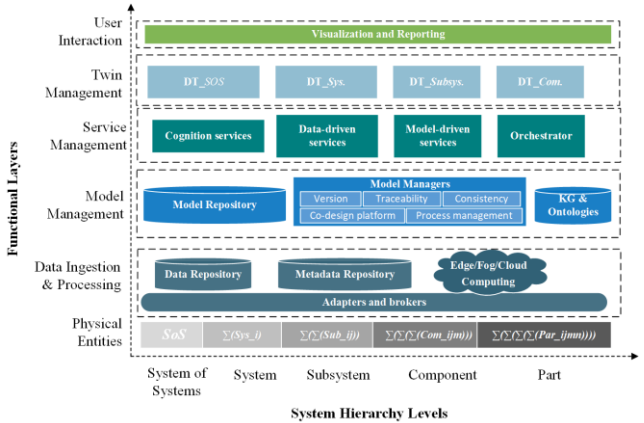
*a Al Faruque et.al. 2021. Cognitive Digital Twin for Manufacturing System

Cognitive Digital Twin

- Reference Architecture
  - Full lifecycle phases
  - System Hierarchy levels
  - Functional layers

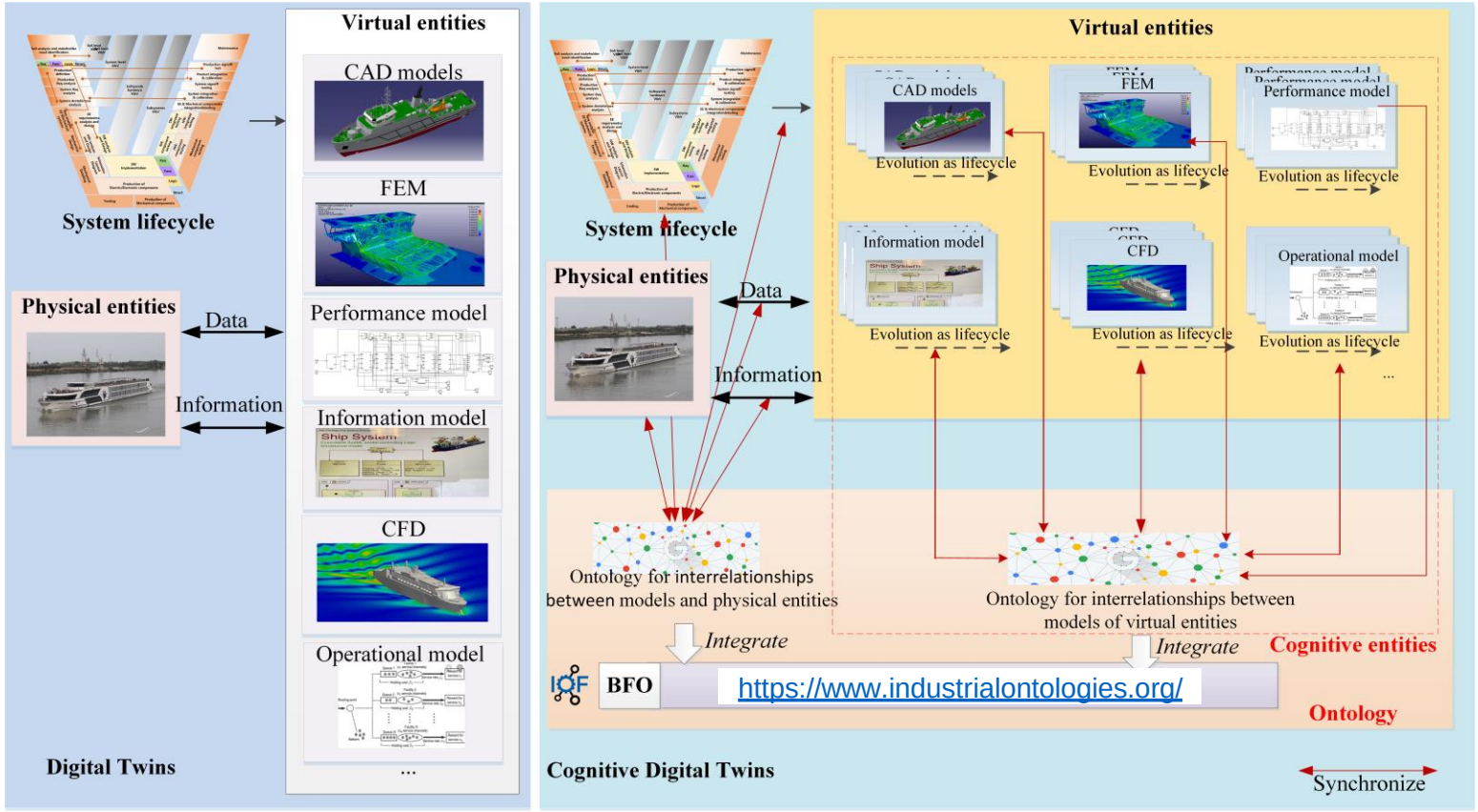






Cognitive Digital Twin

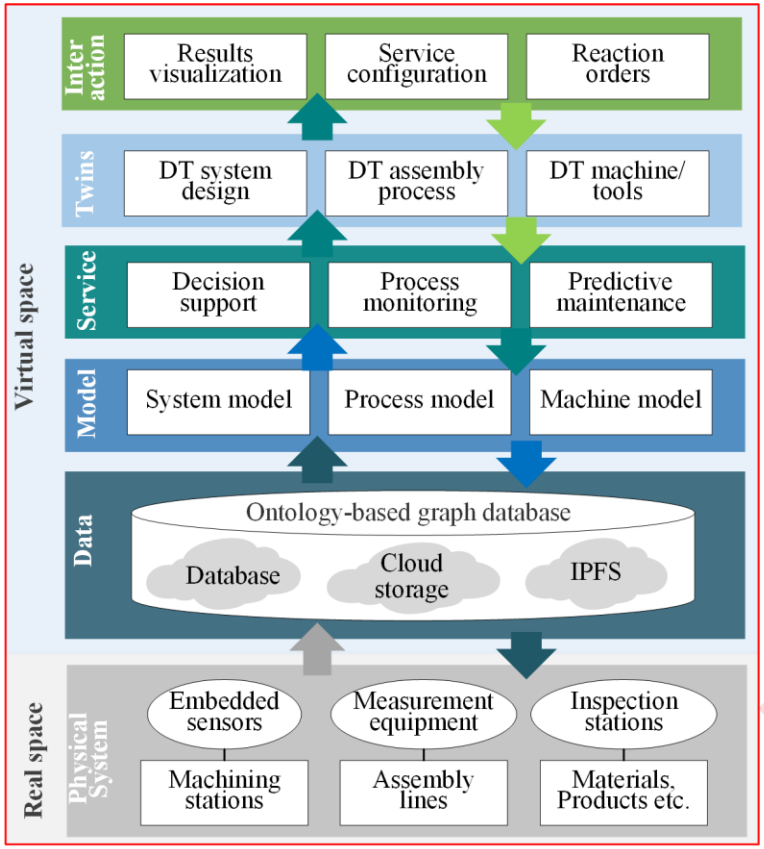
- DT vs CDT

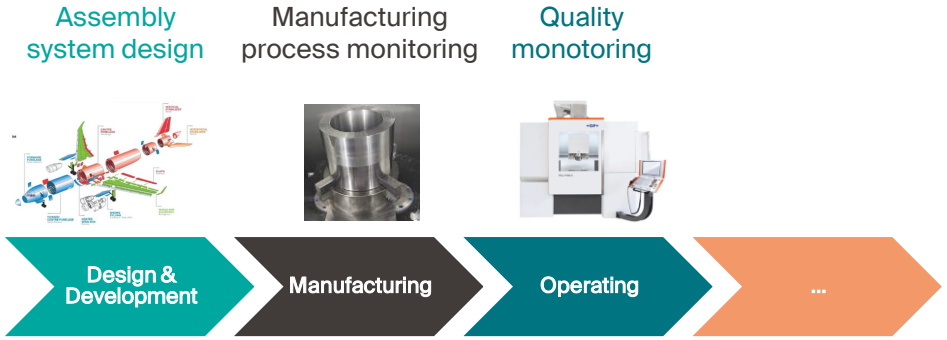


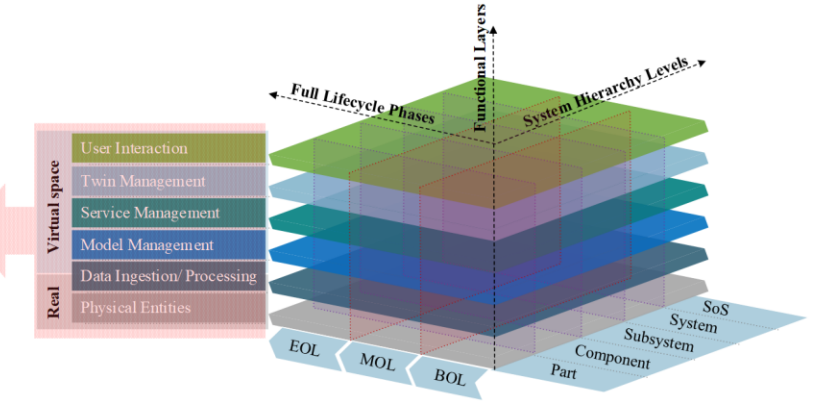
https://www.tandfonline.com/doi/full/10.1080/00207543.2021.2014591

Application cases

- Multiple lifecycle phases:

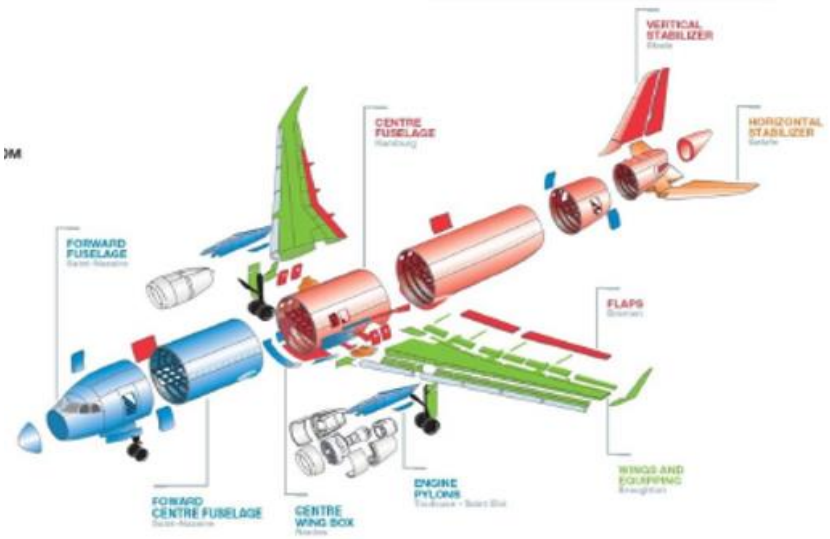


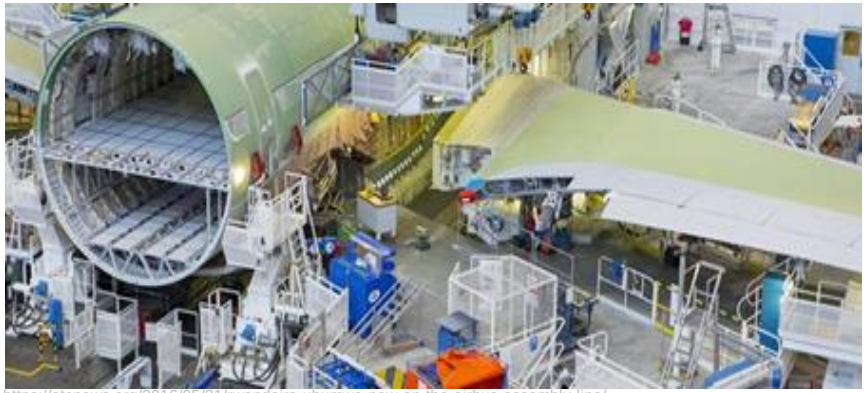




Application case

