Robot Revolution & Industrial IoT Initiative

STANDARDIZATION COUNCIL INDUSTRIE 4.0

Hannover Messe 2026

Solution LabAutomation & Digitalization / Expert Stage 2- Hall 26, booth E43

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Germany and Japan collaboration

SCI 4.0 and RRI

Advancing Semantic Interoperability Layer as an enabler for AI-driven Manufacturing Transformation

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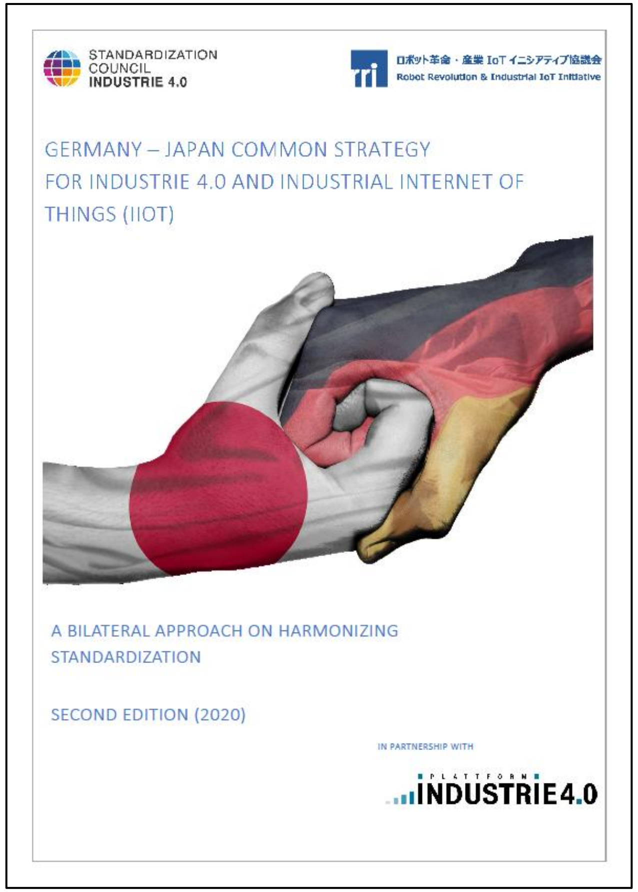
0. Overview of Germany - Japan collaboration

In 2016, Robot Revolution & Industrial IoT Initiative (Japan) and Plattform Industrie 4.0 (Germany) have agreed to cooperate on standardization in the field of smart manufacturing.

IIoT/Industry 4.0 requires an unprecedented degree of system integration across domain borders, hierarchy borders and life cycle phases.

It is critical to consider the standardization as a basis for open and interoperable system architecture for industrial implementation of the vision of Smart Manufacturing.*

This presentation is based on the Germany – Japan collaboration for advancing semantic interoperability In smart manufacturing.


STANDARDIZATION COUNCIL INDUSTRIE 4.0
ロボット革命・産業IoTイニシアティブ協議会
Robot Revolution & Industrial IoT Initiative

GERMANY – JAPAN COMMON STRATEGY FOR INDUSTRIE 4.0 AND INDUSTRIAL INTERNET OF THINGS (IIOT)

A BILATERAL APPROACH ON HARMONIZING STANDARDIZATION

SECOND EDITION (2020)

IN PARTNERSHIP WITH

PLATTFORM INDUSTRIE 4.0

*: Germany – Japan common strategy for industrie 4.0 and industrial internet of things (IIOT) (https://www.jmfrri.gr.jp/document/library/1650.html)

