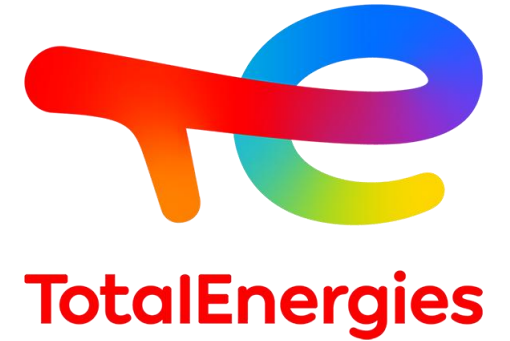
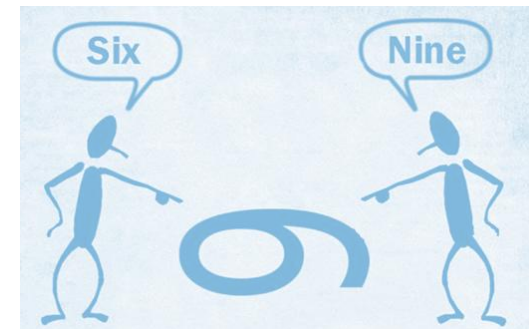




From Formal Ontologies to Real-World Impact

Industrial lessons learned in semantic knowledge modeling

Jean-Charles LECLERC | Innovation & Standards Lead
OneTech, Digital Line: Data & Digital Technologies
TSF (TotalEnergies Semantic Framework)



*graphs don't create meaning ...
... ontologies do.*



DNV

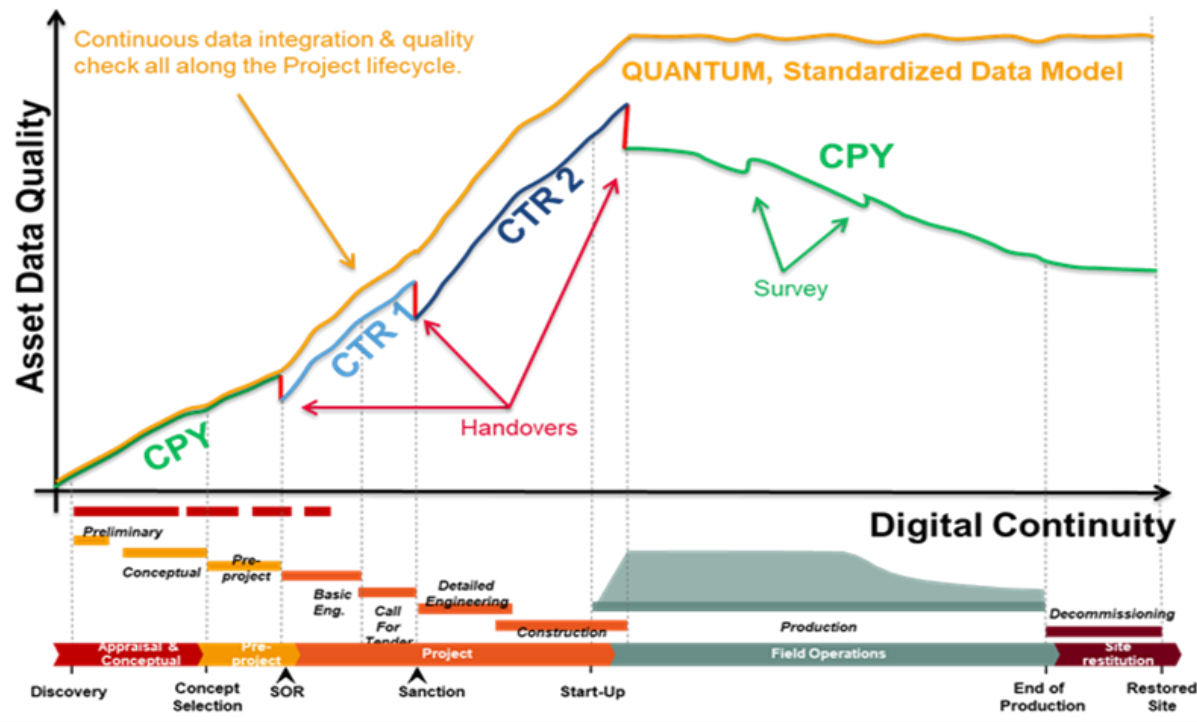
Industrial semantic “interoperability” summit 2026

Oslo Tuesday 9th of June, 2026



TotalEnergies

TOTAL'S “DIGITAL TWIN” CONTINUITY



The problem:
today we often confuse
composition and typology
(classification & serialization)

But no one of those mechanisms can guarantee the “*meaning*”

... most industrial data models organize *things* ...

... very few explain what *things* are ...

“The challenge is preserving shared meaning across systems and over time.”



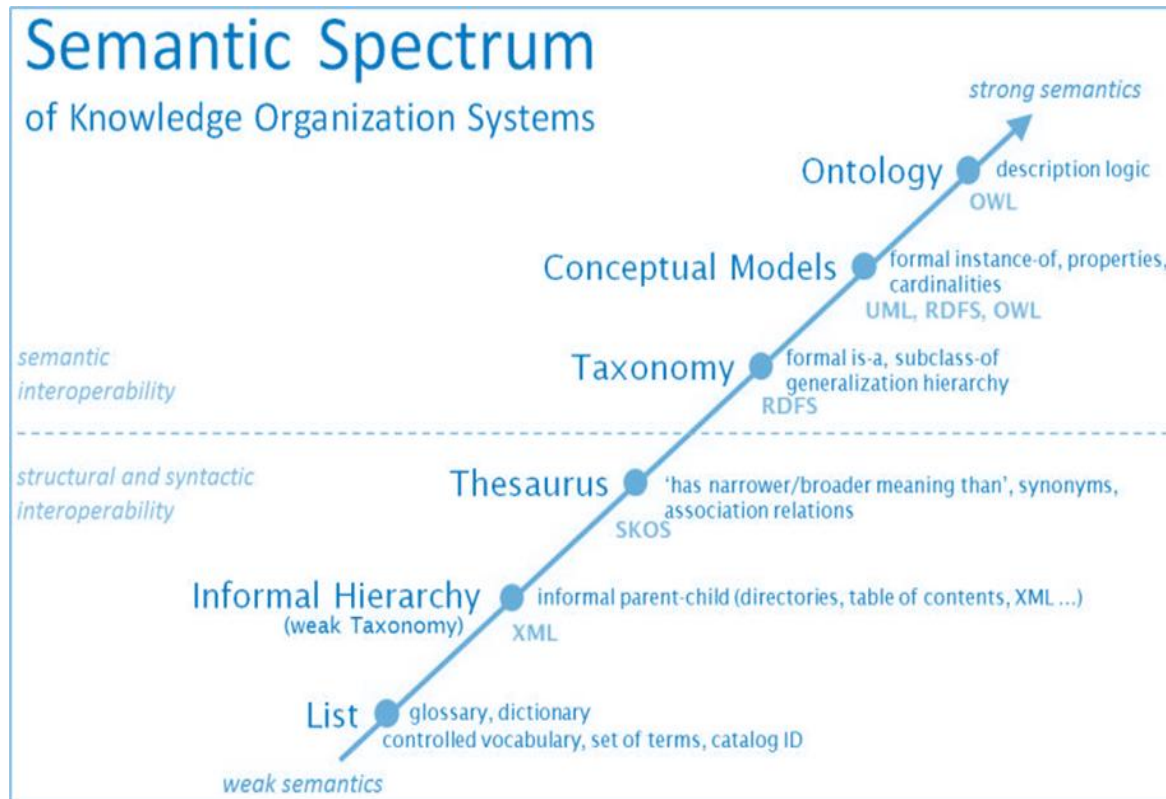
International Industrial Ontologies Workshop, Oslo 02/02/2019, J.-C. Leclerc

From data to knowledge : a strategic shift industry should care

... “we still don’t share meaning” ...

