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Czech Institute of Informatics, Robotics, and Cybernetics
Intelligent Systems for Industry Group

Utilization of Semantic Web Technologies within Industrial Automation Domain

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Agenda

- Cyber-physical system (CPS)
  - Integration challenge of CPS(s)
- Semantic Big Data Historian
  - Plug&Play CPS component
- Ontology Learning for Automotive
- Production Monitoring

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Introduction

- Manufacturing is changing
  - Time-to-Volume and Time-to-Market: very rapid product introductions to markets in increasing volumes
  - Products become more complex, greater levels of miniaturization
  - Offering personalized products
- Challenge is the integration of the equipment and knowledge
  - All levels of production may communicate
  - Requirements for flexible manufacturing
    - Essential enabler - Explicit specification of knowledge
- All of these aspects are encapsulated within Industry 4.0

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Cyber-Physical Systems (CPSs)

- Around 2006 – term „Cyber-Physical System“
  - Coined by Hellen Gill
  - Increasing importance of the interactions between interconnected computing systems and the physical world

Definition:

CPSs are integrations of computation and physical processes.

Embedded computers and networks monitor and control the physical processes.

Cyber-Physical Systems Architecture

Basic concept of CPS architecture – 3 parts:

- Cyber part
  - Computing core – transforms physical process information into a model of a software system
  - Operate according to a given control algorithm
- Physical part
  - Represents a controlled object
- Network
  - Communication medium between a cyber and a physical part

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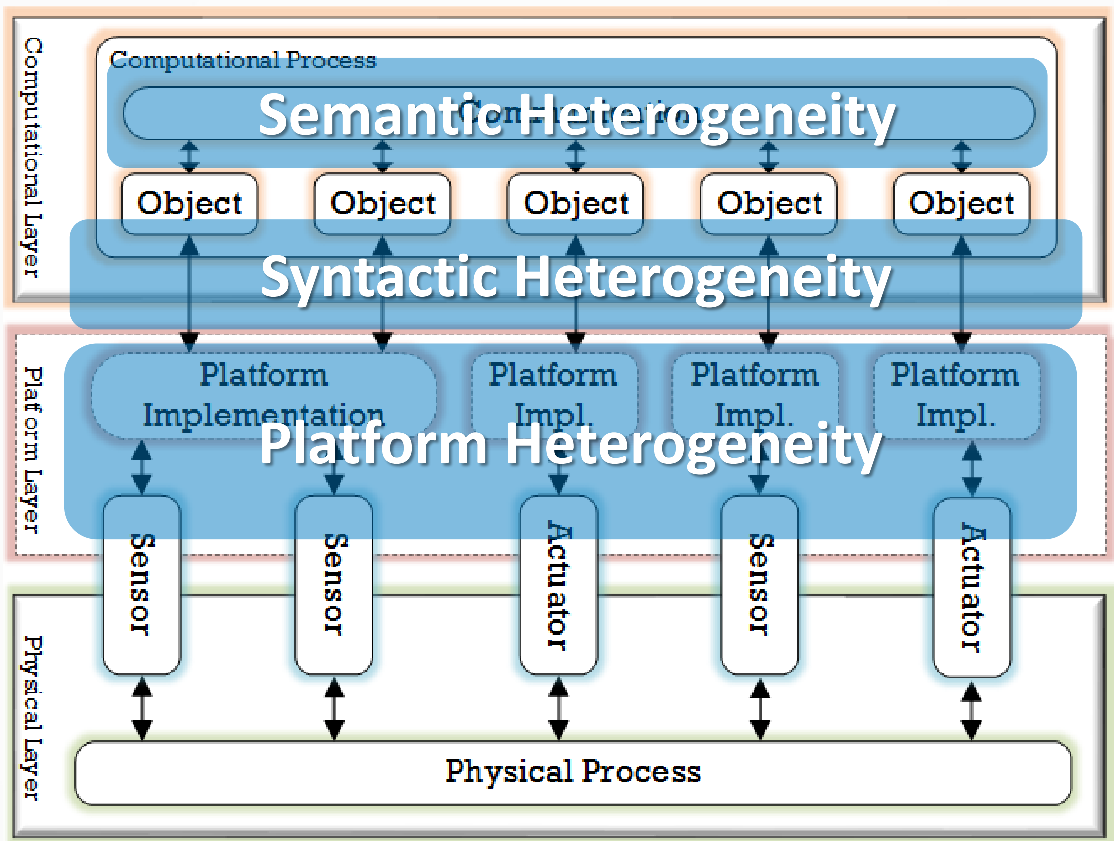
Integration Challenge of CPSs

Integration Challenge of Cyber-Physical Systems (CPSs)

- Two different levels of a CPS integration - the low-level and the high-level integration
- Low-level integration
  - Integration of CPS components – sensor(s), actuator(s), data model(s) of computational process
- High-level integration
  - Integration of various CPSs to form a more complex and capable system
- Integration process
  - Platform heterogeneity, Syntactic heterogeneity, Semantic heterogeneity

CPS: Low-Level Integration

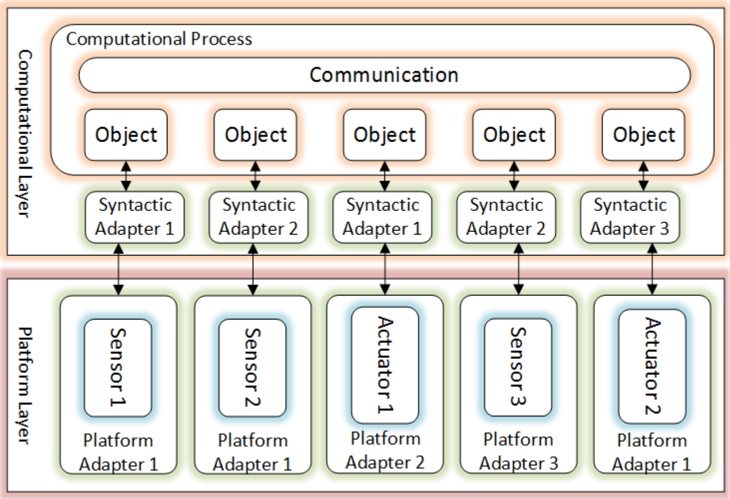
- General CPS architecture



Integration Process of CPS Components

Integration task: **unification of interfaces and knowledge**

1. Platform heterogeneity
   - Different devices used for CPS from various manufacturers
   - *Solution*: a unification of different interfaces provided by various manufacturers using **adapters**
2. Syntactic heterogeneity
   - Components may use different formats for data representation
   - Solution: a unification of different formats using **adapters**