- **CDT supports aircraft industrial system design**
  - Focuses on the R&D phase of the assembly line for a new model of aircraft
    - Fuselage orbital junction process for a given assembly station of a Final Assembly Line (FAL) for the new aircraft model

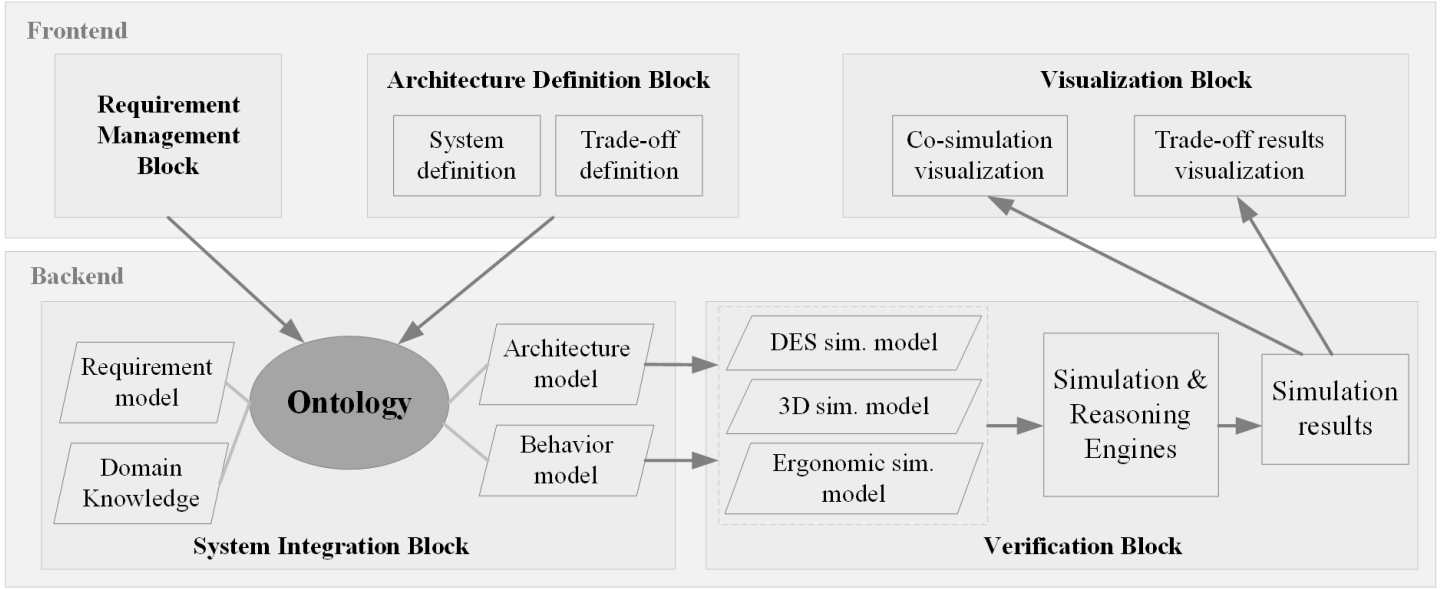




https://atcnews.org/2016/05/31/rwandairs-ubumwe-now-on-the-airbus-assembly-line/

Application case

- **CDT supports aircraft industrial system design**
  - Supports automatic trade-off among different performance parameters under different industrial scenarios
  - Key functional block of the trade space framework for system integration, e.g. requirement model, architecture models and behavioral models etc.