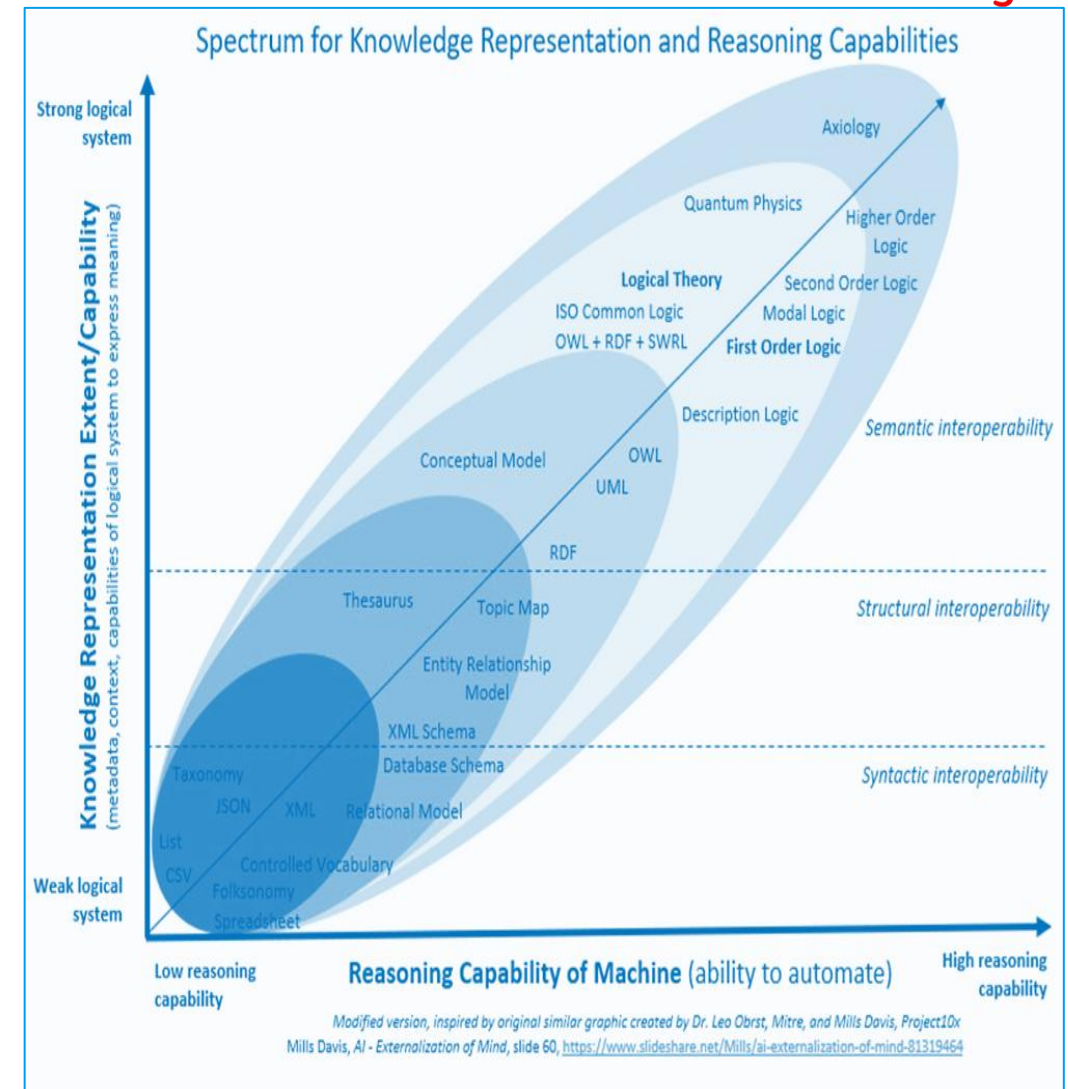


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Semantic Interoperability as a Strategic Capability

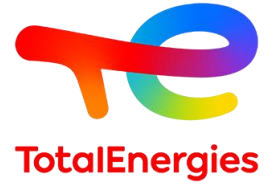
- Data fragmentation limits operational efficiency and scalability
- Classical integration approaches reach structural limits
- Semantic interoperability becomes a **strategic industrial asset**



The real problem is **loss of shared meaning**

Why a formal ontology ?

Axioms make knowledge operational



Semantics ≠ structure

- The key differentiator is not the graph itself, but the **formal semantics** underneath it. This is what makes knowledge computable, verifiable, and reusable across systems.
- Formal axioms provide explicit constraints and relationships between entities, enabling consistency checking, inference and true interoperability.
- This is why rigorous semantics is a prerequisite for real interoperability.

Axioms make knowledge operational

- ✓ Explicit constraints between entities
- ✓ Consistency checking
- ✓ Inference and reasoning
- ✓ Cross-system interoperability

Without formal semantics, a graph is just a map without rules

Axioms example for a « supplying business process » Class (IOF ontology)

Node info : supplying business process

Infos Axioms Properties MetaData

UUID <https://spec.industrialontologies.org/ontology/construct/SupplyingBusinessProcess>

GRAPH <https://spec.industrialontologies.org/ontology/core/Core/>

subClassOf	https://spec.industrialontologies.org/ontology/construct/BusinessProcess
type	http://www.w3.org/2002/07/owl#Class
label	en-us supplying business process
isDefinedBy	https://spec.industrialontologies.org/ontology/core/Core/
adaptedFrom	https://www.oberio.com/e-commerce-wiki/supply
commentExample	A BMW dealer supplies a car to a Customer in the US, but the BMW Manufacturer in Germany does not supply the car to the Customer. The BMW Manufacturer supplies the car to the BMW dealer.
explanatoryNote	1. To supply a product means to deliver the product to another agent. 2. To supply a service means to perform a process (e.g. commercial service) for another agent, typically involving a service agreement. 3. It should be noted that we consciously exclude the person-to-person transactions, but person-to-business is not excluded.
firstOrderLogicAxiom	$\text{SupplyingBusinessProcess}(x) \rightarrow \text{BusinessProcess}(x) \wedge \exists y(\text{Supplier}(y) \wedge \text{hasParticipantAtSomeTime}(x,y)) \wedge (\exists p(\text{MaterialProduct}(p) \wedge \text{hasParticipantAtSomeTime}(x,p)) \vee \exists c(\text{CommercialService}(c) \wedge \text{occurentPartOf}(x,c)))$
isPrimitive	1
naturalLanguageDefinition	en-us business process wherein a product or service is supplied
primitiveRationale	There are insufficient constructs to create necessary and sufficient conditions. Namely, constructs for economic transactions, service or product provision and ownership are lacking
semiFormalNaturalLanguageAxiom	if x is a 'supplying business process' then x is a 'business process' that 'has participant at some time' some 'supplier' and x 'has participant at some time' some 'material product' or is 'occurent part of' some 'commercial service'
example	en-us BMW dealer supplies a car to the Customer; US importer of steel from China supplies the steel to a US manufacturer; company (supplier) supplied (ship directly) a product to a buyer who bought the product on Amazon (seller)

Class hierarchy

- entity
 - occurent
 - process
 - planned process
 - business process
 - supplying business process

Restrictions

onProperty	constraint	targetClass
has participant at some time	someValuesFrom	supplier



Being a BFO / IOF **Process** imply Ontological Commitments ... :