Integration Process of CPS components

Integration task: **unification of interfaces and knowledge**

3. Semantic heterogeneity
   - Different data models used by CPS components (e.g., same real-world entities are represented by different concepts)
   - *Solution*: Models integration
     - Identification of corresponding concepts
     - Identification of corresponding relations among concepts
     - Identification of corresponding meaning in a given context
     - Utilization of an ontological description of CPSs and their components. I.e., Web Ontology Language (**OWL)**
     - Ontology matching methods may be exploited for elements identification

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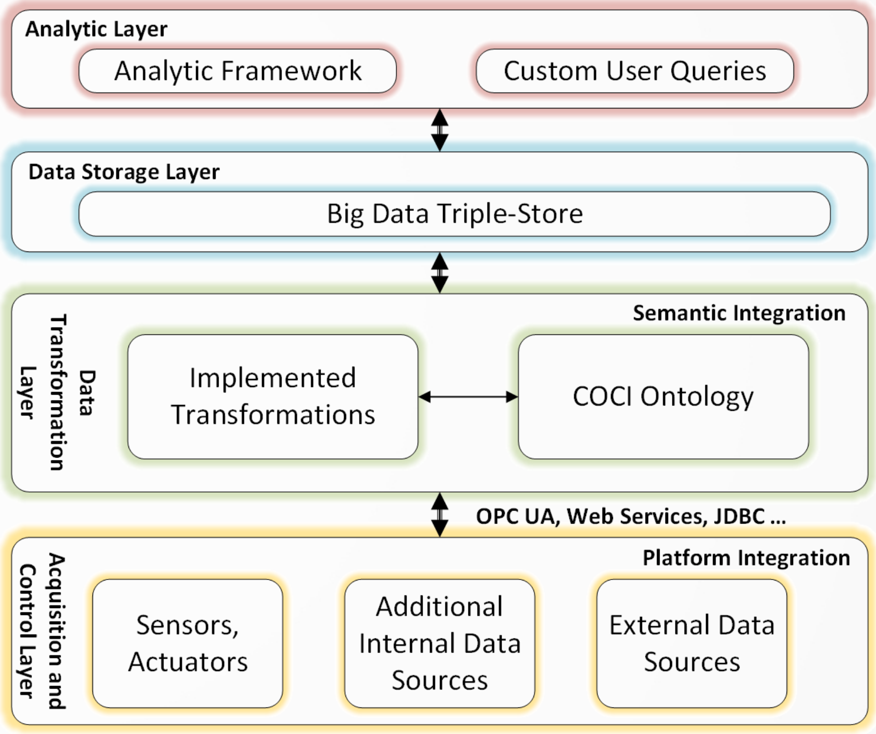
Semantic Big Data Historian

Storage of Shop Floor Data Represented in OWL

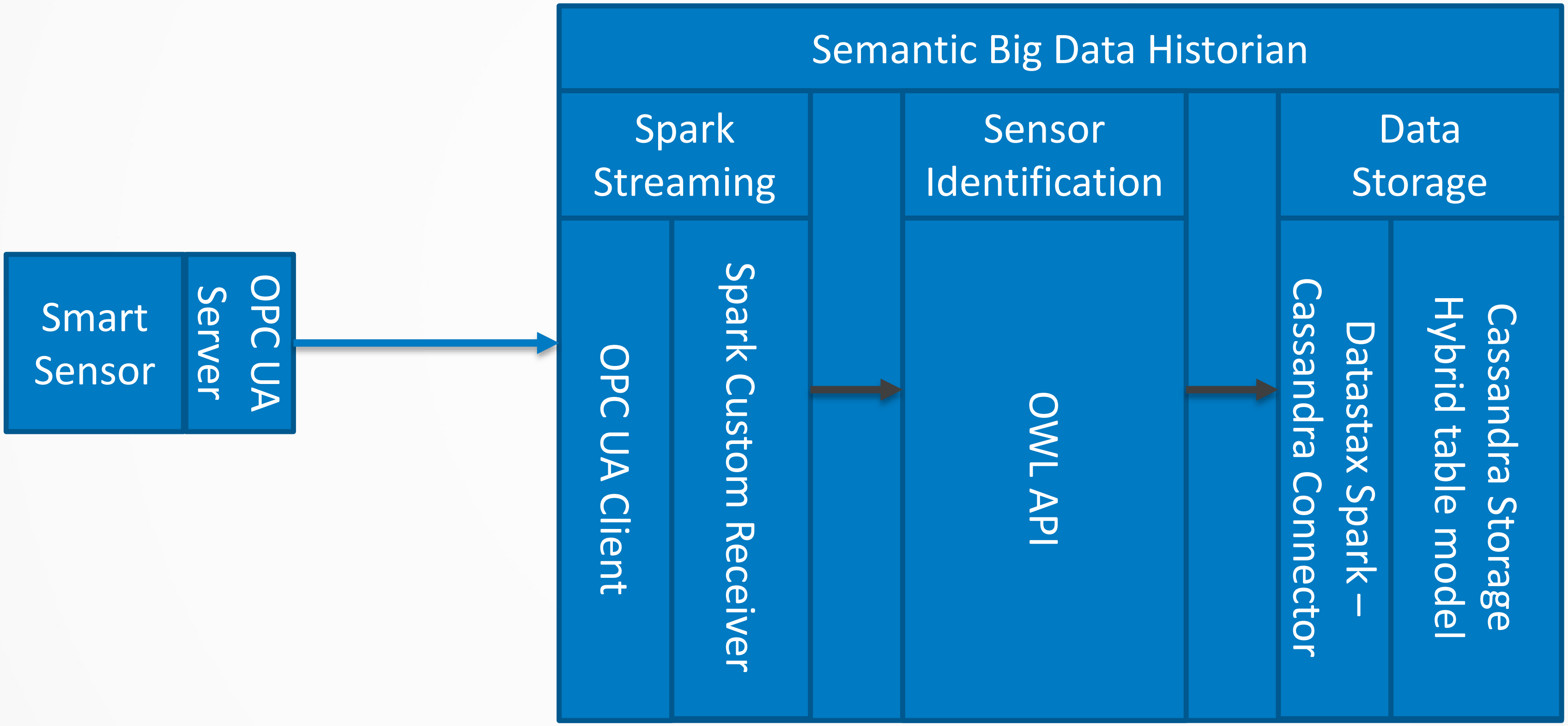
- Representation of information about CPS components in OWL may cause performance problems
- The solution for suitable RDF storage consists of two main components
  - An exploitation of a framework which is able to
    - Form distributed system
    - Support data streaming
    - Methods for Big Data processing
  - Suitable structure for RDF storage respecting shop floor data nature
- Semantic Big Data Historian fulfills aforementioned requirements