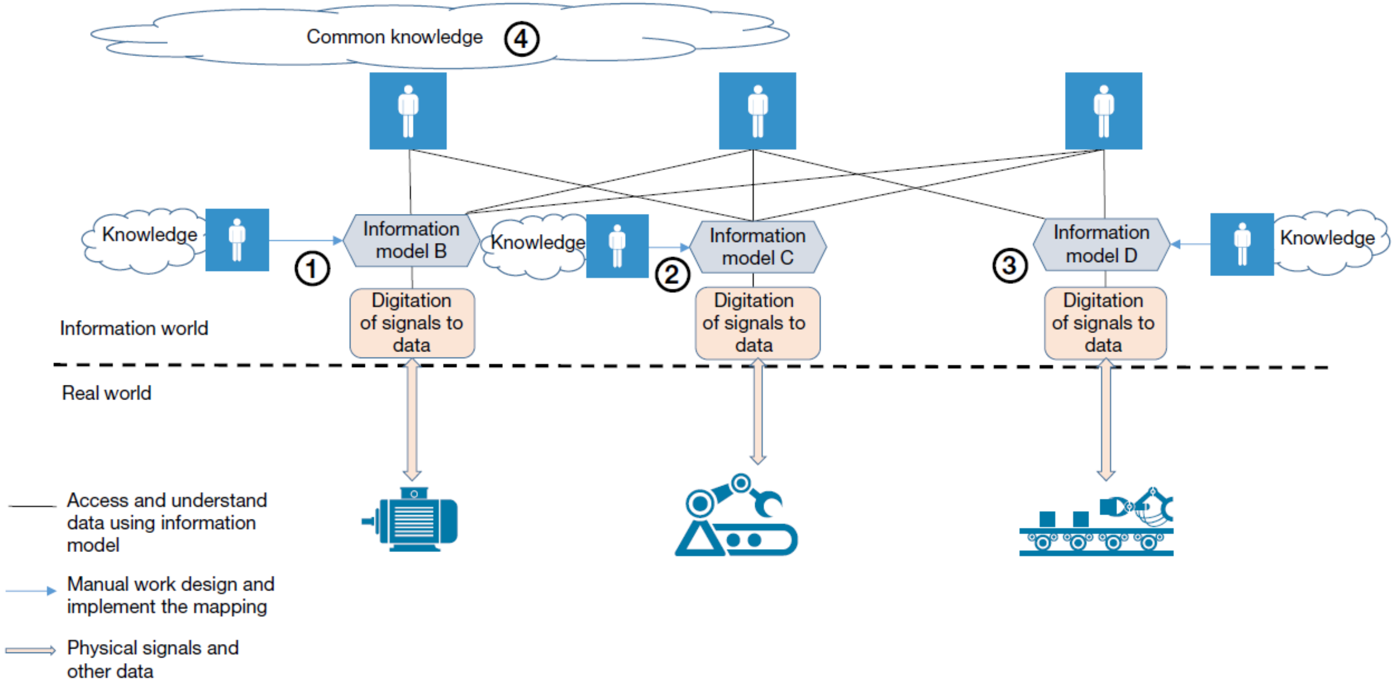
1. Introduction: Background

Cross-domain data exchange becomes increasingly important in smart manufacturing.

Ontologies for information models play an essential role for semantic information sharing.

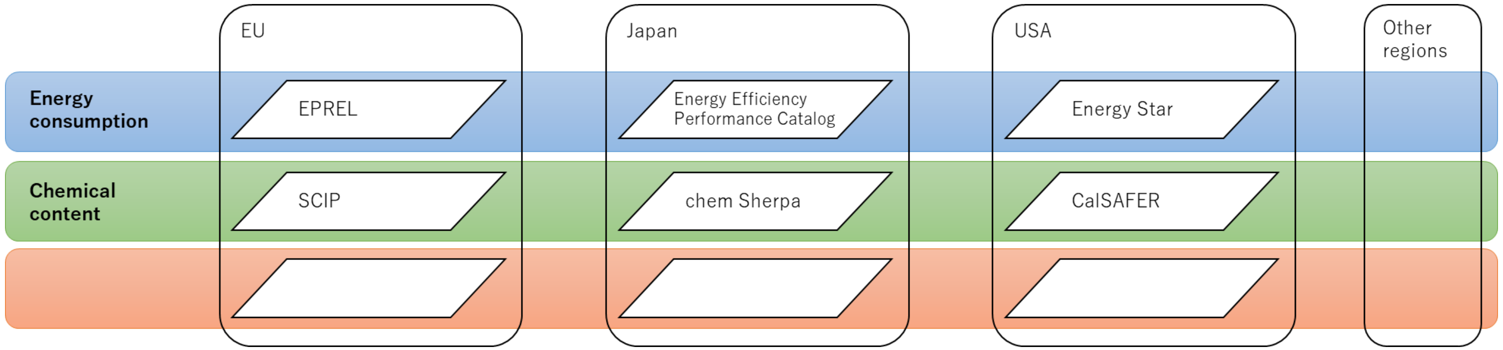
However issues of comprehensive semantic information sharing in dynamically evolving industrial environment are not well recognized and understood.