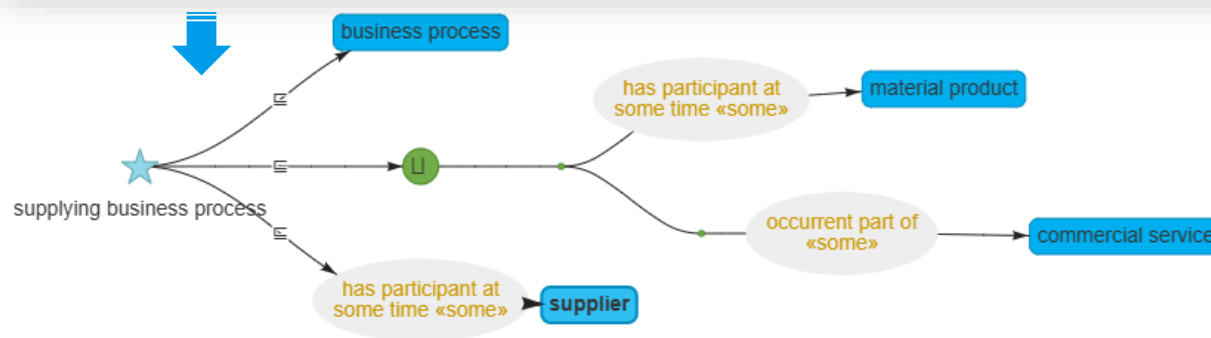
Process

- Every process instance must have something that realizes it
- Every process instance must have something that participates in it.
- Processes are extended over time, so they must have at least two occurrent parts.
- Every process has at least a starting process boundary. Optionally, they have ending process boundaries.
- Every process instance occupies some one-dimensional temporal region.

Process Boundary

- Every process boundary is occurrent part of some process.
- Every process boundary occupies some zero-dimensional temporal region.
- Every process boundary must precede at least one occurrent that is an occurrent part of the process it is the boundary of.

...



Key formal patterns to drive our governing principles structuring rules

New axiom copy triples delete triples

Class: supplying business process

SubClassOf:

business process,
has participant at some time some supplier,
(has participant at some time some material product) or (occurent part of some commercial service)

SupplyingBusinessProcess

<https://spec.industrialontologies.org/ontology/construct/SupplyingBusinessProcess> <http://www.w3.org/2000/01/rdf-schema#subClassOf> <https://spec.indus>

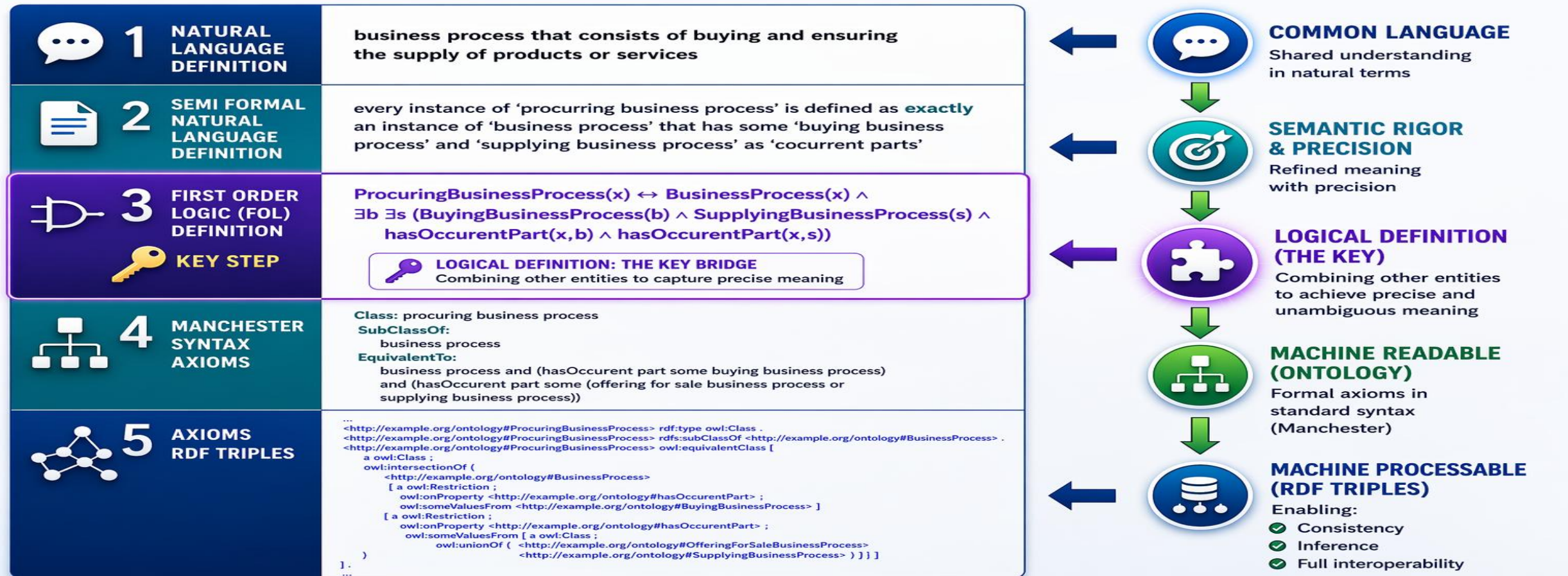
<https://spec.industrialontologies.org/ontology/construct/BusinessProcess> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.w3.org/2002/07/ow>

<https://spec.industrialontologies.org/ontology/construct/SupplyingBusinessProcess> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.w3.org/2002/07/ow>

<https://spec.industrialontologies.org/ontology/construct/SupplyingBusinessProcess> <http://www.w3.org/2000/01/rdf-schema#subClassOf> <http://www.w3.org/2002/07/ow>

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Axioms example for a « supplying business process » Class (IOF ontology)



FROM NATURAL LANGUAGE TO MACHINE-READY KNOWLEDGE
A SEMANTIC PIPELINE FOR INTELLIGENT SYSTEMS



CONSISTENT



INTELLIGENT

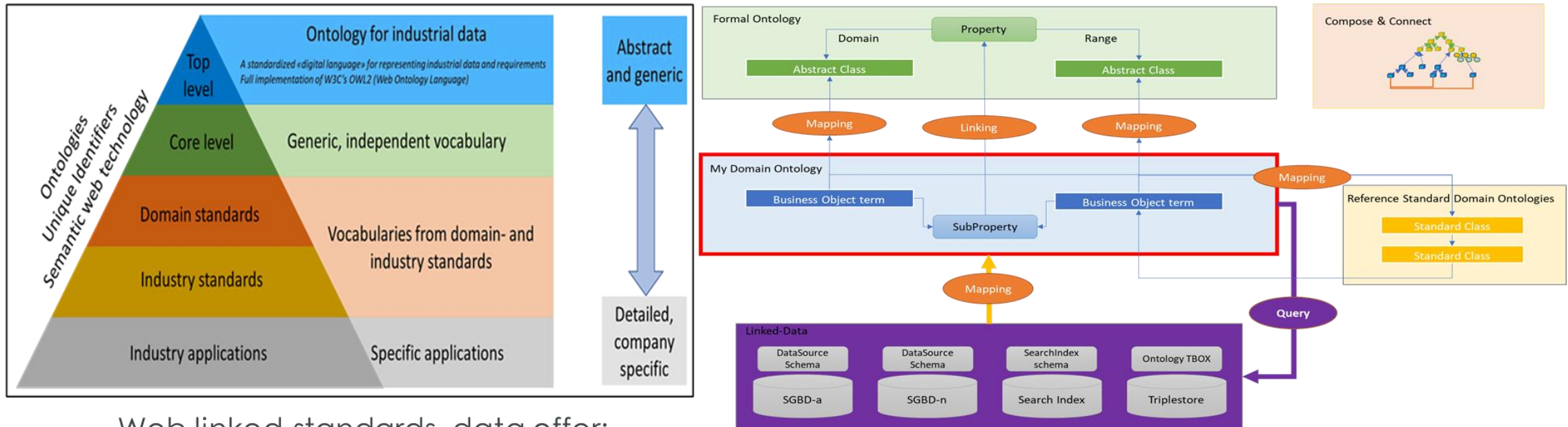


INTEROPERABLE

How do we methodologically implement this ?