Semantic Big Data Historian (SBDH)

1. Data acquisition layer
   - Collects data – sensors, other relevant system MES/ERP
2. Transformation layer
   - Transforms data to the unified semantic form according to COCI ontology
3. Data storage layer
   - Apache Spark and Apache Cassandra
4. Analytic layer
   - Provides access to directly connected storage for custom analytic programs or custom user queries



SBDH Data Flow



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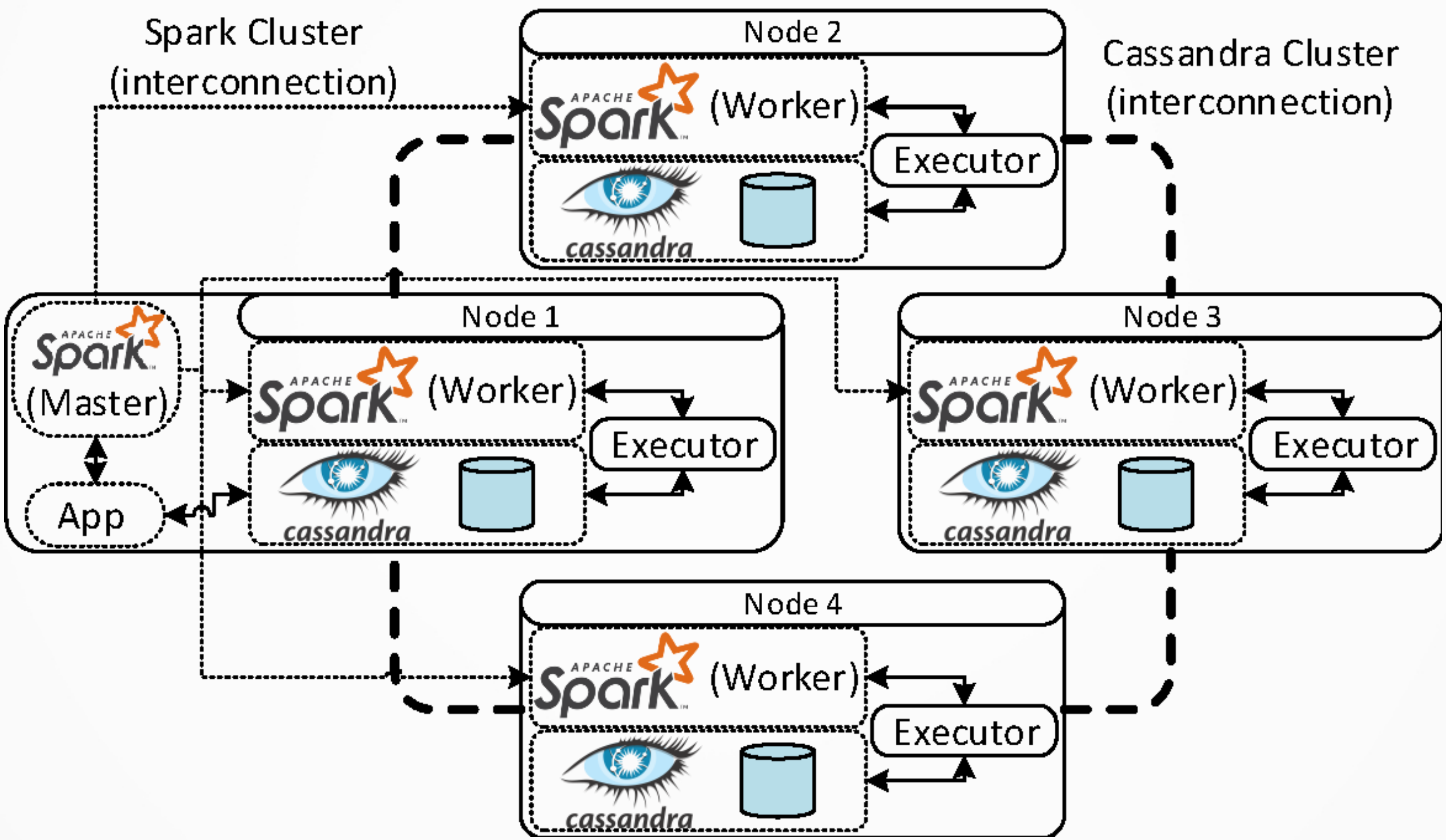
Semantic Big Data Historian Based on Apache Spark and Apache Cassandra



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Data Storage

Vertical Partitioning Model

- Triples are partitioned with the respect to their property
- Stored in files named according the property
- Disadvantages - data are not homogeneously distributed

Example: file named *hasQuantityUnitOfMeasurement*

```
:CO2ds048 :parts-per-million
:THSds075 :percentage
:THSds075 :degreeCelsius
```

Hybrid SBDH Model

- Previous model – poor performance when querying samples with range filter, etc.
- **Proposed for sensor measurements**
- Partitions – subject and property + timestamp

Example: file named CO2ds048#hasQuantityValue:

```
2012-04-29T00:00:10 355.0
2012-04-29T00:00:40 355.1
2012-04-29T00:01:10 355.0
```

Plug&Play CPS Components

Feasibility of the Integration of CPS Components

Feasibility of proposed solution (together with functionality of SBDH) was demonstrated on