Different concepts based on different knowledge result in different information models *



*: IEC White paper: Semantic interoperability: challenges in the digital transformation age, 2019.

Semantic information sharing in dynamically evolving industrial environment in different regions



Can we establish a global single point of truth for globally interoperable data ecosystems?

X, Y ···Z

Collection of data points for application specific Use Cases → e.g. as submodel template for AAS

X+a,b,c

Country A

Country (region) specific legal requirements for DPP-Data

…

X+m,n

Country N

Country (region) specific legal requirements for DPP-Data

International standardized semantics for unambiguous description of data points.
This could be done at
- recognized standardization bodies → IEC + ISO CDD
- consortia → e.g. ECLASS

International standards describing requirements on the technological base layer (system). E.g.:
- IEC 63278-series on AAS
- IEC 61360-1 describing information model of Common Data Dictionary (CDD)
- …

1. Introduction: Objective

Extensive works are now in progress in smart manufacturing standardization community for semantic information sharing, where semantics is often treated as static, like fixed dictionary definitions. However, in dynamic and heterogeneous industrial reality, it should be viewed as a dynamic process that evolves with new properties and functions. In smart manufacturing, enabling cross-domain information flow requires a flexible framework where multiple domain-specific dictionaries can coexist and interoperate.

For aiming to cope with the situation above, the objective of this presentation is to discuss:

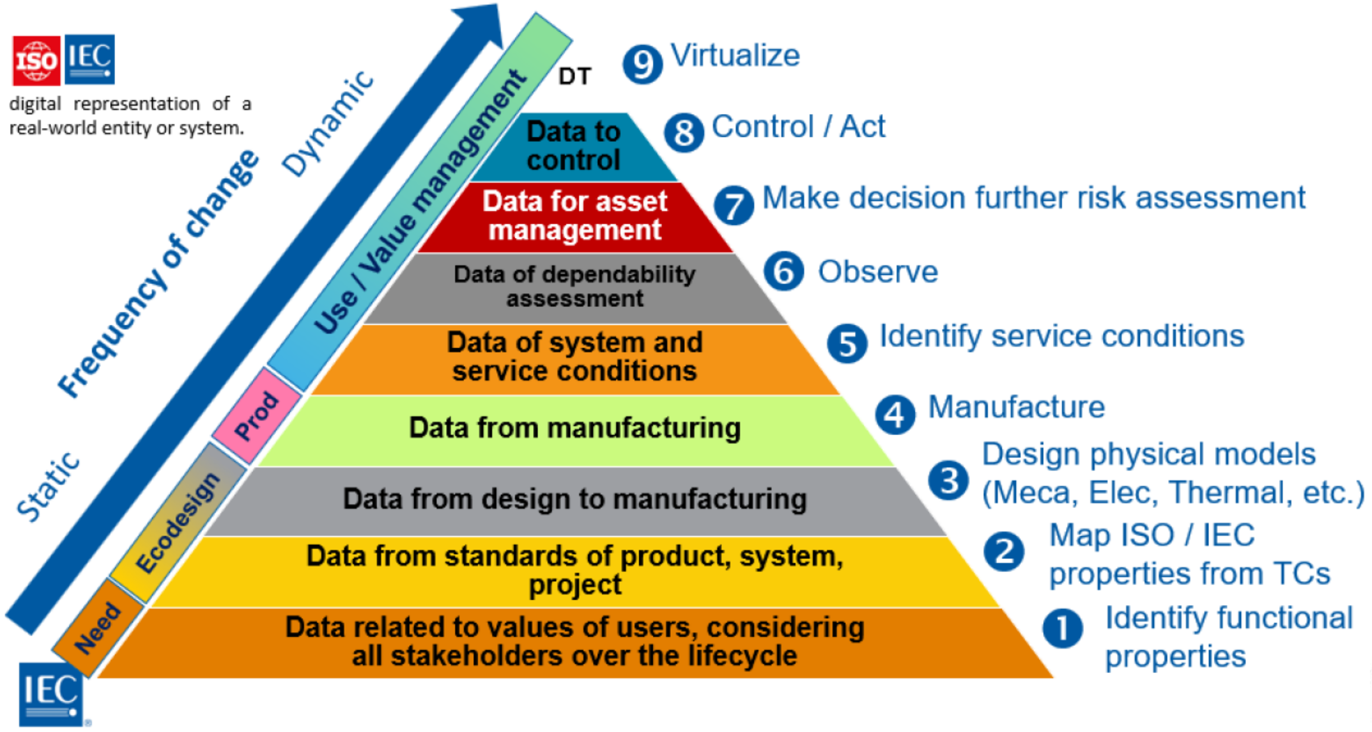
- fundamental challenges in semantic interoperability,
- proposed framework for designing toward flexibility, extensibility and coexistence,
- appropriate use of AI capabilities and governance.