“BFO gives a theory of reality; IOF brings it into industrial practice.”

- ✓ Using top-and-upper levels ontologies (BFO, IOF, ...) to structure any of our **data domain's knowledge**
- ✓ Mapping our sources concepts and develop SKGs
- ✓ Consistent queries and interoperability across systems

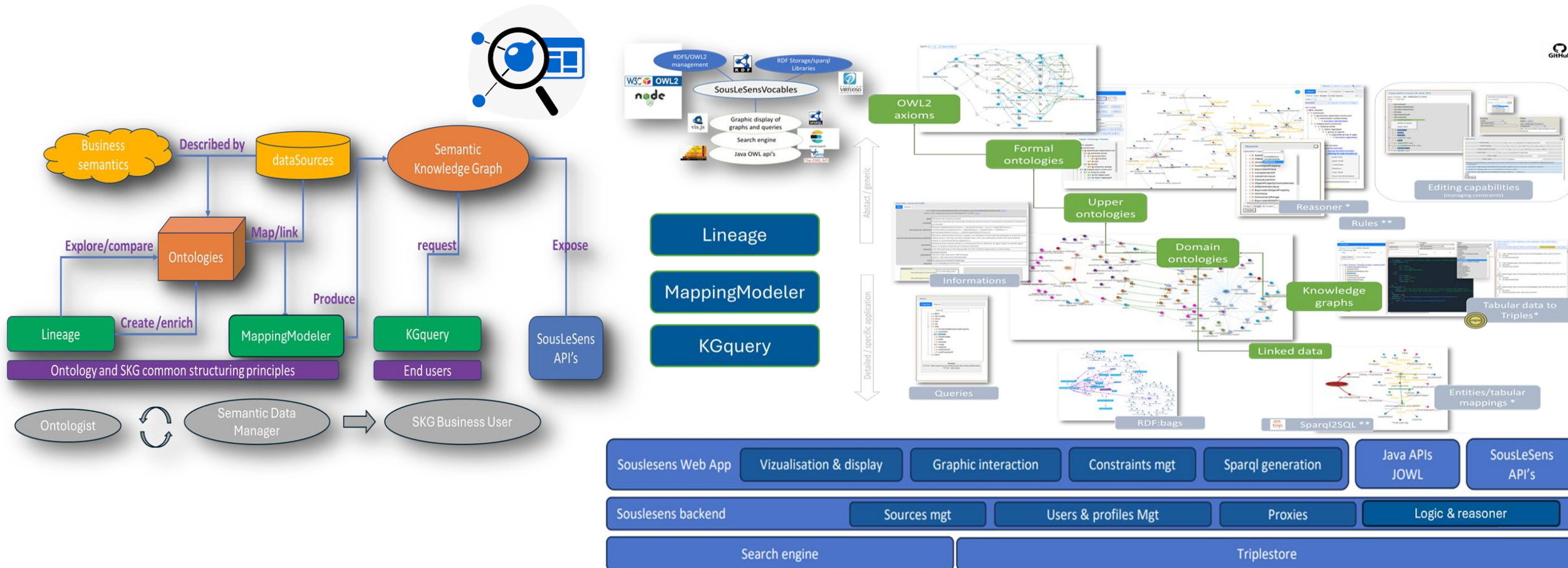


Web linked-standards- data offer:

- Each object must have a universal unique identifier (URI)
- Each object can be described thru an assembly of other objects thru semantic relationships (triples)

How do we methodologically implement this ?

SousLeSens in a Nutshell (*rdv @demos day #3*)



Fauconnet, C., Leclerc, JC., Sarkar, A., Karray, M.H. (2024). **SousLeSens** - A Comprehensive Suite for the Industrial Practice of Semantic Knowledge Graphs. In: Meroño Peñuela, A., *et al.* The Semantic Web. ESWC 2024. Lecture Notes in Computer Science, vol 14665. Springer, Cham. https://doi.org/10.1007/978-3-031-60635-9_10



How do we methodologically implement this ?

A Proven Foundation: Standards + Axiomatic Semantics

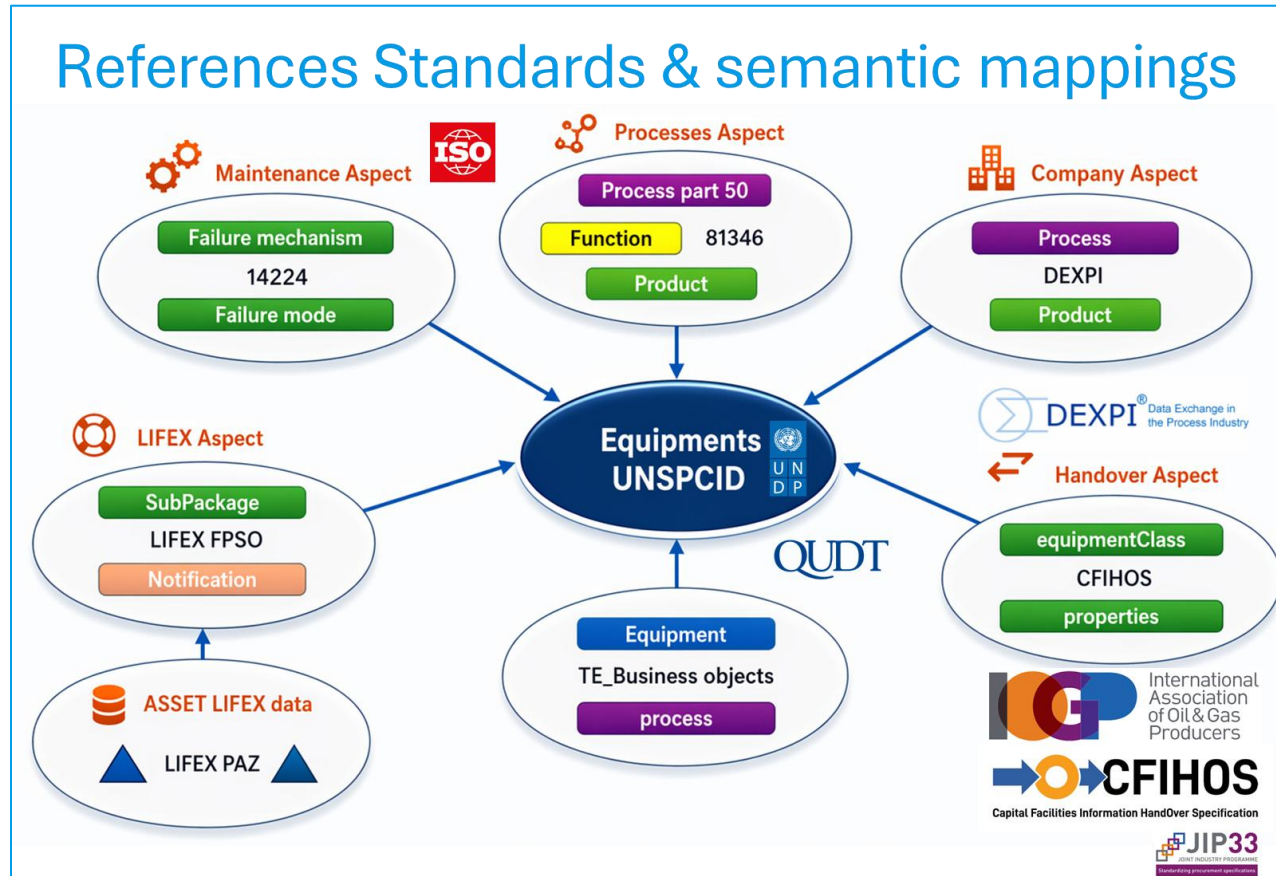
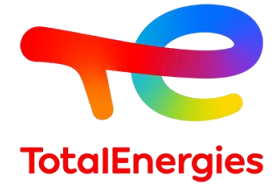
- Distinguish as foundational:
 - what persists (continuants)
 - what happens (occurents)
- Align business objects, processes and lifecycle
- Scale to **hundreds of interconnected entities (ICE)**

We deliberately adopted a **formal ontology (FOL)** stack based on **BFO (ISO 21838-2)** and industrial core ontologies such as **IOF**.