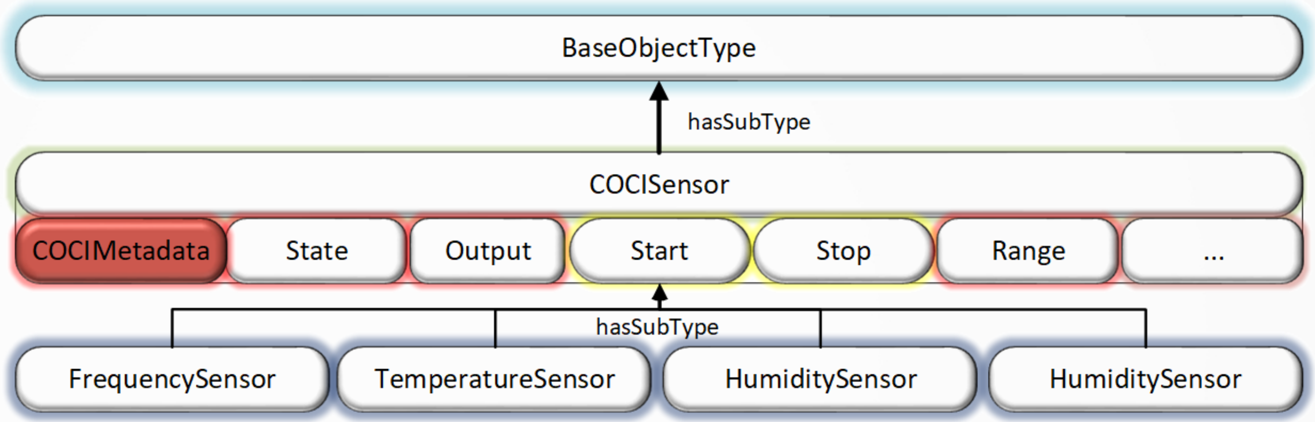
- Concept of Plug&Play CPS components
- Experimantal CPS

Concept of Plug&Play CPS components

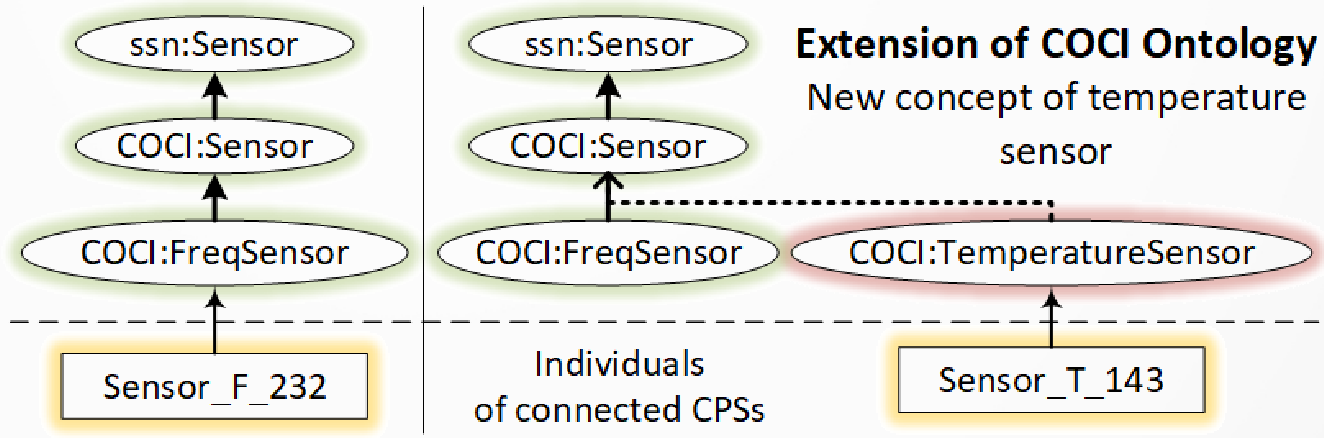
- Definition (or identification) of devices (CPS components) using COCI ontology
- Definition of device is stored in OPC UA model (COCImetadata)
- Immediate device utilization without any additional configuration of a system

Concept of Plug&Play CPS Components

OPC UA data model: COCIMetadata



Connection of known and unknown sensor



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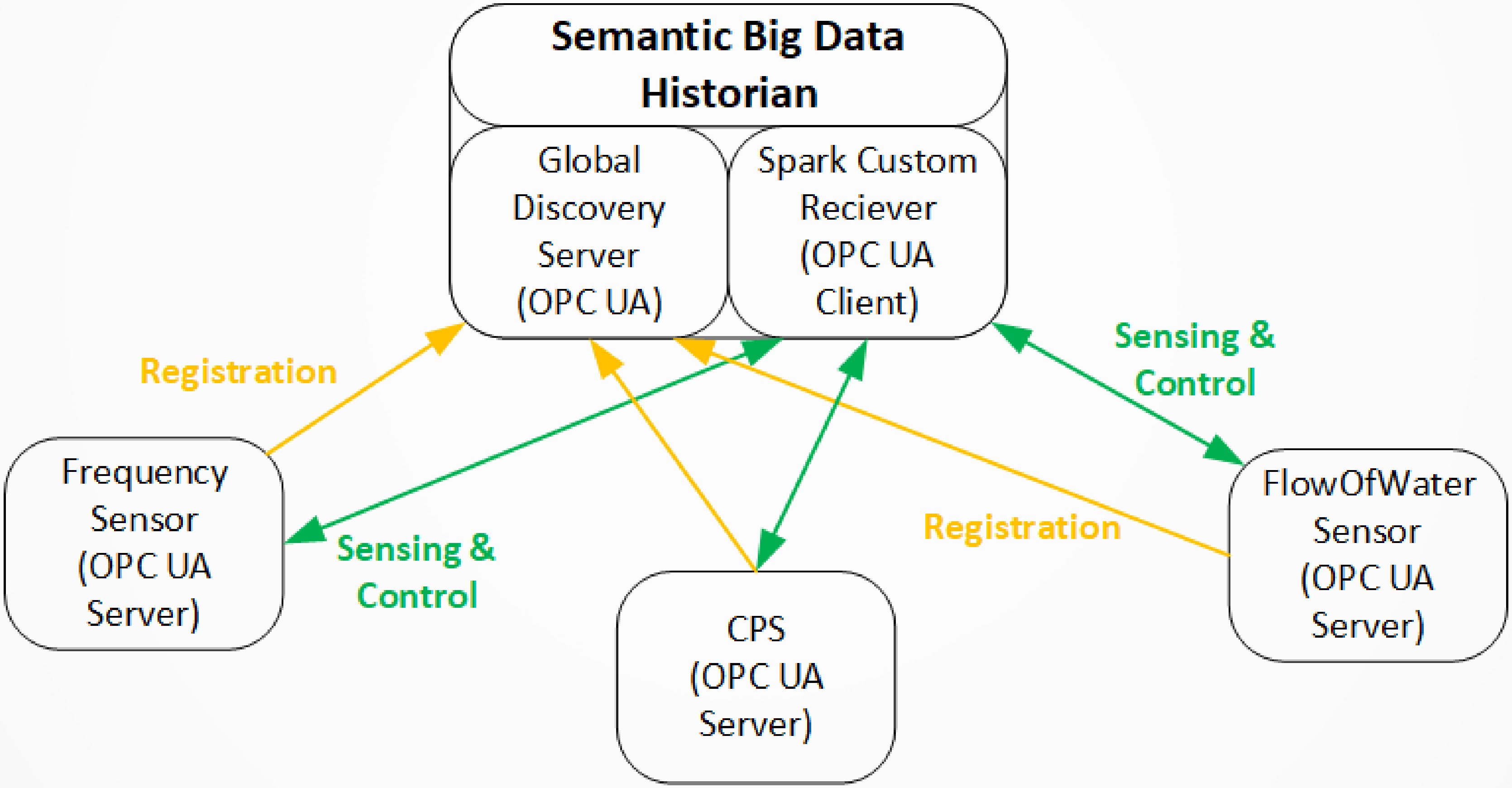
Semantic Big Data Historian Global Discovery Server