Application case

Requirement

ReqIF

Mission model

Operation model

Function model

MOFLP at
MetaGraph 2.0

DSM

Frontend
Requirement Management Block
Architecture Definition Block
System definition
00
Visualization Block
Co-simulation visualization
Trade-off results visualization
Backend
Requirement model
Ontology
Architecture model
Behavior model
DES sim. model
3D sim. model
Ergonomic sim. model
Simulation & Reasoning Engines
Simulation results
Domain Knowledge
System Integration Block
Verification Block

2D/3D
CoSimulation

Domain Knowledge

Ontology

Graphical rep. of 2D/3D models in MetaGraph 2.0

Application case

Formalisms for defining transformation rules

Transformation rules

Knowledge management & Decision-making

KG for MBSE models

KG for real worlds

Ontology

GOPPRRE ontology

Requirement ontology

BFO-ontology/**BFO**

Architecture models

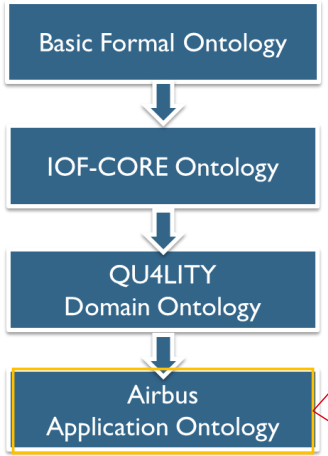
Real system manufacturing processes

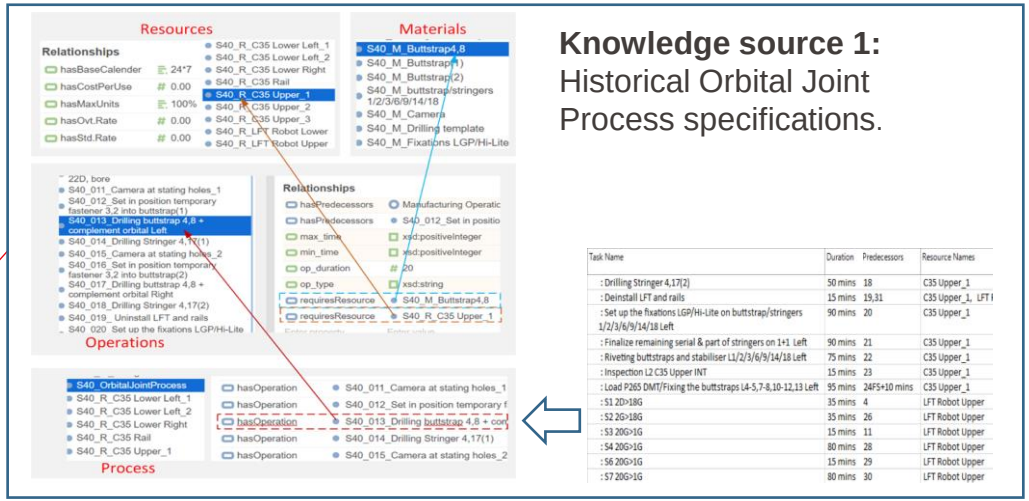
DTs

Aircraft Assembly

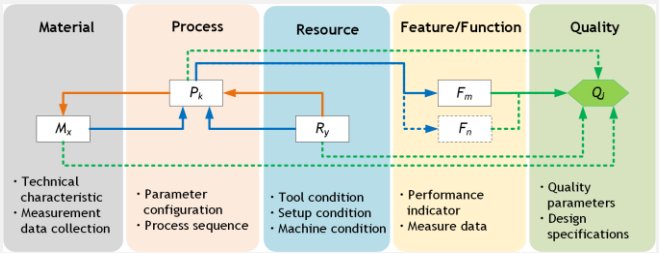
Application case

- **Ontology development**





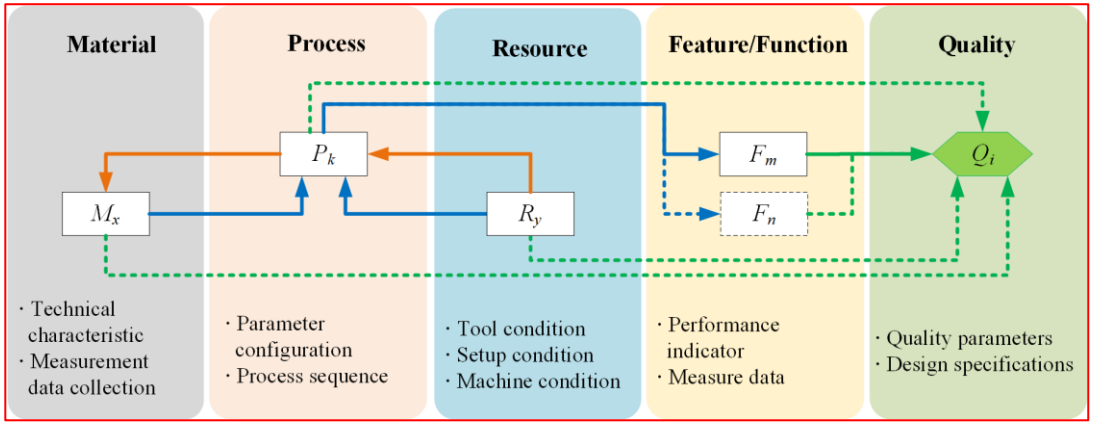
Knowledge source 1:
Historical Orbital Joint Process specifications.



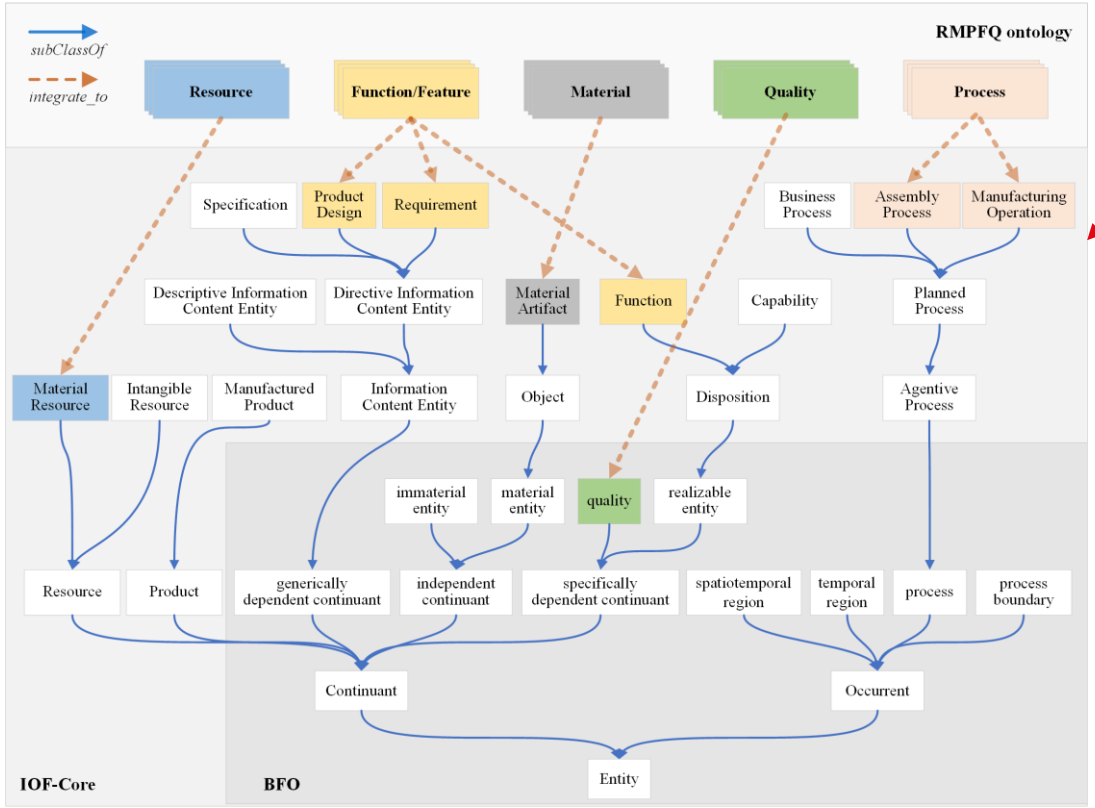
Knowledge source 2:
Domain experts' knowledge.