- This stack is extended through domain-specific business object models aligned with standards, taxonomies and classifications.
- It gives us what industry actually needs: a foundation to distinguish what persists, what happens, and how both relate over time.

A Strategic Choice: Standard-Based Semantic Foundation

- Adoption of **BFO (ISO 21838-2)** and **IOF** as core ontologies
- Alignment (today) with industrial standards (UNSPSC, CFIHOS, DEXPI, ISO/IEC 81346, ISO14224, ..., QUDT, W3C stack ...)
- Shift from data structures to **formal representation of reality**
- Knowledge modeled through **formal axioms (FOL)**
- Enables **consistency, scalability and AI readiness**



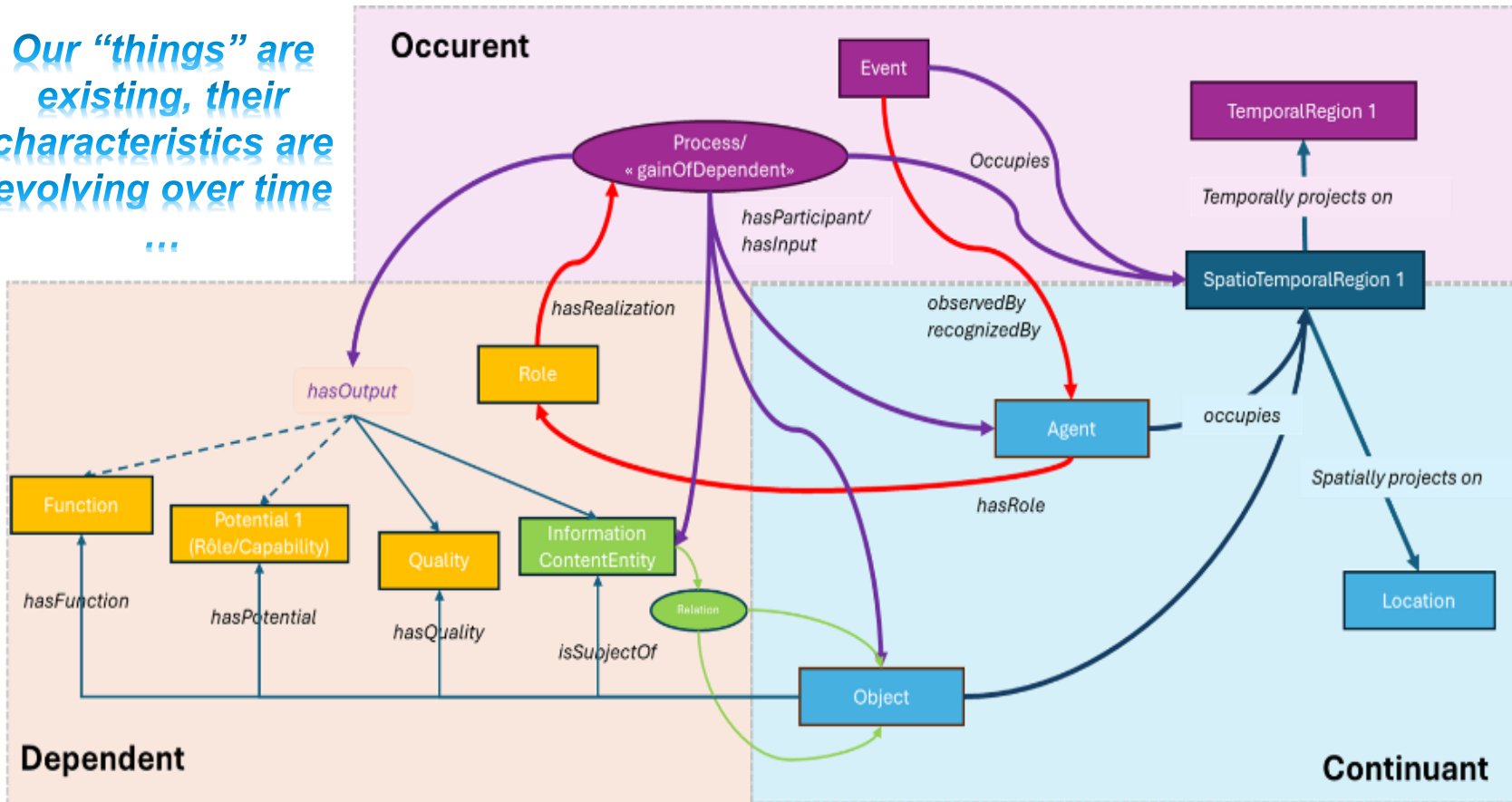
Many approaches stop at structuring data.
Our goal is to make knowledge explicit, formal and operational:

- *Connect objects, processes and lifecycle*
- *Scale to complex industrial systems*

Industrial reality is 4D

- ✓ Moving beyond static taxonomies to **dynamic semantic models**
- ✓ Concepts like '**gainOfRole**' enable to capture occurring changes
- ✓ LCI's dynamic relationships in References' Technical Domains Ontologies & SKG

Our "things" are existing, their characteristics are evolving over time



Change must be explicit, not implicit ; change is fundamental, not optional.

- Industrial **systems evolve over time** (states, events, replacements)
- We must model **occurrences**, not just definitions (Objects exist through occurrences)

Industrial systems evolve through time: installation, operation, inspection, maintenance, failure, replacement

We must model **occurrences**, not only definitions, classes or labels

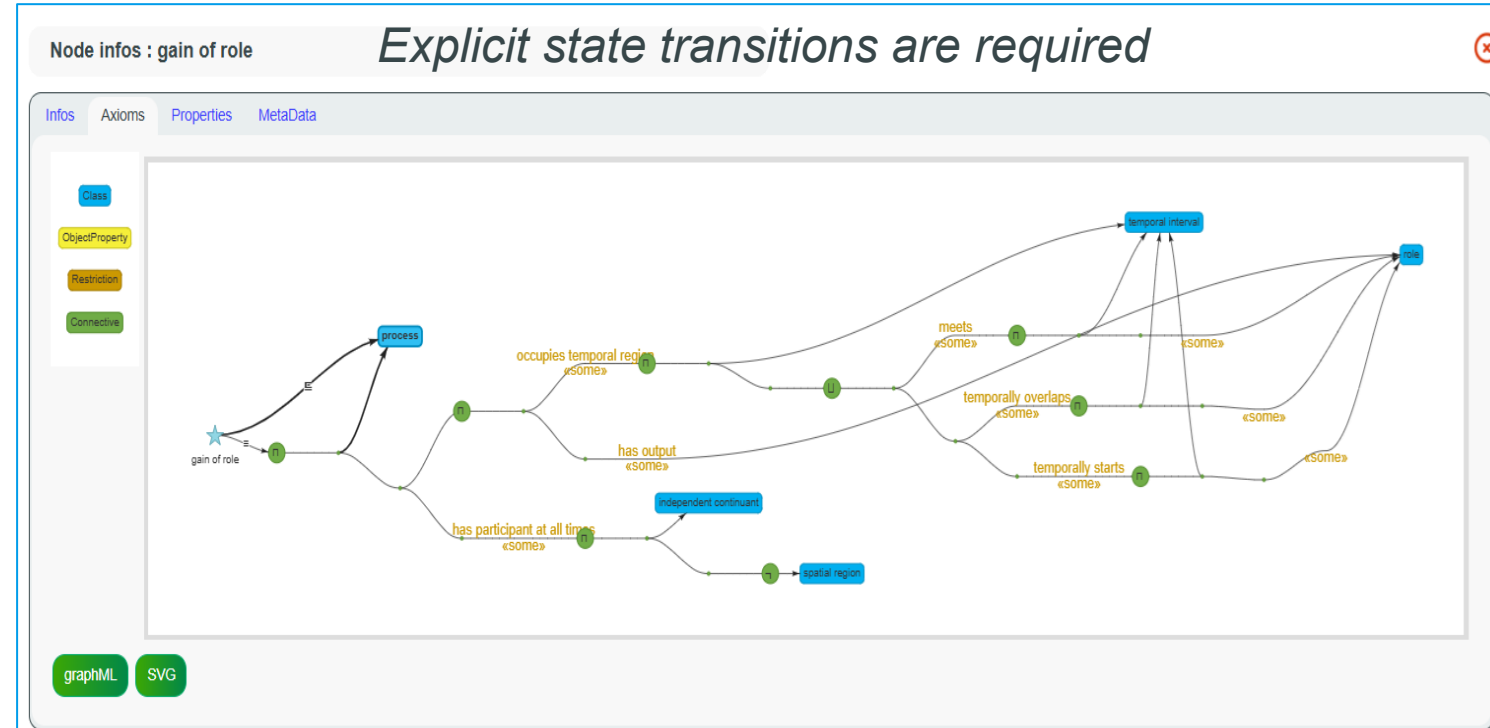
Change must be represented explicitly as part of the knowledge model