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Semantic Big Data Historian
Example of Deployment

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Experiments - „Stop-Problem“ of the Hydro-Electric Power Plant

Stop-problem

- Turbine vanes are fouled up with filth during the turbine usage
- Decrease in turbine performance
- Turbine restart
  - Shock wave cleans turbine vanes
- Problem/task - identify the optimal moment for a restart.

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Experiments
Hydroelectric Power Plant

- Verifying the concept of cyber-physical systems integration using COCI ontology and SBDH
  - i.e., handling a huge amount of RDF triples
- 38 sensors in the power plant
  - Sampling rate - 5 seconds
  - Sensors are connected via OPC UA
- Sensors produce 656,640 samples per day -> 5,253,120 triples per day -> 1,917 mil. triples per year

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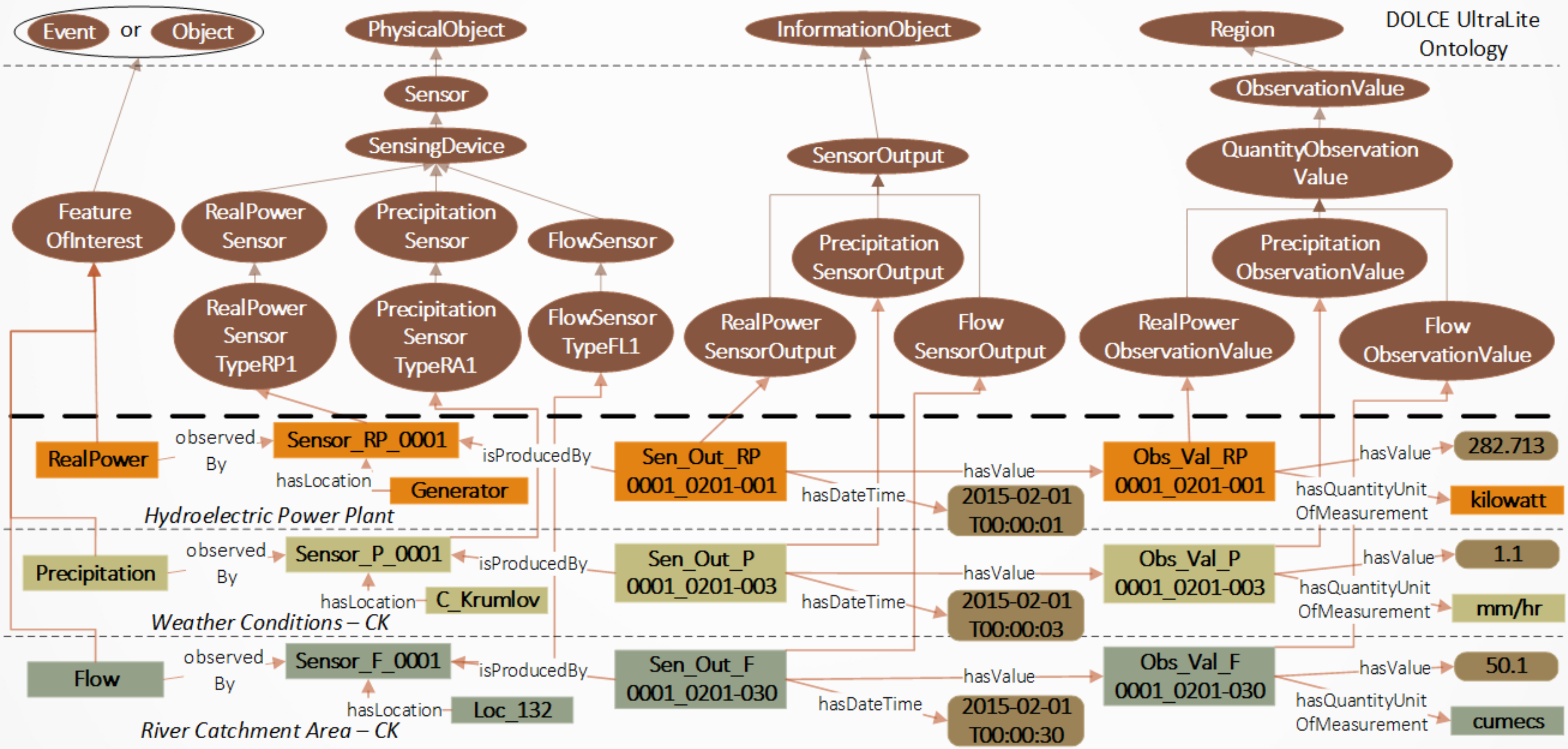
Experimental Cyber-Physical System



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Ontology Learning for Automotive

Problem statement

- Ontology learning – acquisition of new concepts/relations and extension of existing ontology.
- Integration of spare part records into Ford supply chain ontology.
- Abbreviated spare part description as input for ontology learning process.

