Connecting the Dots in Smart PLM:
preparing Big PLM Data for Intelligent Analytics

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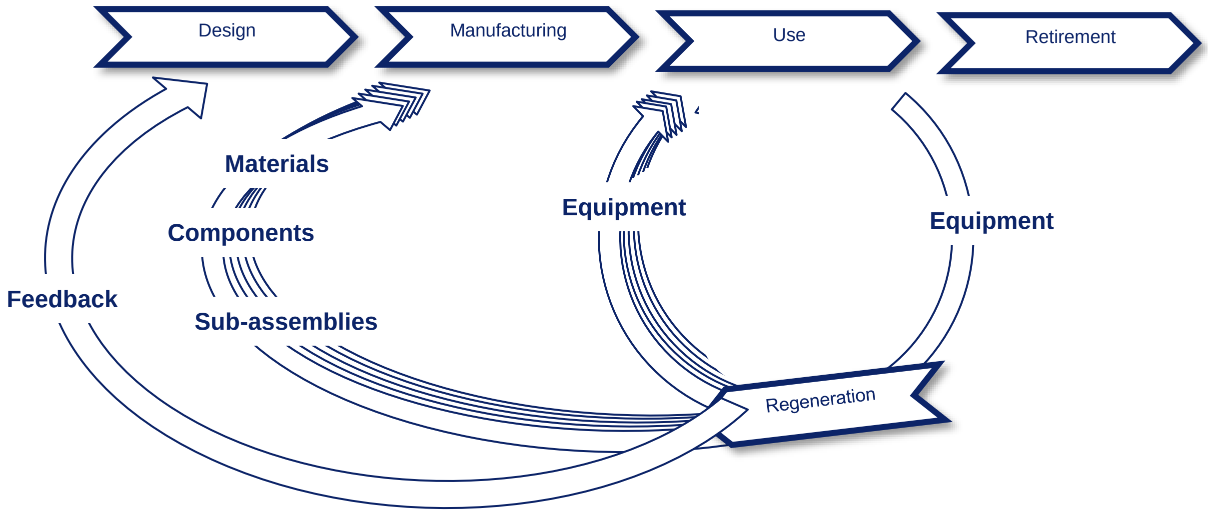
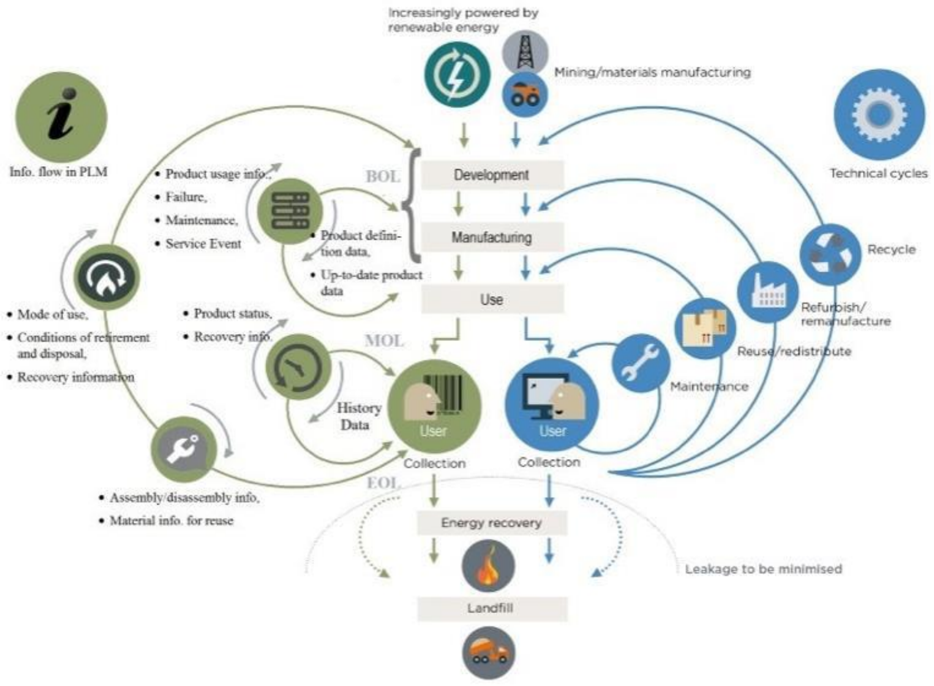
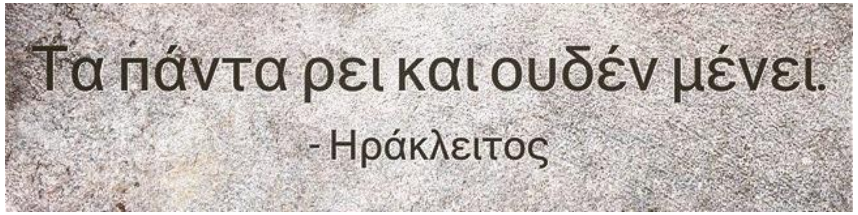