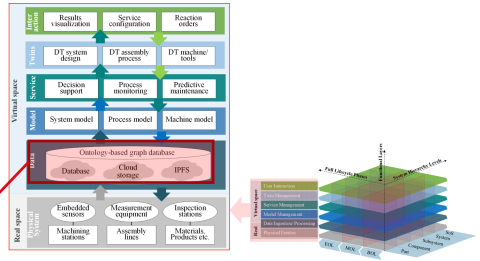
RMPFQ model

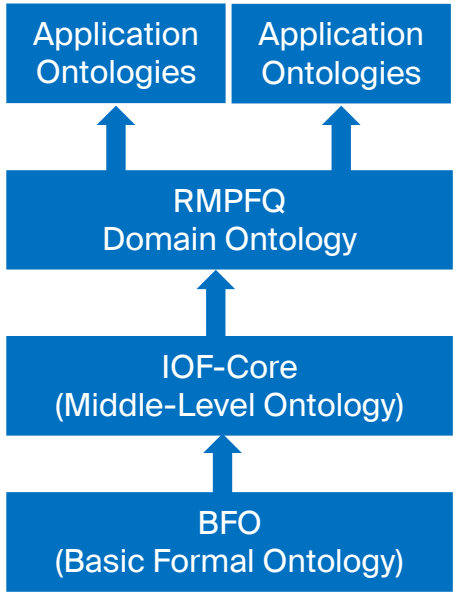
- **RMPFQ-model:**
  - **Resource**: devices, tools and means to produce goods and services, except raw material and product components [ISO 15531].
  - **Material**: raw materials, product components and assemblies etc., that is needed to produce a certain product.
  - **Processes**: processing and transforming materials into the final goods by using machines, tools and human labour.
  - **Functions/Features**: distinguished characteristics of a product, e.g. functionalities like specific tasks, actions or processes that the product is able to perform; and/or other features like performance
  - **Quality**: the degree of conformance of final product functions and features to designed requirements [ISO 9000].



From BFO to RMPFQ to applications





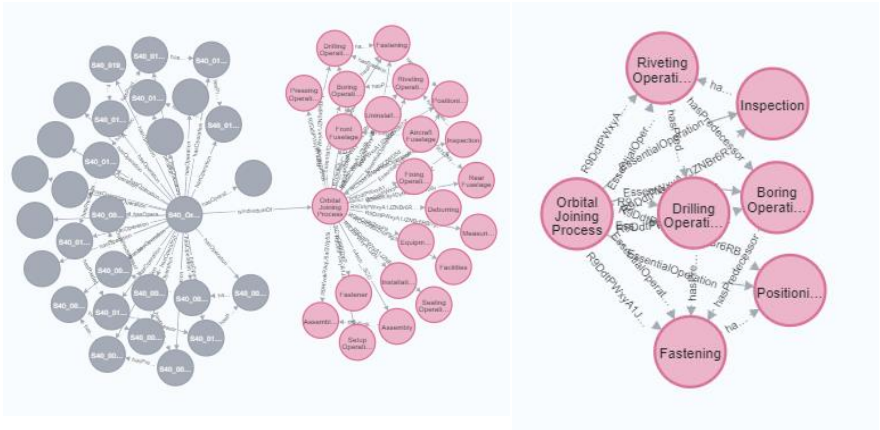


Cognitive Digital Twins

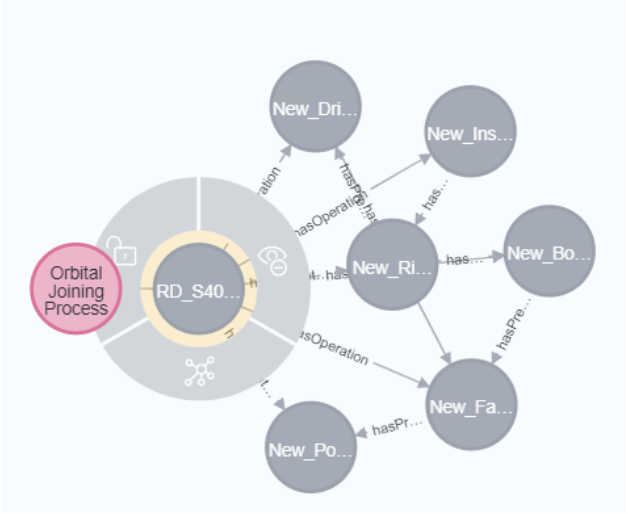
AIRBUS EPFL Fraunhofer VISUAL COMPONENTS ICT4SM

Ontology support new process design

- Knowledge captured from the existing orbital joining process is represented in the ontology by a generalized class which contains necessary operation classes and their relationships
- When designing a new Orbital Joint Process, the new instance (e.g. Individual RD_S40_OrbitalJointProcess) automatically inherit the predefined properties (operations).
- It provides starting point for Industrial System Engineer for new system design