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Input Data Characteristics

- Examples:
  - BLK CYL
  - PAN ASY OIL
  - SE CSHAFT RR OIL
- Translation using internal database of acronyms
- Ambiguous translation of abbreviated labels
  - SE = Seal, Sealant, September, Selenium, …
  - RR = Regulatory Requirement, Rear

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Ontology Learning using WordNet and DBpedia

- Search suitable concepts in structured resources.
- Contain semantic relations, meronymy/holonymy, hypernymy/hyponymy.
- Simplified approach – use all permutations and subsets of all possible spare part label translations.

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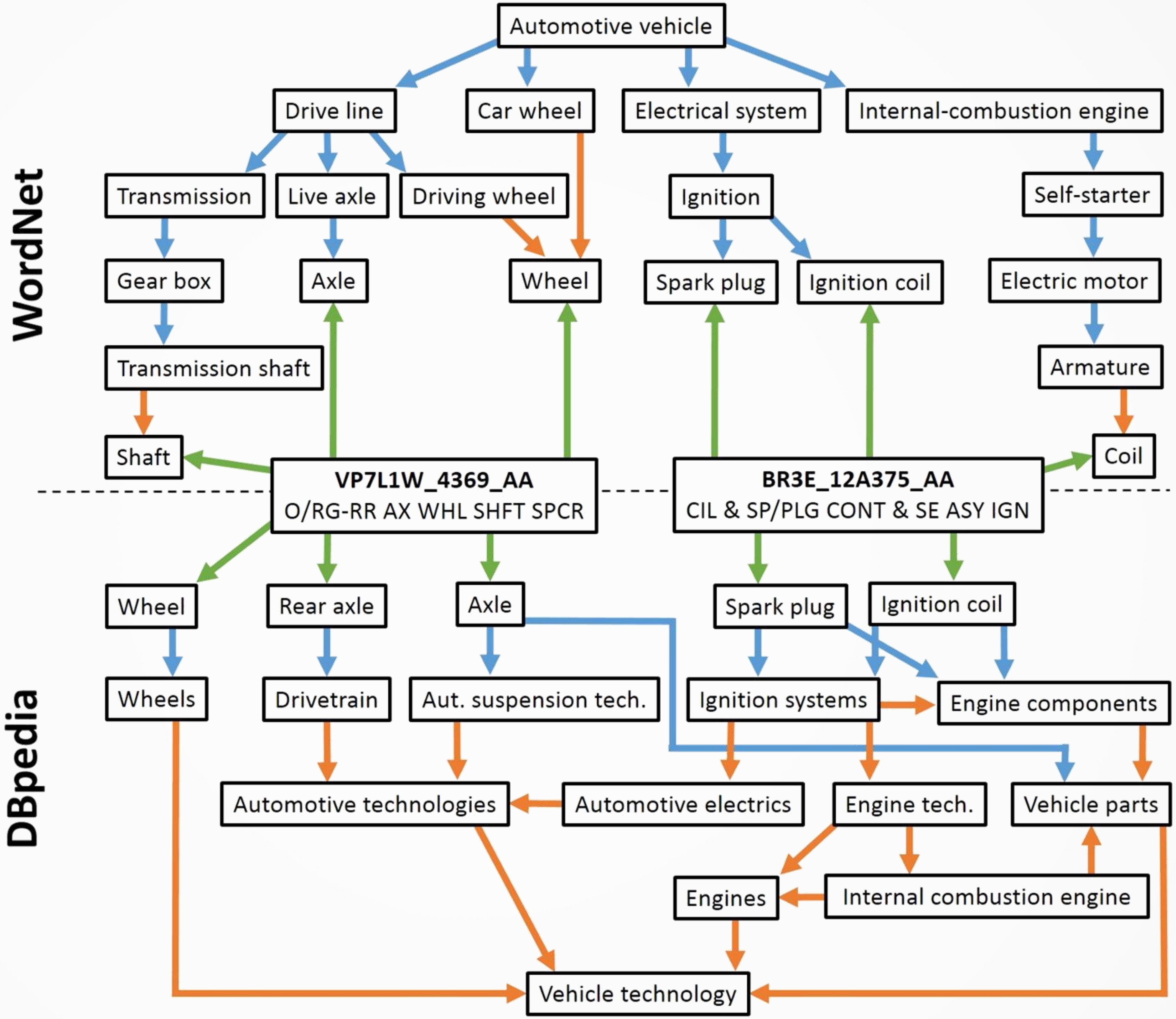

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Problems

- General concepts in both datasets
  - Only mappings for subsets of spare part description
  - Out of context
  - Meaningless mappings.
- Mappings for given spare part are unrelated.
  - SW ASY-OIL PRESS SDR → *Switch* in WordNet
  - *Station wagon, Oil pressure* in DBpedia
  - INSRT-VLV ST INTK → *Intake, Valve seat* in DBpedia
  - *Intake, Intake valve, Valve, Seat* in WordNet
- Need to take full context into account.