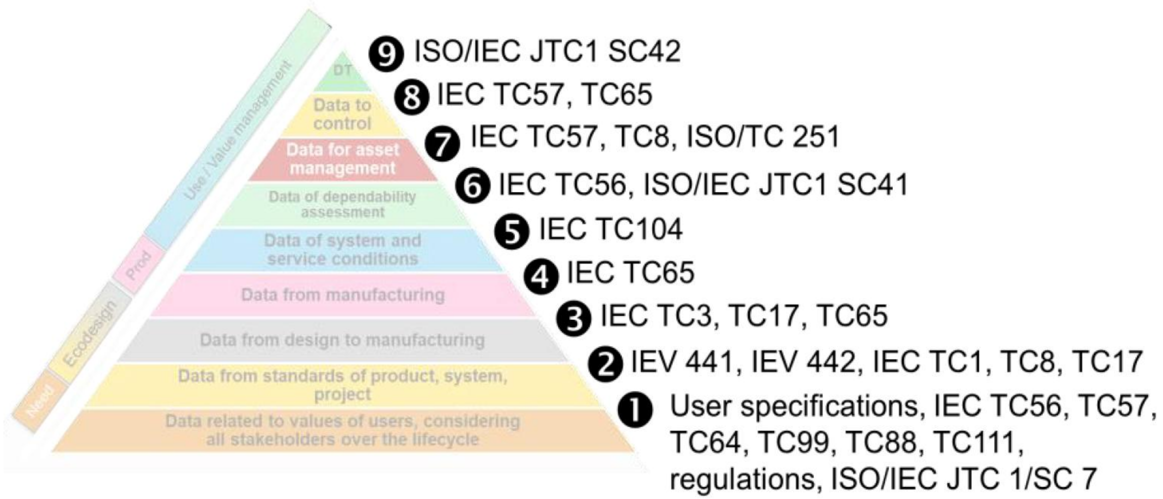
2. Fundamental Challenges in Semantic Interoperability

1. Dynamic and evolving dictionaries
    - Domain diversity
    - Regional and regulatory variations
    - Continuous evolution of technologies
2. Fragmentation and growth of domain-specific dictionaries
    - Coexistence of local models
    - Convergence of technologies and IT/OT integration
    - Legacy knowledge as industrial assets
3. Standardized interoperability in processes and accessibility
    - Mapping inconsistency
    - Controlled accessibility
    - Organizational and legal hurdles