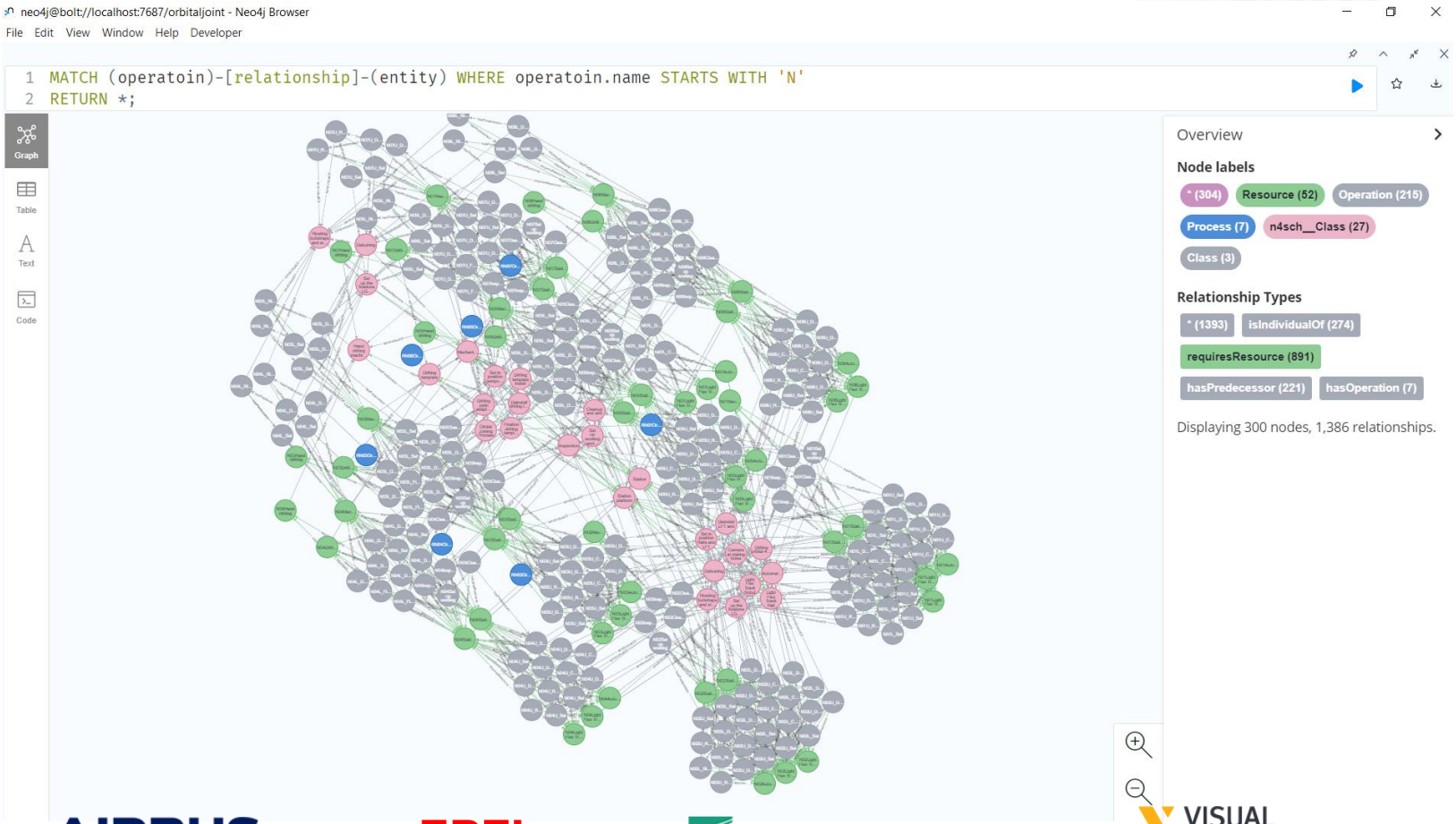


Captured Knowledge



Knowledge instantiating

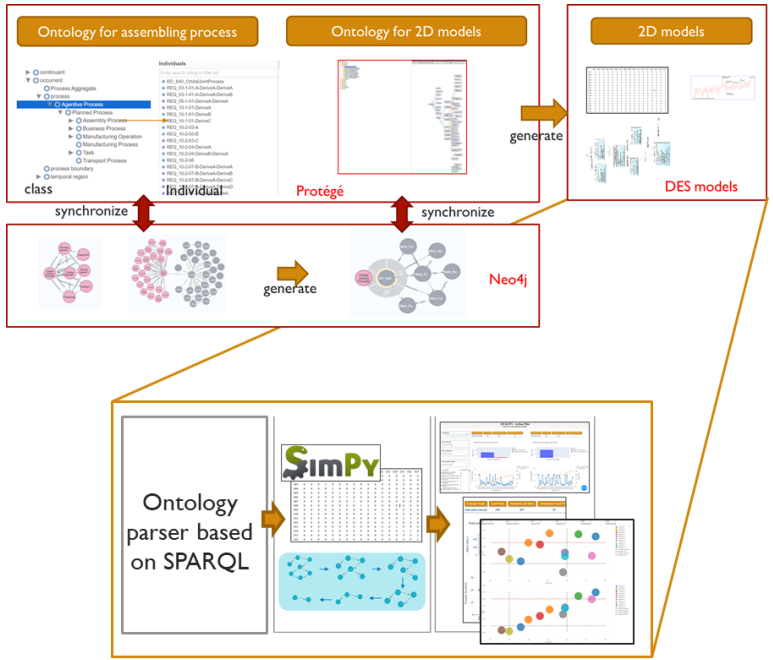
Ontology in Graph Database - Neo4j

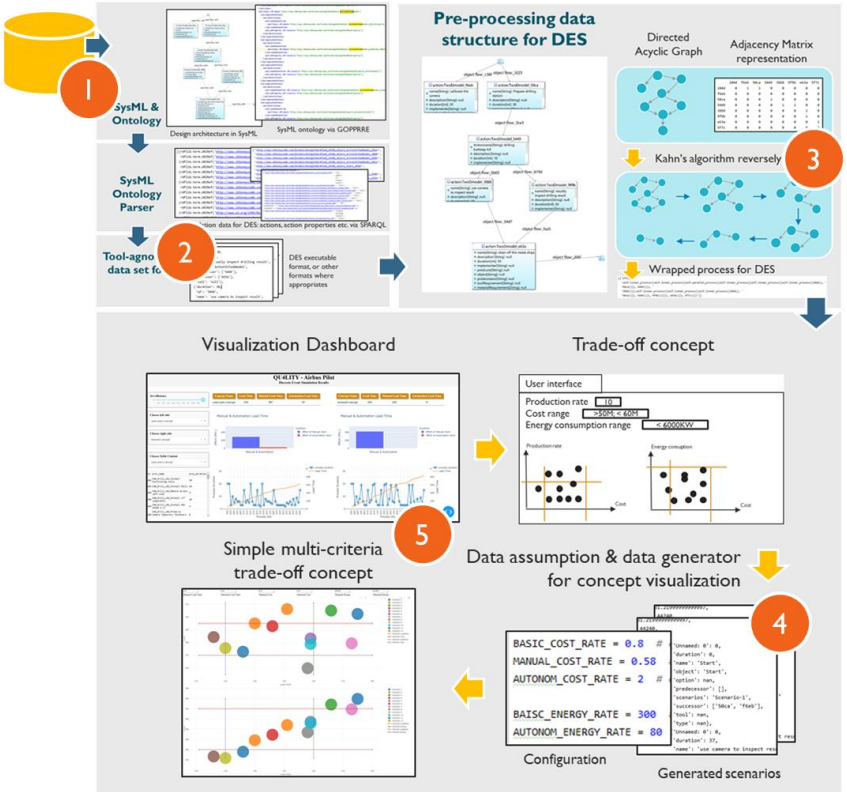


AIRBUS EPFL Fraunhofer VISUAL COMPONENTS

2D Simulation

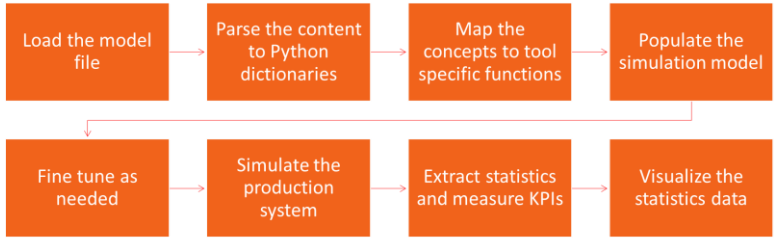
- Generate Discrete Event Simulation (DES) model from application ontology, which describes a design architecture
- Automatic generation covering different scenarios for assembly process designing
- Achieve decision supports with DES and data analysis during industrial system design

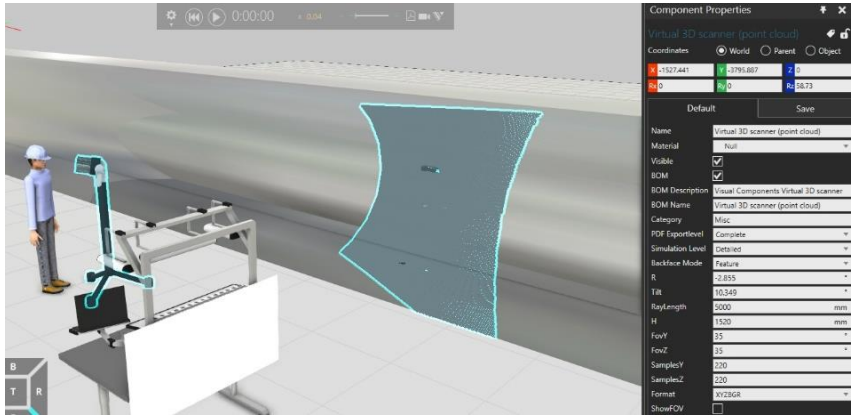


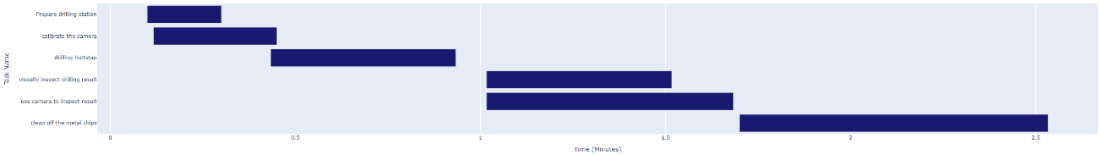


3D Simulation

- Once created the virtual scenario faster validation, allows using 3D simulation from the initial design steps
- Easy validation of different cases (workers, resources,..), independent of the facility
- Mapping from Ontology to Simulation:

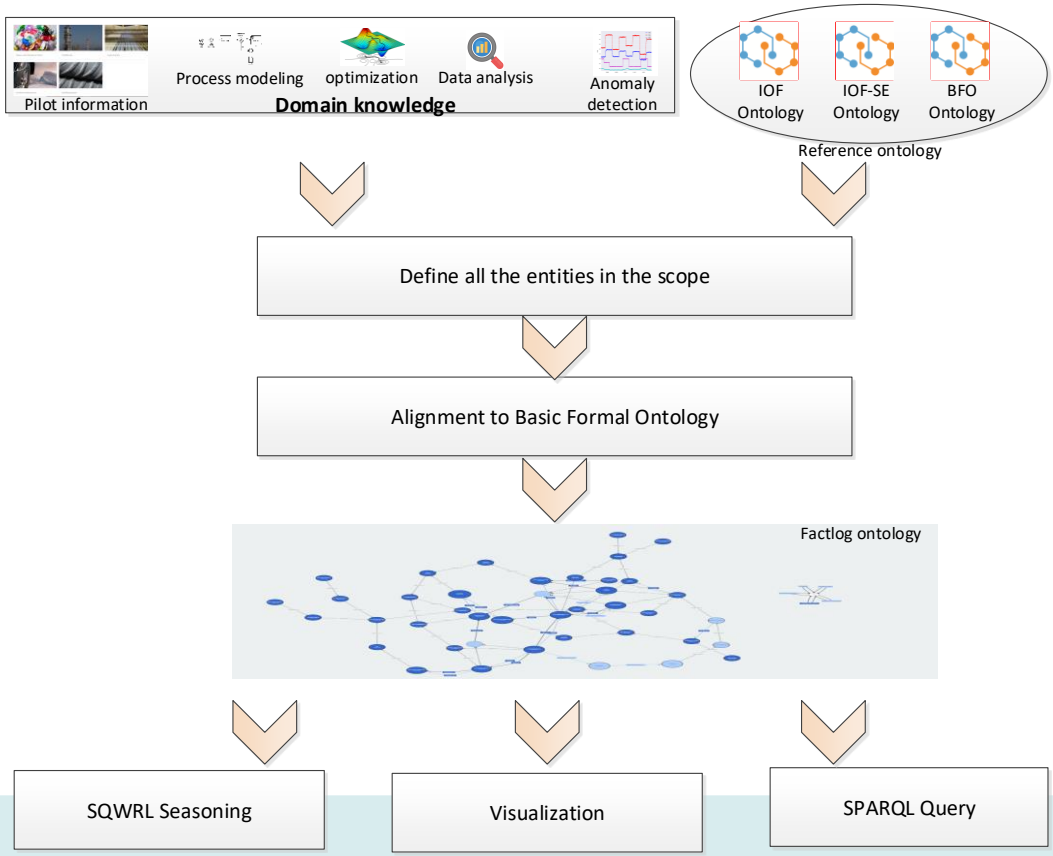






Design options

Research methodology



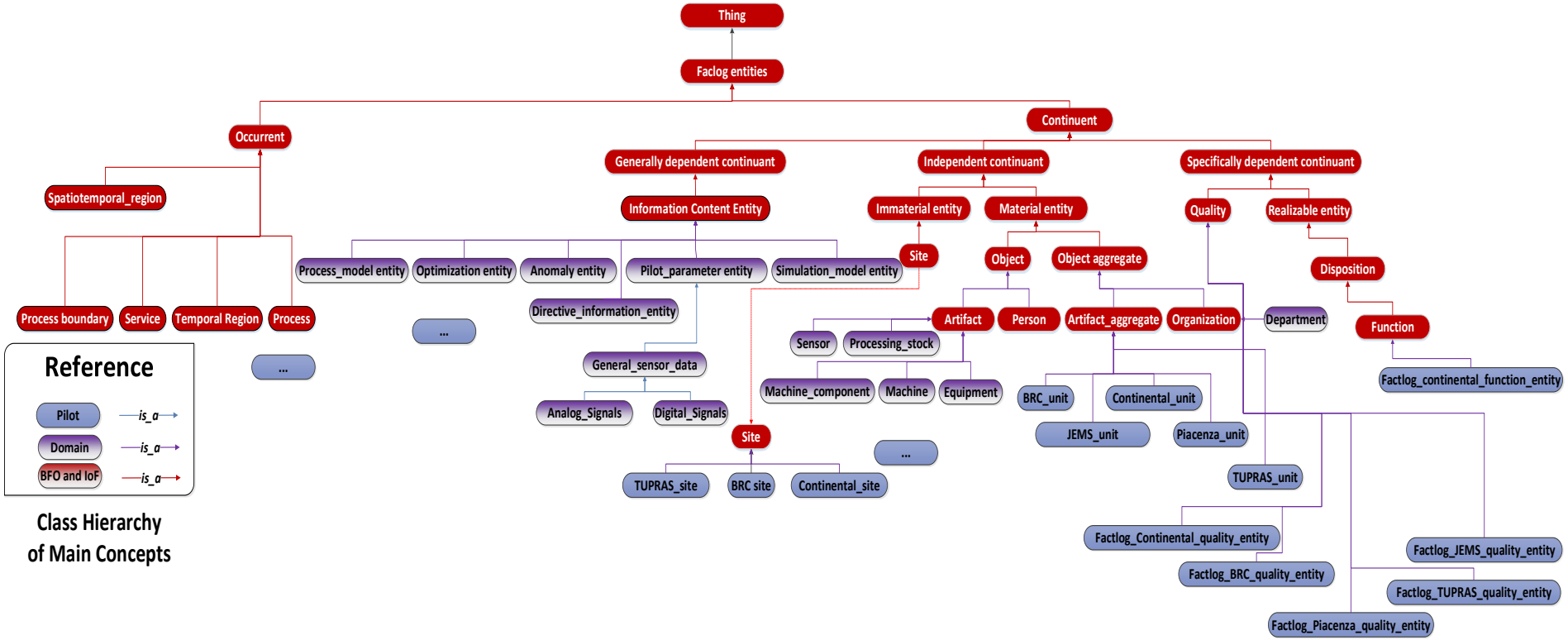
Unified description of digital twins and information across FACTLOG platform

Anomaly detection for cognition

- NEO4J for KG representation
- CYPHER for query

Visualization of the interrelationships of all the ontology entities and individuals