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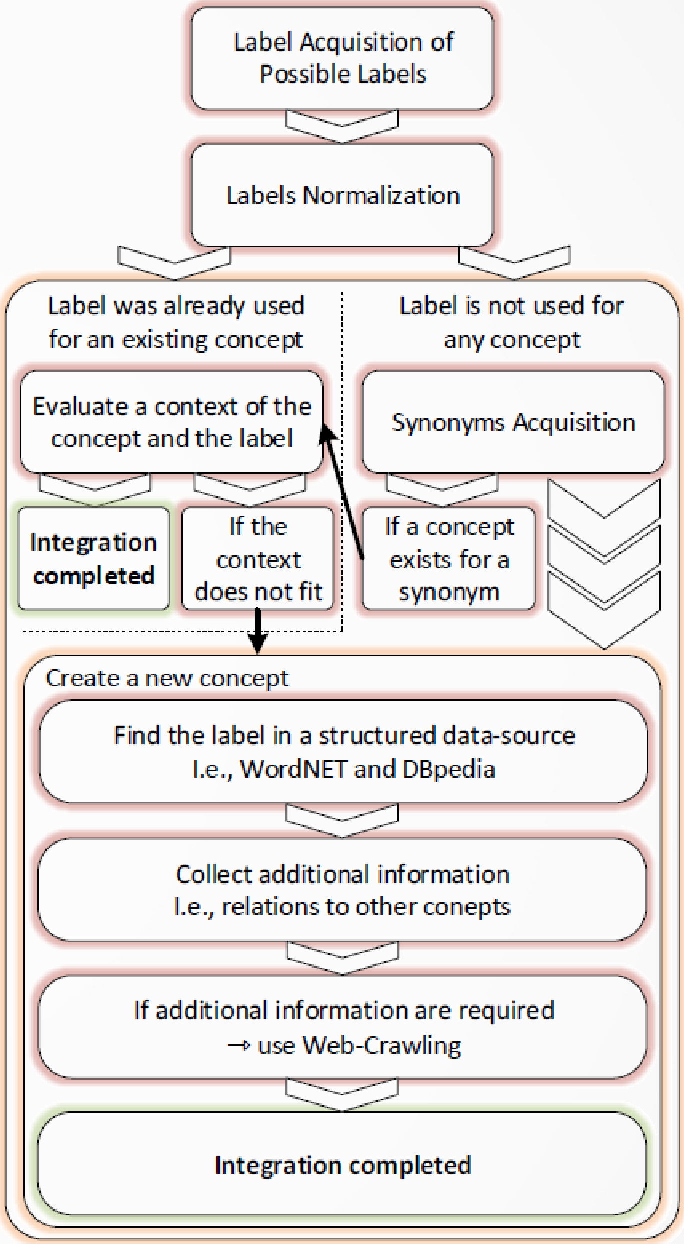
Proposed approach

- Use web mining to find correct translation of the spare part label.
- Define specialized concepts.
- Define general concepts using DBpedia and WordNet.
- Find relations between specialized concepts and general concepts using web mining.



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Concept name

- Search permutations of full label and count occurrence in web documents.
- Most frequent combination is used as the correct spare part label.
- E.g., SE CSHAFT RR OIL = Crankshaft rear oil seal

Semantic relations

- Search lexico-syntactic patterns in web documents to find semantic relations between the specialized concept and general concepts.
- *Meronymy*: within, part of, …
- *Holonymy*: consists of, have, with, …
- *Hypernymy*: is a, is typically a, …
- *Hyponymy*: called, like, …

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Examples

- Main bearing: … *most engines have at least two main bearings…* → holonymy
- Impeller: *Impeller is a rotating component of a centrifugal pump…* → meronymy
- Oil filter: *The overpressure relief valve is frequently incorporated into the oil filter.* → meronymy
- Crankpin: *A crankpin or crank journal is a journal in an engine…* → meronymy, hyponymy

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Production Monitoring

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Production Monitoring

- Definition – a transformation of observations into a state (product) classification
- Depends on many factors (e.g., sampling rate of sensors, quality of their output, etc.)
- Influences (or part of) various processes and systems
  - Scada, MES, ERP
  - Monitoring of KPIs
  - Diagnostics

Semantic Web Technologies for Production Monitoring

- Utilization of
  - Web Ontology Language
  - Reasoning
  - Semantic Web Rule Language
- Production monitoring task
  - Transformation of observations (a given individual) into a corresponding concept
  - Recognize and classify a (semi-)product (as well as situation) in some “level of completeness”
  - Be able to determine subsequent operations, etc.

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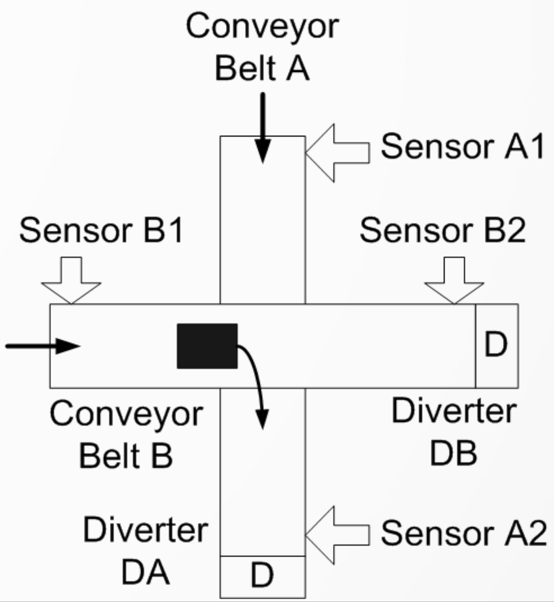
Production Monitoring Reasoning

- Reasoners are able to classify individuals into suitable and corresponding concepts
- Benefit – no additional tool and description are needed
  - Only definition in OWL and reasoner
- Restrictions
  - Close-World vs. Open-World reasoning
  - → Proper definition of ontology axioms is needed
    - Closures are needed

Production Monitoring Reasoning

- Example
  - Sensors
    - At the beginning and the end of the conveyor belts
  - Stolen workpieces from conveyor
  - New workpieces on the conveyor
  - Fallen workpieces from conveyor B to A
- Monitoring Using OWL Language
  - Two approaches to monitoring
    - Detecting inconsistency (diagnostics)
    - Classification to a class

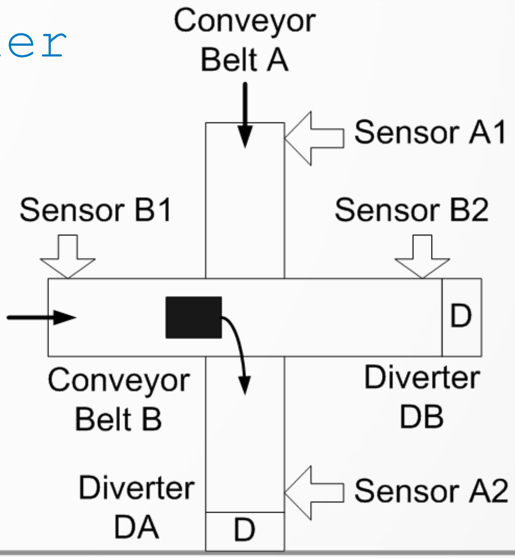


Production Monitoring Reasoning

- Monitoring of system behavior using consistency checking
  - Illustration on scenario with workpieces
    - Constraint – a workpiece is on one carrier at most