3. Proposed Framework: Designing for Flexibility, Extensibility, and Coexistence

Shifting from static dictionaries to dynamic processes is crucial for semantic interoperability in AI-driven manufacturing transformation





Source of drawings: Presentation of Thierry Cormenier, FR, to the IEC SyC WG3 TG1 & TG4 (2026-03-13)

3. Proposed Framework: Why standardization? Advantages of using a standardized system

Freight traffic **previously**: Different freight formats

Loading break-bulk cargo at the Port of New Orleans, early 20th century. Source: Port of New Orleans (historical photograph), Public Domain.

- Individual packaging for transport
- No fixed formats, which means that a lot of preparation and space is needed
- Variations depending on the type of ship and shipping
- High transportation costs

Standardization

Freight traffic **today**: Standardized containers

By Petar Milošević - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=144715351

- Standardized format
- Only one defined interface system
- Covers multiple manufacturers
- Consistent process
- Significant reduction of transportation costs

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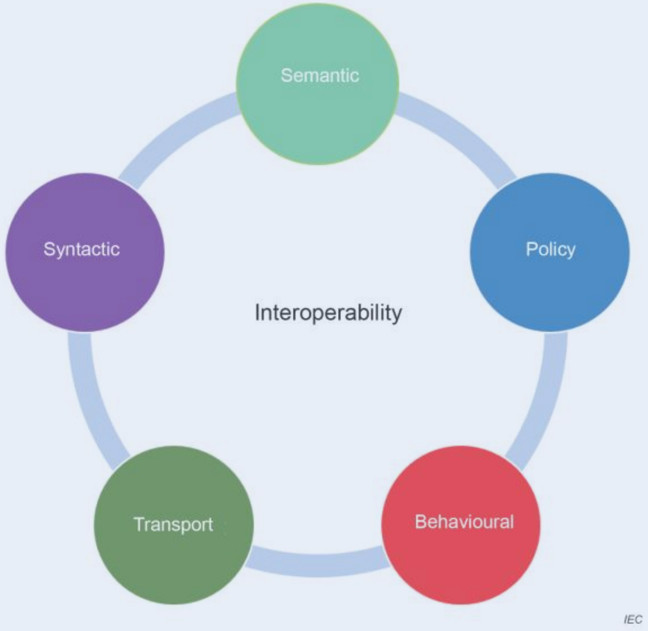
3. Proposed Framework: Semantic interoperability is one of the key enabler for digital transformation



Source: ISO/IEC 21823-1:2019

Semantic is focusing on one of the main aspects of interoperability

Facets	Aim	Objects	Requirements	Examples
Transport	Data transfer between systems	Physical connections Signals	Protocols of data transfer	HTTP/S, MQTT
Syntactic	Receive data in an understood format	Data	Standardized data exchange formats	JSON, XML, ASN.1
Semantic	Receive data using an understood data information model	Programmatic interface	Common interpretation of data information model	Directories, data keys, ontologies
Behavioural	Obtain expected outcomes to interface operations	Information	Behavioural model(s) of the invoked IoT entity	UML models, pre- and post-conditions, constraint specifications
Policy	Assurance that interoperating systems follow applicable regulatory and organizational policies	Regulatory and organizational polices and interoperation context	Conditions and control for use and access	Security policies of IoT system stakeholders, restriction on cross-border data transfer, regulations controlling PII

Source: ISO/IEC 21823-1:2019

3. Proposed Framework: Compare different standards and definitions for coexistence

Both standards comes from different directions:

Technical view vs. Governance view

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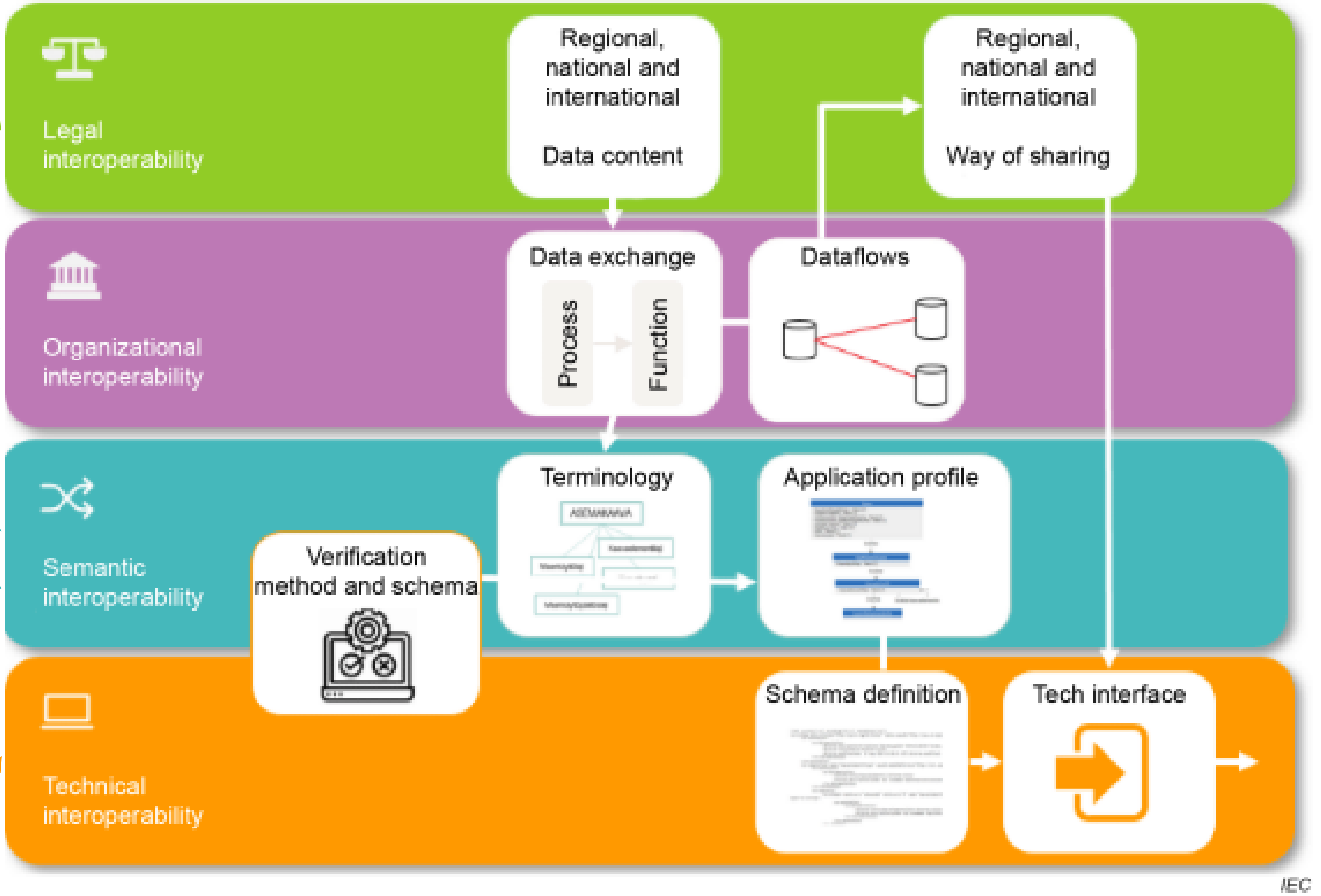
Source: ISO/IEC 21823-1:2019

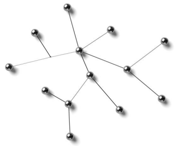
European Interoperability Framework (EIF)



Source: IEC SRD 63417:2025-06 Guidance and plan to develop smart energy ontologies
https://ec.europa.eu/isa2/eif_en/

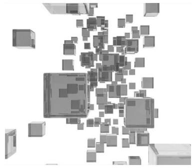
3. Proposed Framework: Flexibility, Extensibility, Coexistence