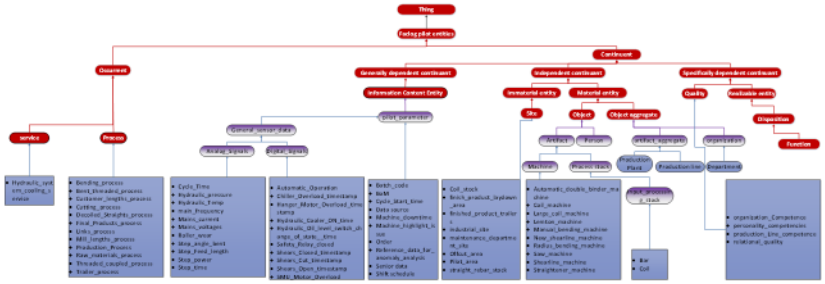
Ontology framework



Class Hierarchy of Main Concepts

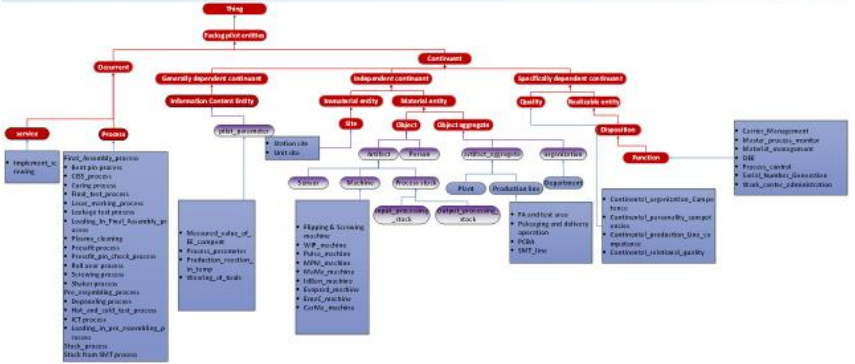
Factlog Pilot Ontology

Ontology



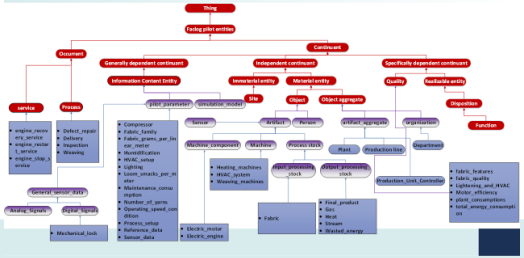
BRC

Ontology



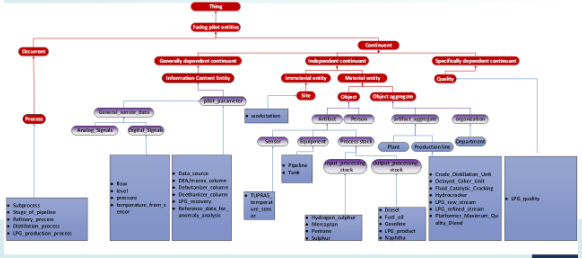
Continental

Ontology



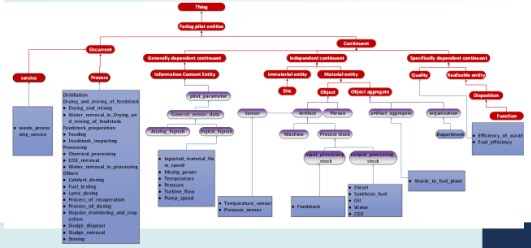
Piacenza

Ontology



TUPRAS

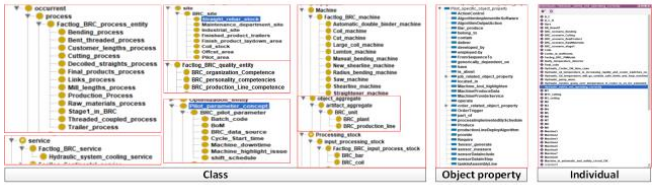
Ontology



JEMS

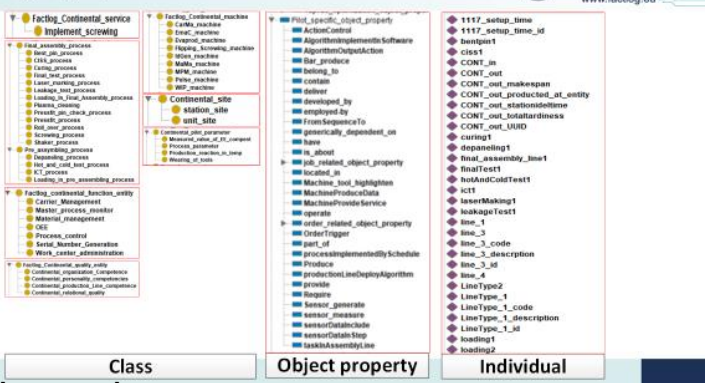
Factlog Pilot KG models

Knowledge graph model



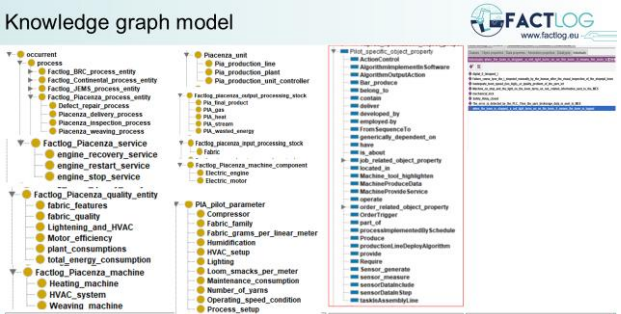
BRC

Knowledge graph model



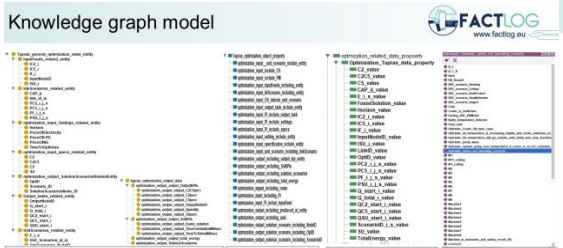
Continental

Knowledge graph model



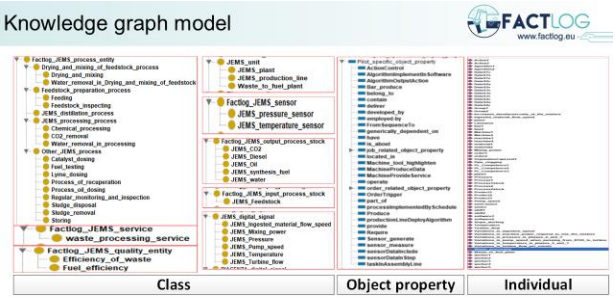
Piacenza

Knowledge graph model