1/ How to set up loops in the technical sphere?

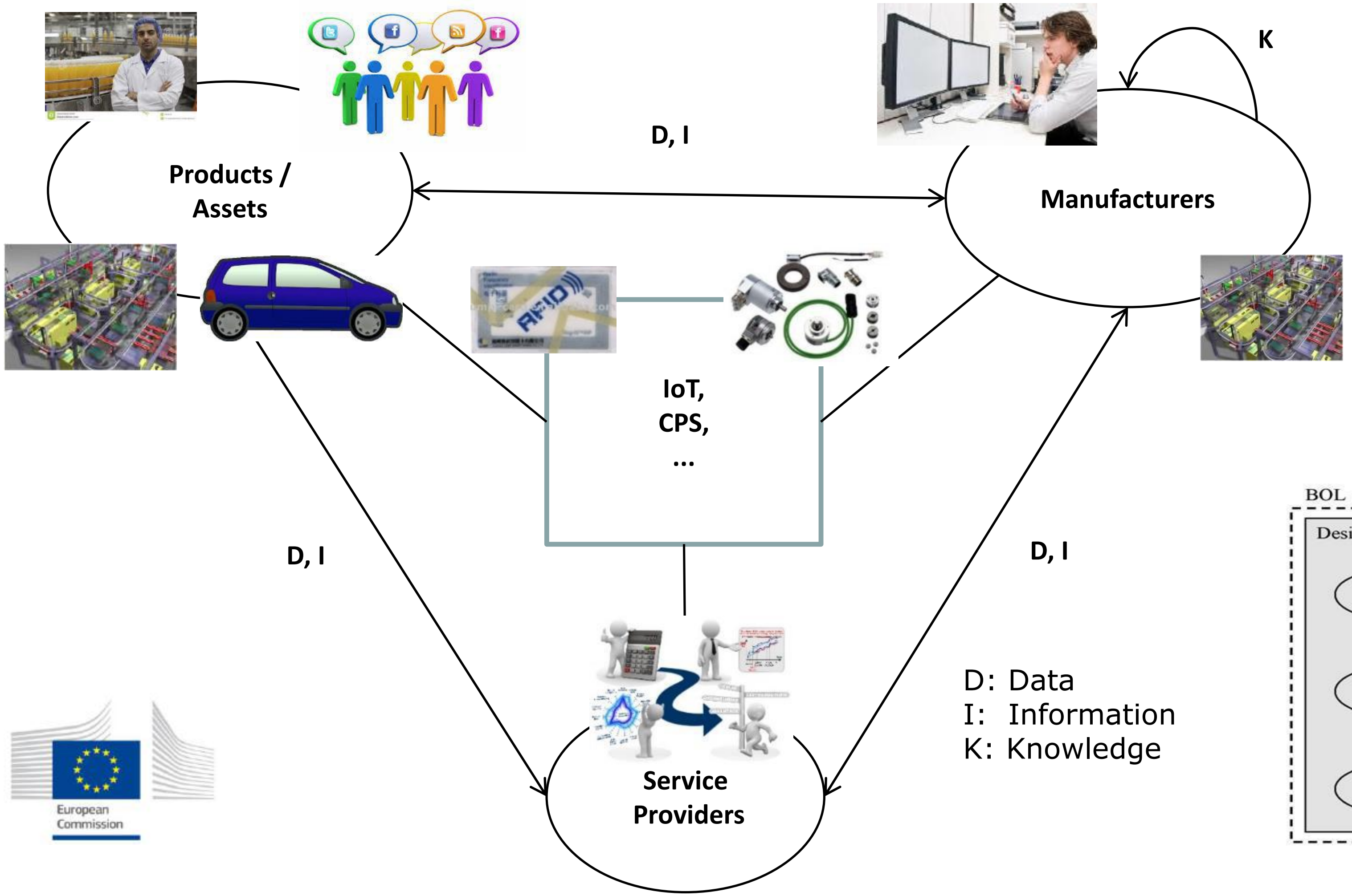
- ➔ **Take into account several cycles of use**
  - ➔ Loops (exploitation - regeneration - exploitation / manufacture)
  - ➔ Levels of products (equipment, subassemblies, components, materials)



2/ How to guarantee the sustainability of the loops?