Why graphs alone are not enough ?

Graph = structure
Semantics = meaning
A graph without axioms = ambiguous interpretation

4D foundations & the « *Pattern of Changes* » *modeling change explicitly*

- Industrial reality (*is 4D !!!*) = continuity + discrete changes
- Changes must be modeled explicitly:
 - Installation
 - Operation
 - Maintenance
 - Failure
 - Repair, replacement
- Requires:
 - continuants vs occurrents
 - formal state transitions



Industrial continuity depends on the explicit representation of **state transitions**

A robust model must capture installation, modification, failure, maintenance and replacement as formal semantic patterns. Without our pattern of changes, lifecycle semantics remained partial and fragile.

Tooled' Semantic Web Governance

combining knowledge & data

*Logical Formalization of Knowledge,
Unification of Concepts*

Semantic Web

Complexity management

Semantics

**(ontologies)
OWL2**

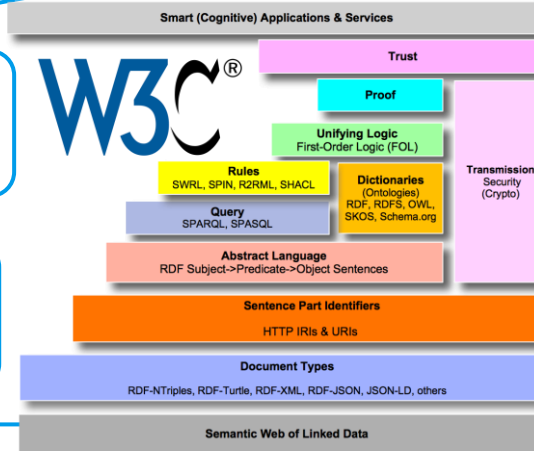
Taxonomies

Constraints

**Typing of individuals &
properties inheritance**

Axiomes

Reasoner, rules & Shacl



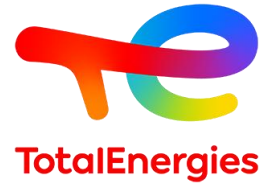
Graph

RDF RDFS

Triples stores

Sparql

From business objects to 4D entities & operations



- Business objects = **time-evolving entities**
- Connected to events, states, and history (lifecycle transitions)
- Reusable across systems and domains
- **Business objects: the concrete proof point to semantic operationalization**
- Our semantic modeling has been applied to equipment, work orders, inspections, costs and documents within a BFO/IOF-aligned OWL ontology.

Compressor → physical asset /
maintenance event / inspection report /
operational state / replacement history ...

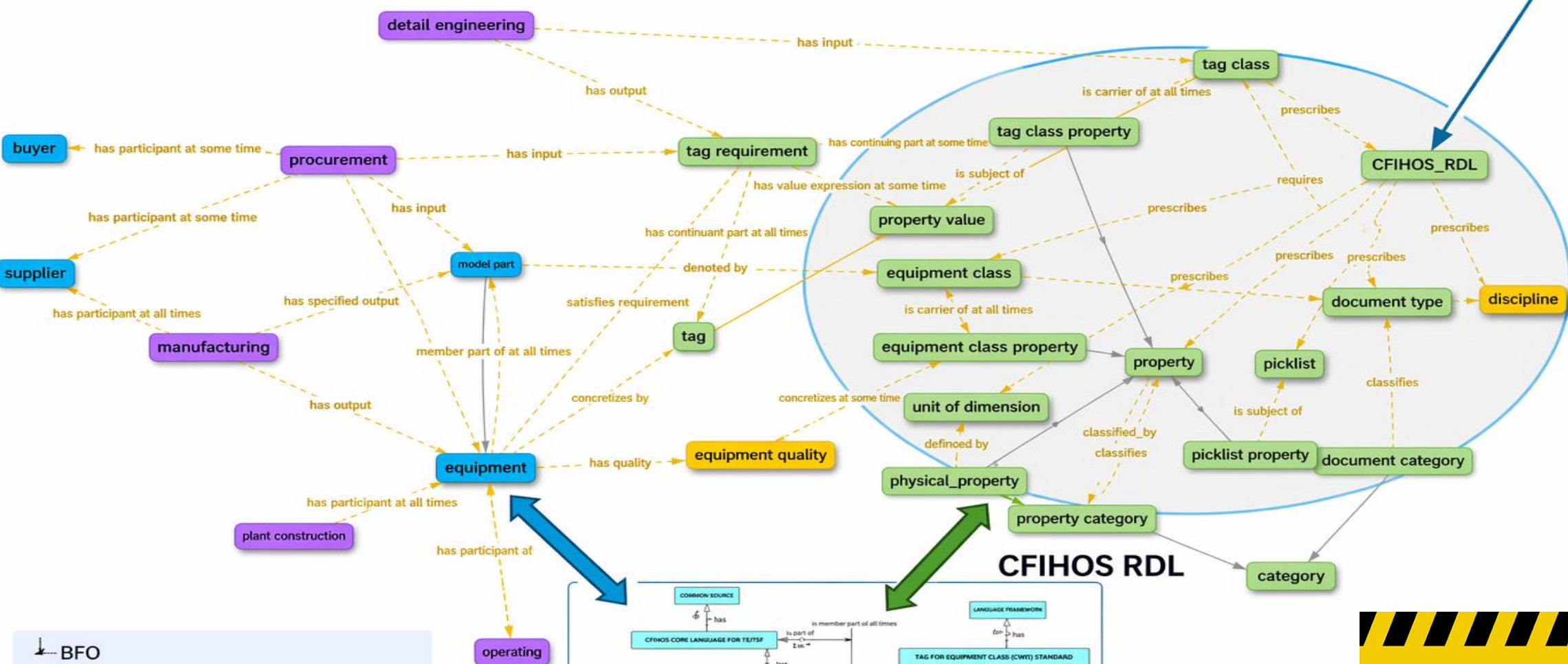
We built semantic knowledge graphs from multi-source FPSO data, representing several millions of RDF triples per asset: **we forecast future FPSO Work to be conducted ... by analogy !**

The objective is to transform fragmented data into a structured and interoperable knowledge layer (analogues, patterns, synthesis, automation, prediction & forecast...)