Extensible and Modular Dictionary Architecture (3.1)



- Modular dictionary architecture: Core vocabulary and extensions
- Interoperability through shared core semantics
- Controlled namespace management
- Forward compatibility
- Clear terminology to ensure consistent understanding across humans, systems, and AI models.
- **FAIR** principles for all semantic assets

Property Management and Versioning Strategy (3.2)



- Property-oriented modeling
- Strict property versioning and governance rule
- Clearly distinguishing between initial values and default value
- Flexible storage strategies

Semantic Interoperability Layer (with Flexibility & Coexistence)

Federated Semantic Model (3.3)

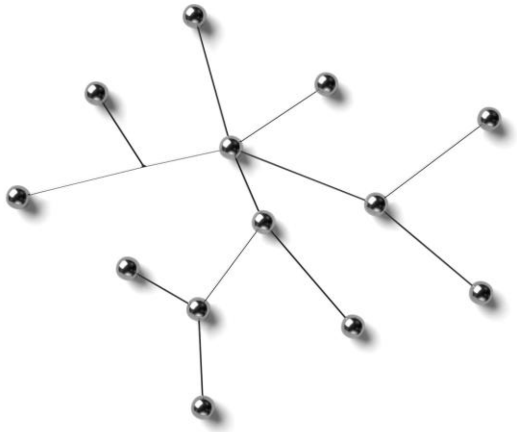
- Principle of Coexistence as the foundation of a federated semantic interoperability layer
- Harmonization through reuse international standards, mappings and semantic bridges
- Positions versioned properties as the primary mapping units
- Uses global reference ontologies or top-level ontologies as pivots
- Aligns with current industrial and regulatory initiatives (e.g., DPP, CIRPASS-2, IEC/ECLASS alignment)
- Bridging diverse models with global reference points and top-level ontology support (ISO/IEC 21838-series)

Standardized Interoperability Process Model (3.4)

- Repeatable, governed workflows
- Formalizes discovery and validation, and governance of semantic assets across their lifecycle.
- AI- and software-driven interoperability
- Trust, and access control
- Changes in one layer shall be reflected in all other layers

3. Proposed Framework: Flexibility, Extensibility, Coexistence

Extensible and Modular Dictionary Architecture (3.1)



- Modular dictionary architecture: Core vocabulary and extensions
- Interoperability through shared core semantics
- Controlled namespace management
- Forward compatibility
- Clear terminology to ensure consistent understanding across humans, systems, and AI models.
- **FAIR** principles for all semantic assets (**Findable, Accessible, Interoperable, Reusable)**

3. Proposed Framework: Flexibility, Extensibility, Coexistence

Property Management and Versioning Strategy (3.2)

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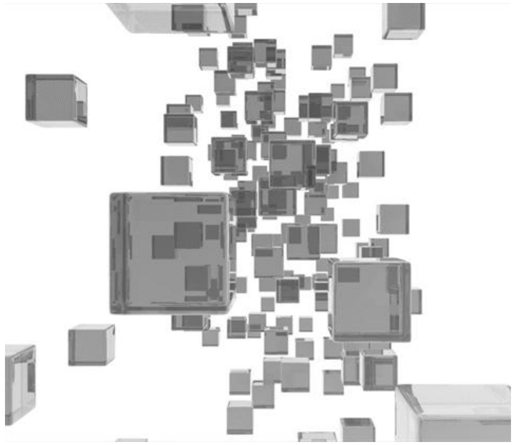