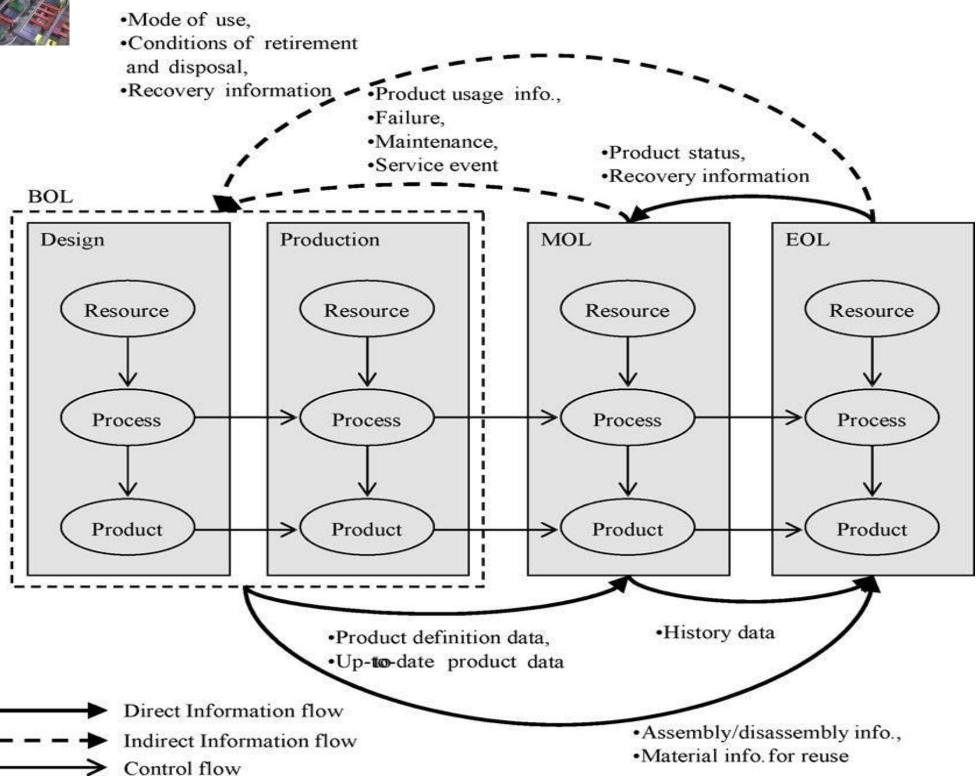
- ➔ **Make sure that the product can have new cycles of use**
- ➔ **Use decision aids**