Become reusable semantic building blocks

CFIHOS-IOF semantic model TE/TSF

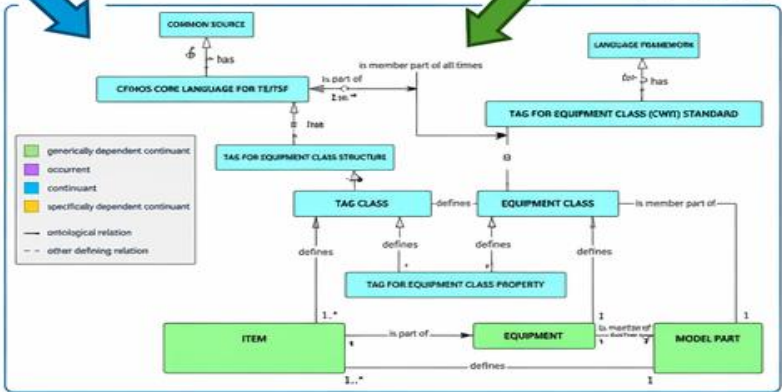
Build CFIHOS RDL



BFO

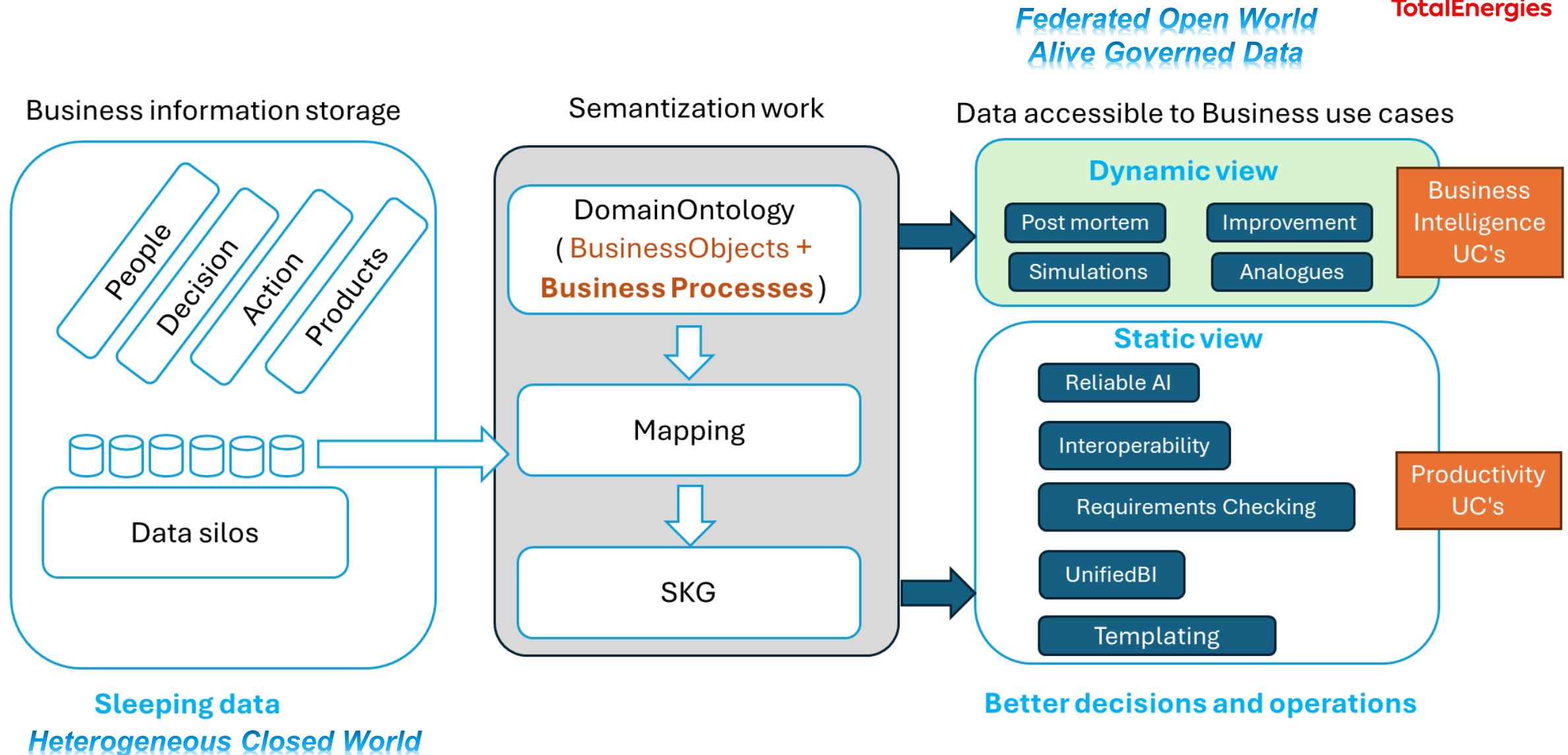
- generically dependent continuant
- occurent
- continuant
- specifically dependent continuant

↑ bearerOf



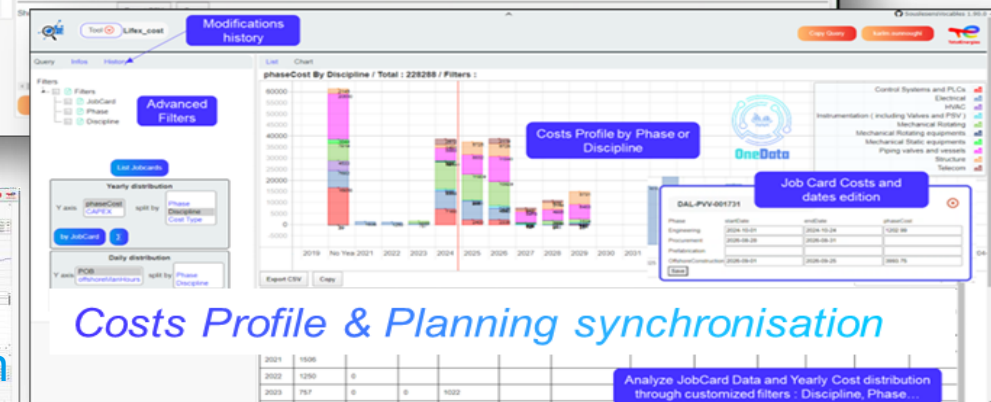
WORK IN PROGRESS

From CWA to OWA, what are we doing @TSF ?



-
- The diagram illustrates a semantic network for project data integration, organized into four main domains represented by colored circles and labeled with blue banners:
- Activity data (Top Left):** Includes entities like **Job Cards DB** (QUEST logo), **Keyword**, **Task**, **WBS** (Work Breakdown Structure), **WBSActivity**, **isAbout**, **PartOf**, **occursRelativeTo**, **isAbout**, **activeParticipant**, **manning**, **JobCardExecution**, **realizedIn**, **hasPassiveParticipant**, **closer_to_m_from**, **Discipline**, **locatedRelativeTo**, **Package**, **tag**, **residesIn**, **subLocationOf**, **FunctionalLocation**, **hasWeight**, **Weight**, **EquipmentItem**, **hasCost**, **Cost**, **SAP**, **DeepOffshore**, **ORACLE**, **PRIMAVERA**, **WBS**, **after**, **represents**.
 - Temporal data (Top Right):** Includes entities like **ReviewClass**, **hasQuality**, **Document_Tag**, **isAbout**, **Document**, **concretizes**, **Phase**, **qualityOf**, **Project**, **participantIn**, **DocumentRevisionReception**, **hasParticipant**, **DocumentRevisionOutput**, **DocumentStep**, **DocumentStepScheduledDate**, **hasTemporalPart**, **New Prodom** (New Solution for Project & Doc. Management), **OneData**.
 - Document data (Bottom Right):** Includes entities like **Document**, **concretizes**, **Phase**, **qualityOf**, **Project**, **participantIn**, **DocumentRevisionReception**, **hasParticipant**, **DocumentRevisionOutput**, **DocumentStep**, **DocumentStepScheduledDate**, **hasTemporalPart**.
 - Spatial data (Bottom Left):** Includes entities like **locatedRelativeTo**, **Package**, **tag**, **residesIn**, **subLocationOf**, **FunctionalLocation**, **hasWeight**, **Weight**, **EquipmentItem**, **hasCost**, **Cost**, **SAP**, **DeepOffshore**.
- Relationships are indicated by arrows and labels such as **isAbout**, **PartOf**, **occursRelativeTo**, **hasPassiveParticipant**, **closer_to_m_from**, **locatedRelativeTo**, **tag**, **residesIn**, **subLocationOf**, **hasWeight**, **hasCost**, **hasQuality**, **isAbout**, **concretizes**, **qualityOf**, **participantIn**, **hasParticipant**, **hasTemporalPart**.