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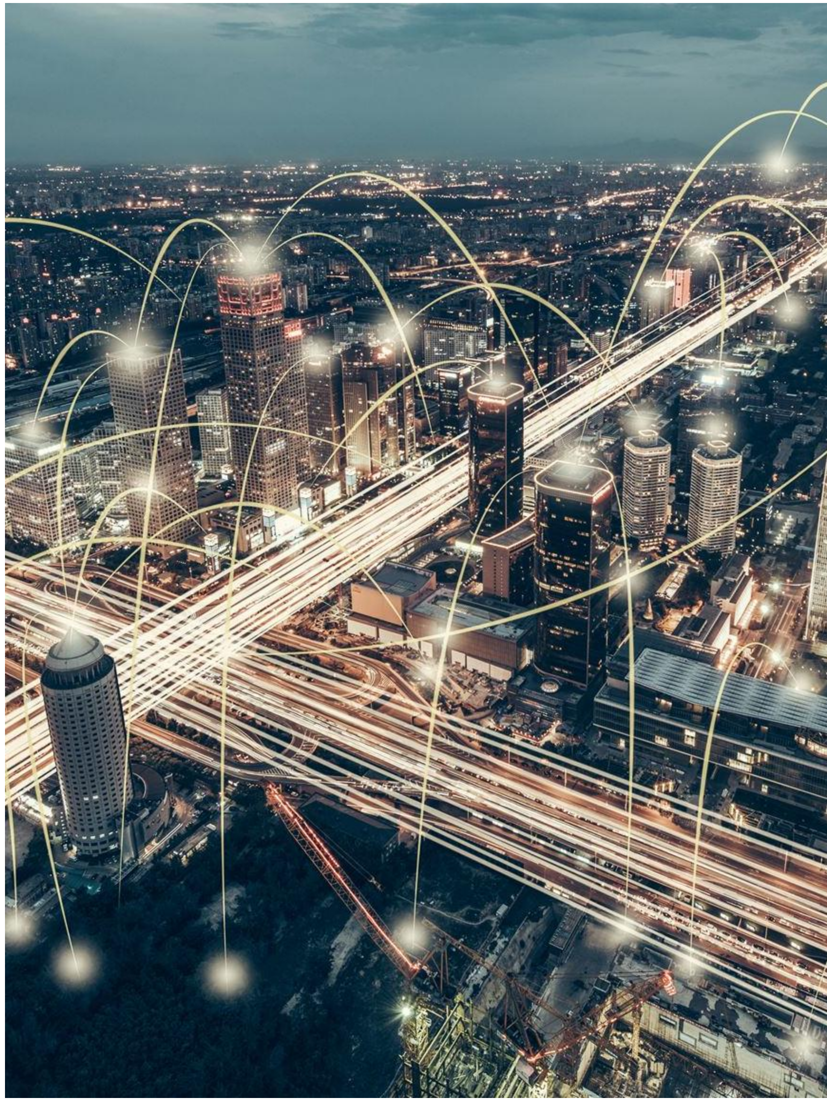
4. Duality of Artificial Intelligence and Semantics: Empowering and Empowerment

- **Importance of Semantic Interoperability**
  Semantic interoperability is essential for AI-driven manufacturing, ensuring machine-interpretability and preventing errors.
- **AI Supports Semantic Management**
  AI leverages handling semantic complexity by identifying inconsistencies, unambiguity, and semantic heterogeneity in federated ecosystems.
- **Governed AI Usage**
  Strong need for governing AI by means of transparency, trustworthiness, reliability, provenance, and traceable semantics with strict version control to meet strong industrial requirements.
- **Coexistence and Governance**
  Multiple semantic models will coexist, requiring explicit mappings, (semi-)automatic translation for correctness, safety and compliance.



5. Summary and conclusion

This presentation discusses:

- fundamental challenges in semantic interoperability,
- proposed framework for designing toward flexibility, extensibility and coexistence,
- appropriate use of AI capabilities and governance.

A team of German and Japan experts plan to work on the identified issues, the proposed framework and appropriate use cases for promoting industrial involvement and practical validations in real industrial situations.

Thank you for your attention

Danke für Ihre Aufmerksamkeit

ご清聴ありがとうございました

The discussion paper will be published on May 20th 2026. You can download it via the QR code below.

https://www.jmfrri.gr.jp/library-english/advancing-semantic-interoperability-layer-as-an-enabler-for-ai-driven-manufacturing-transformation/