TUPRAS

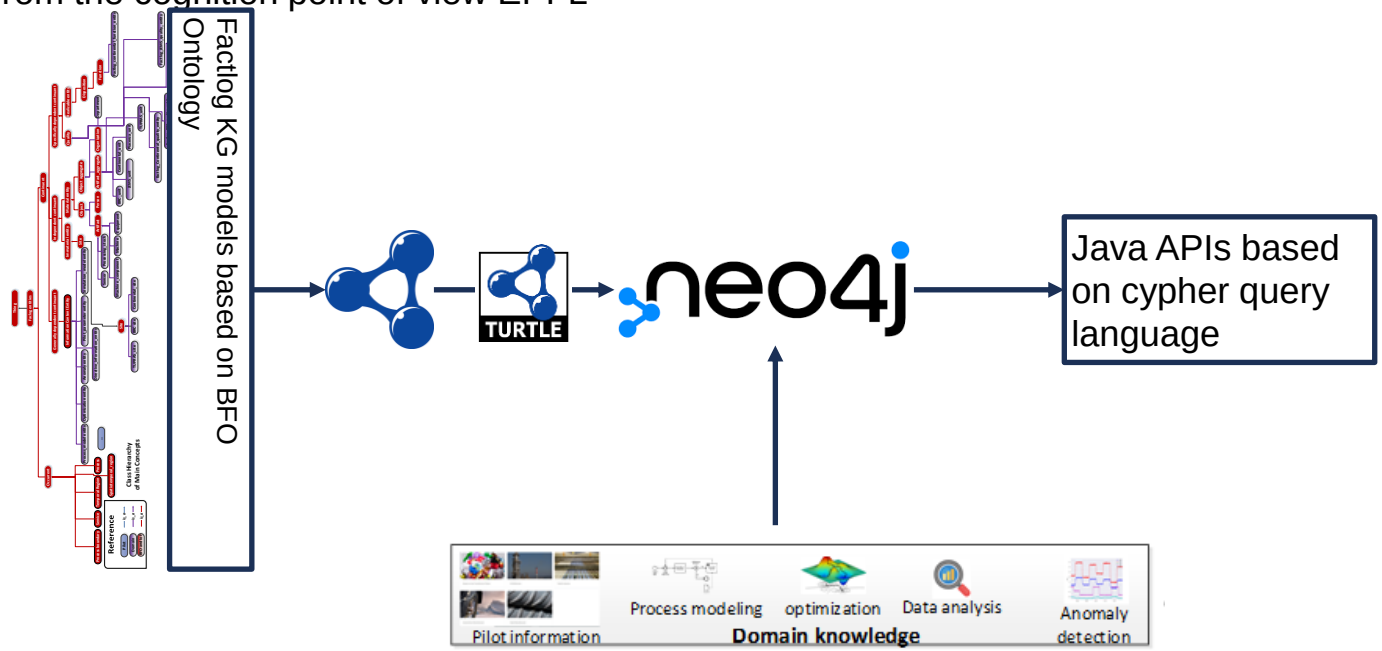
Knowledge graph model

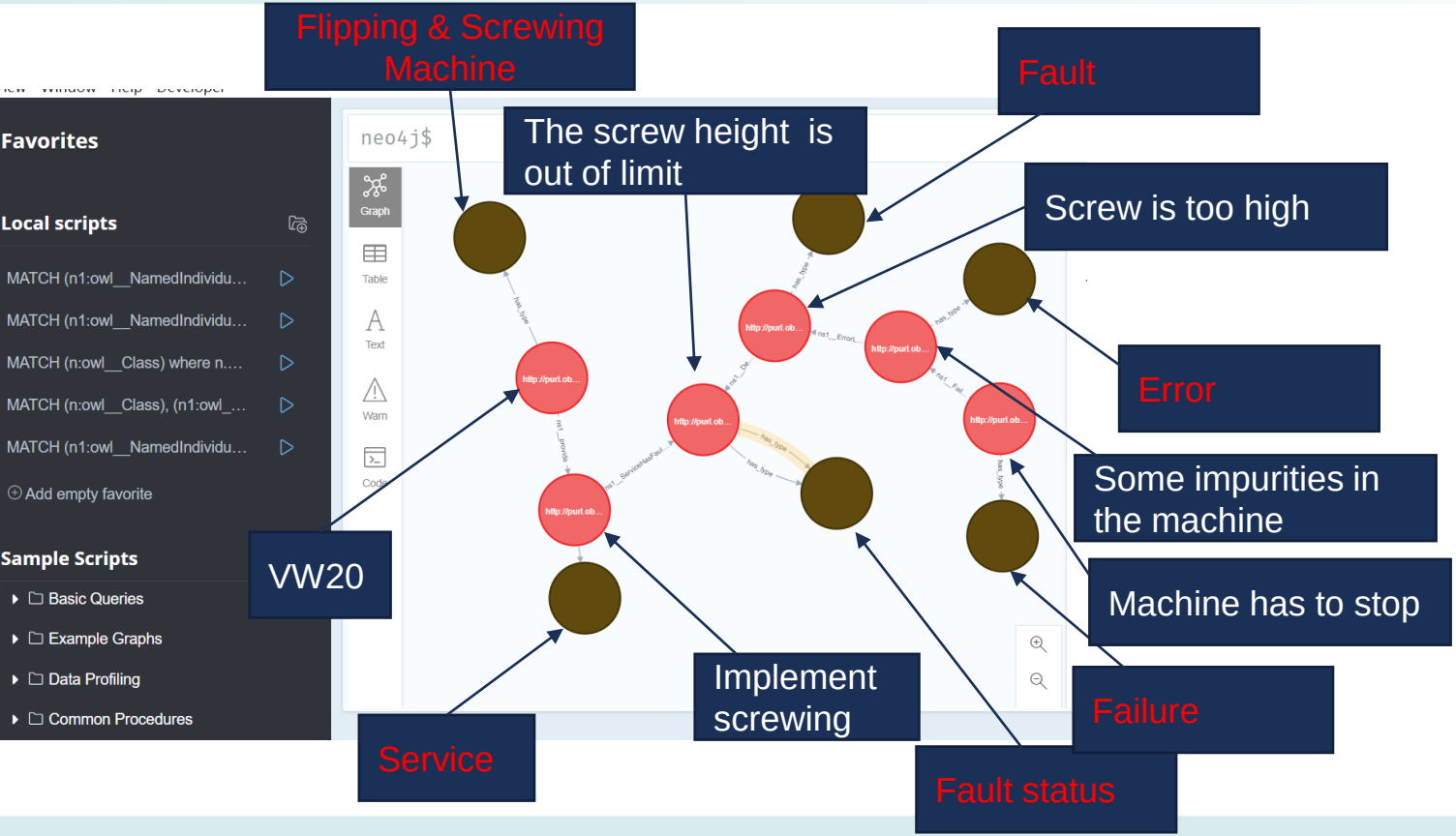


JEMS

KG APIs for Factlog Platform

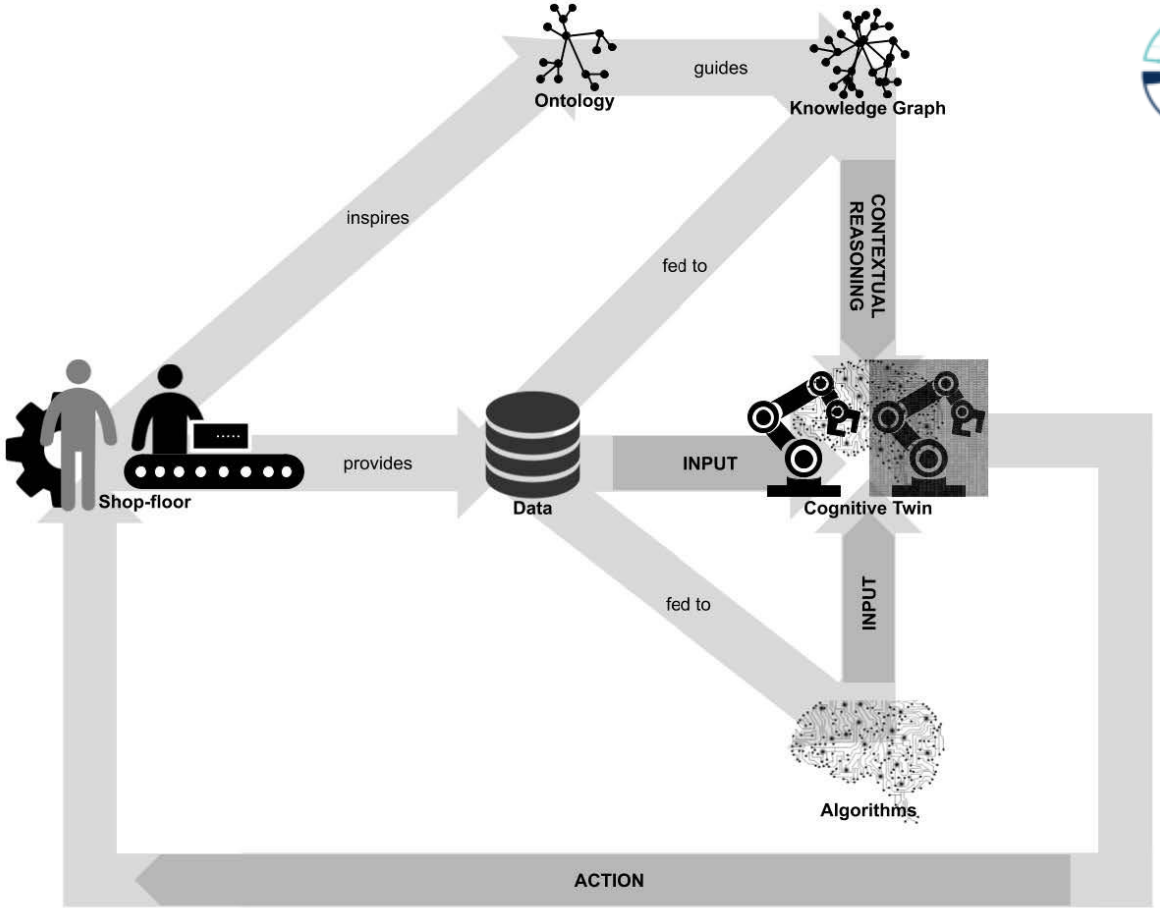
Task 3.3 Factory knowledge 4.0 Interpreting factory knowledge base from the cognition point of view EPFL





Fault status
The screw height is out of limit
Fault
Screw is too high
Error
Some impurities in the machine
Failure
Machine has to stop
Service
Implement screwing
Machine （machine type: Flipping & Screwing）
VW20

Actionnable Cognitive Digital Twin



https://www.factlog.eu/

https://www.tandfonline.com/doi/full/10.1080/00207543.2021.2002967

Thank you for your attention!

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