      Workpiece ⊑ ⩽ 1 isCarriedBy Carrier

    - Workpiece is carried by belt B and fells down to belt A
    - Arrival to sensor A2, update – workpiece is carried by belt A
    - Detection by a DL reasoner – e.g. Pellet

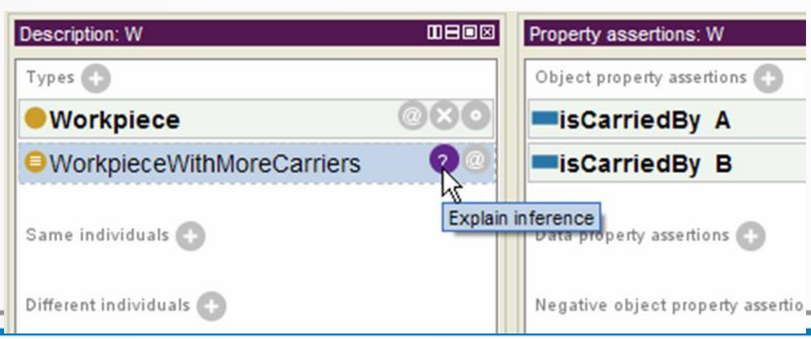


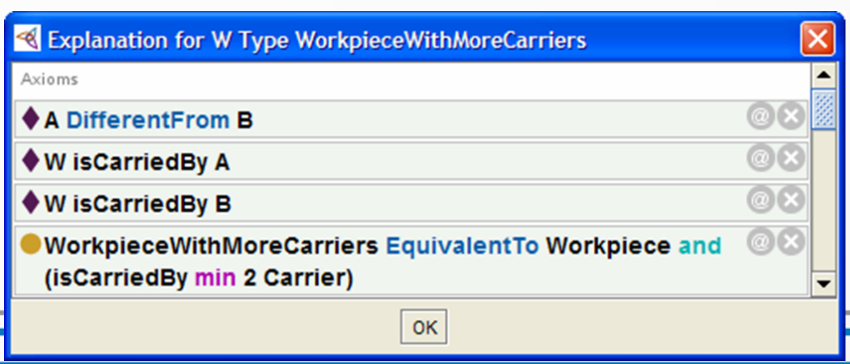
Production Monitoring Reasoning

- Monitoring of system behavior by adding special classes
  - Illustration on scenario with workpieces
    - Special class `WorkpieceWithMoreCarriers` – subclass of the `Workpiece`

$$\texttt{WorkpieceWithMoreCarriers} \equiv \texttt{Workpiece} \sqcap \geqslant 2\ \texttt{isCarriedBy Carrier}$$

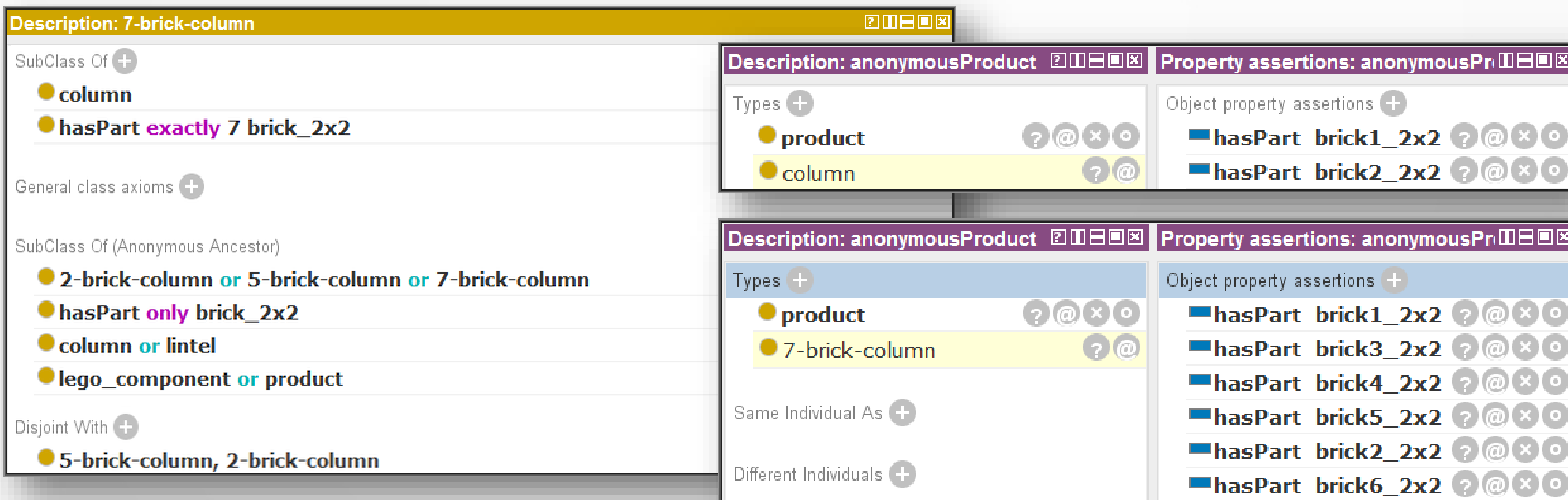
    - Production monitoring – instance of the `Workpiece` is classified by reasoner also as the `WorkpieceWithMoreCarriers`





Production Monitoring SWRL

- Open-World Assumption
  - Related to a definition of a concept using quantification of its component



Production Monitoring SWRL

- SWRL enables a “transition” from open to close world
- Example of 5-brick column

$$product(?p) \wedge brick2x2(?b) \wedge hasPart(?p,?b)$$
$$\circ\ \boldsymbol{sqwrl:makeSet(?bricks,?b)} \circ \boldsymbol{sqwrl:size(?size,?bricks)}$$
$$\wedge\ \boldsymbol{swrlb:lessThanOrEqual(?size,5)}$$
$$\rightarrow sqwrl:select(?p,?size)$$

Conclusions

- Industrial Automation companies
  - Really slow in accepting new technologies
  - Supply chain is typically not transparent
    - Obstacles for flexible manufacturing
- Big Data paradigm
  - Force companies to think about meaning of data
- HW capabilities provide means for processing huge amount of data in format of RDF triples
- Leading vendors of SW and HW understood the **importance of vertical and horizontal integration**