Notifications & historian



Conclusions & perspectives

Control your knowledge ...

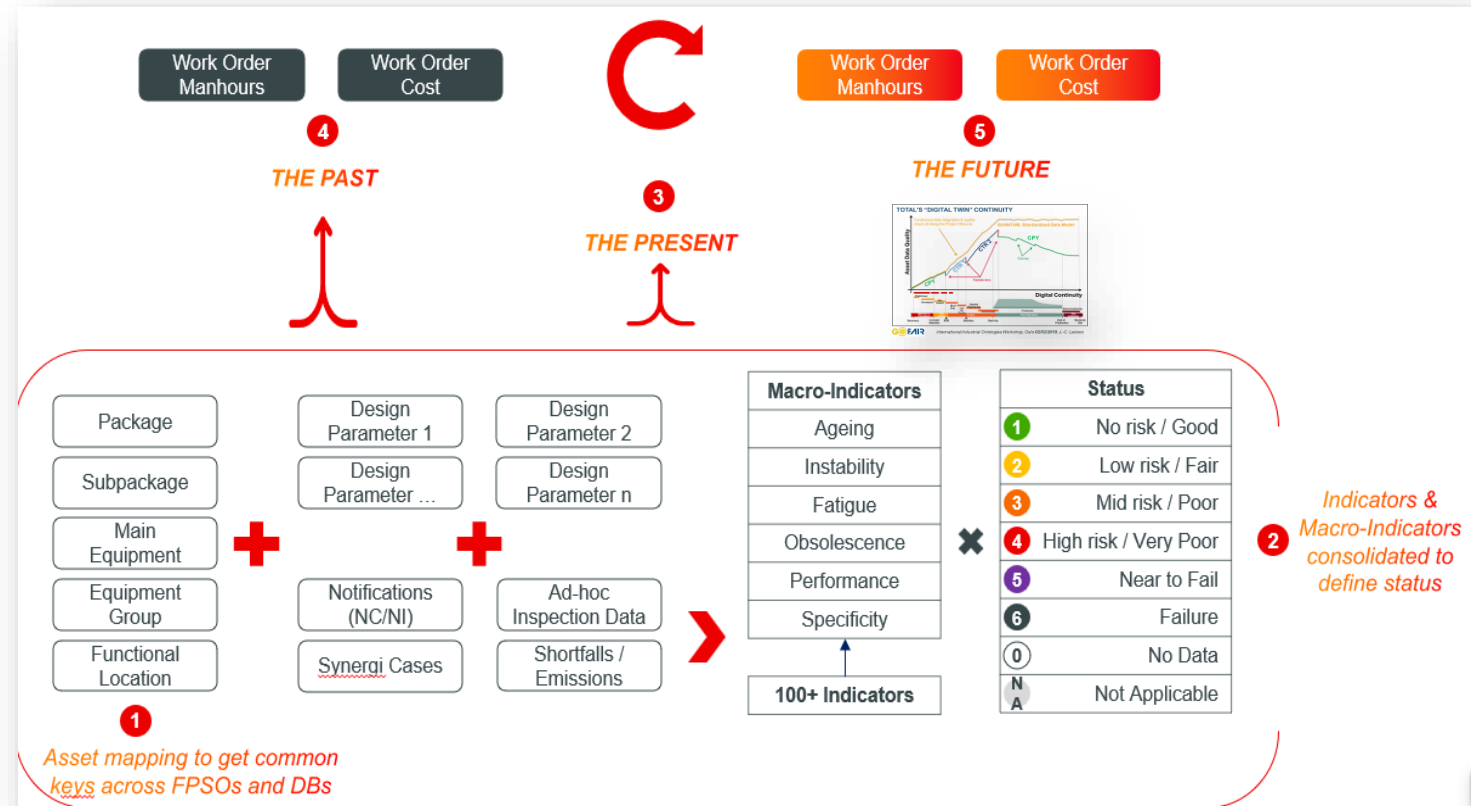
- Knowledge becomes the primary [key] differentiator
- AI without semantics = uncontrolled black box
- Methodology: **governing rules** & common way of modelling
- **Formal** (FOL) and (*native*) **4D** ontology = industrial foundation for AI

In a future where AI models become widespread and commoditized, organizational knowledge may become the primary source of differentiation.

Formal ontologies are not an academic luxury, but a foundational technology for next-generation industrial systems.

This is how semantic modeling becomes a scalable industrial foundation for decision-making and AI.

How to forecast future LifeX works on our FPSO ? *By analogy ...*



Control your knowledge, ... *or your systems will be controlled by someone else's models*

We are not structuring data anymore : *we are industrializing knowledge*

“Norway” can’t be a Class !

CFIHOS Semantics Working Group methodological stack driven by standards [like SPARQL, RDF, RDFS & OWL], assume a great number of foundational topics to make life easier.

But that also allows people to misuse them.

Our developments are based on standards and adoption of common governing principles to federate through a single information modelling framework

There is an axiom called class comprehension, or *simply grounding* axiom

$$\forall x (x \in C \leftrightarrow P(x))$$

*Simply a **Class** is the set of **Individual’s** sharing common characteristics’*

If something has a property, it has a class

A class must have members which shares a property

“**NORWAY**” cannot be a **Class** because we cannot think about any members which will have a *NORWAY-like Property*.”

“I can’t derivate Norway then, a State, a District or a City are not at all SubClass of Norway”

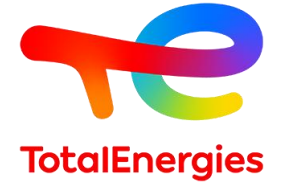
But this axiom cannot be really expressed in our systems, ... so a guide is the only way ...

But whenever there is natural language, there is this risk of misinterpretation ... and we care about it ...

*We all need a **Common Data Culture***

« The limit of my language mean the limit of my world » Wittgenstein

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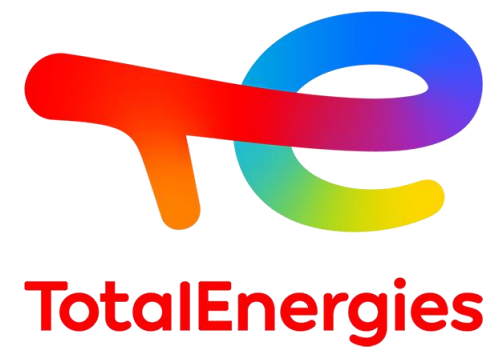
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Thank you
Tusen takk !

Many current initiatives bring valuable contributions in structuring industrial information.

**When time matters, ...
...It almost always the case in real-life...
it's time for the coffee break, now !**

we all need a 4D ontology

In industry, everything changes. Your ontology must handle change natively



My point today is not to dismiss these efforts, but to show why structure alone is not sufficient when reality, time and change must be modeled consistently.