It's about big lifecycle data transformations

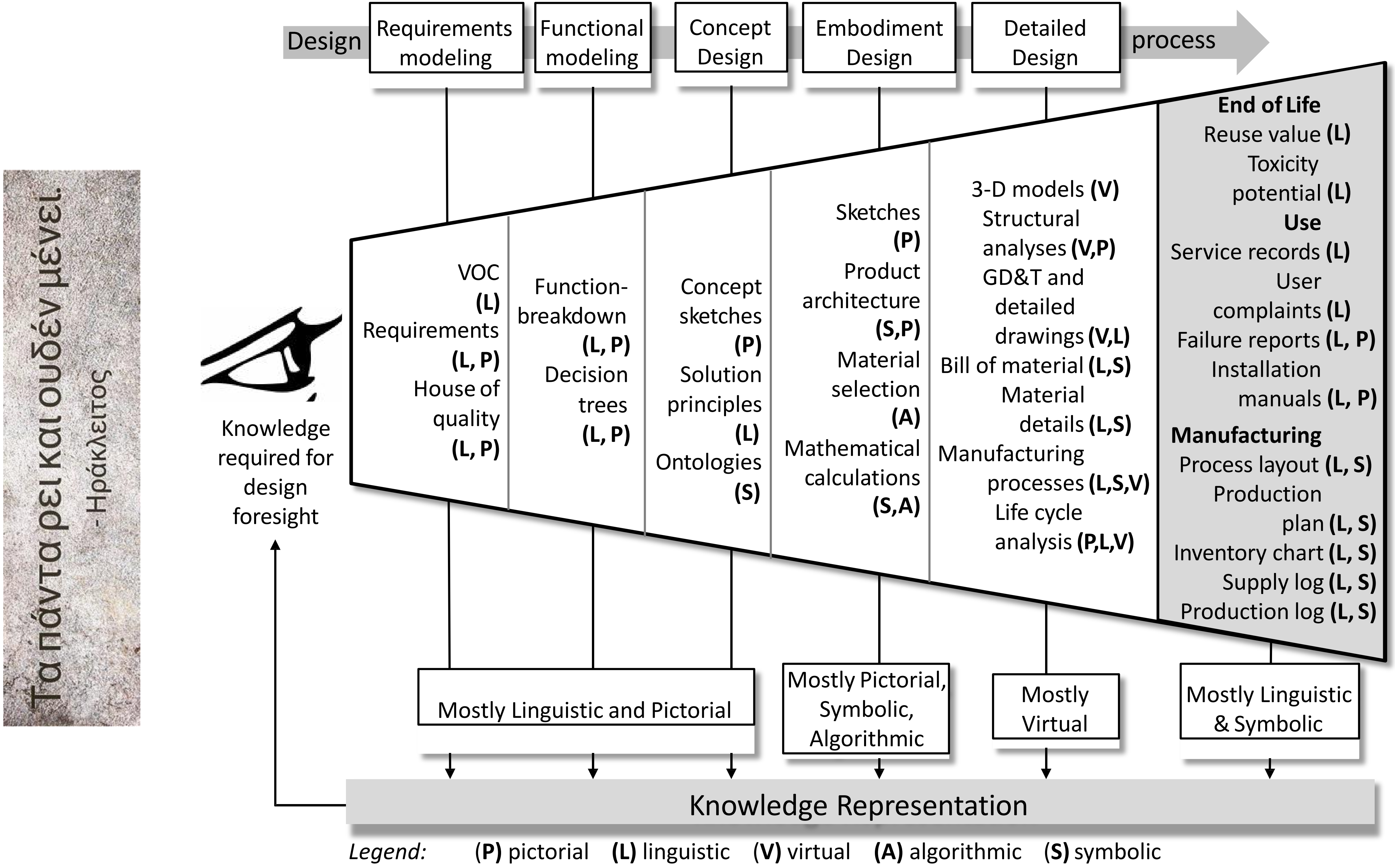


Lifecycle Data-Information-Knowledge Transformations

Semantics-Model-Based Systems Engineering for Big Industrial Data Analytics



LinkedDesign   Z-Fact0r   Z-Bre4k   Boost 4.0 BIG DATA FOR FACTORIES   bIoTope



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.

Use of Ontology in Engineering 1/2

Product engineering refers to the process of designing and developing a device, assembly, or system through a set of production/manufacturing process.

Challenges in engineering	Use of ontology
Product Definition	Ontology supports product definition by modeling and storing product related taxonomies, product structure and facets
Product Design	Ontology supports conceptual design through concepts and rules dealing with design constraints, or feature-based design
Manufacturing process	Ontology supports product manufacturing through concepts and rules dealing with performance monitoring, production process and quality control

Use of Ontology in Engineering 2/2

Challenges in engineering	Use of ontology
Semantic interoperability	Ontology provides well-architected, consensus schemas to support systems interoperability across multiple and heterogeneous systems
Data integration	Ontology supports data integration through the application of Linked Data principles
Data/Information exchange	Ontology encompasses the model and the data and thus can be seamlessly exchanged among different systems on a global basis based on standardized representation languages (OWL/RDF/RDFS)
Information Modeling	Ontology enables information modeling of the product and supports expressing a shared understanding of a domain as a common source of knowledge
Knowledge Engineering	Ontology supports capturing, storing, and retrieving knowledge taking advantages from reasoning mechanisms to infer hidden and tacit facts

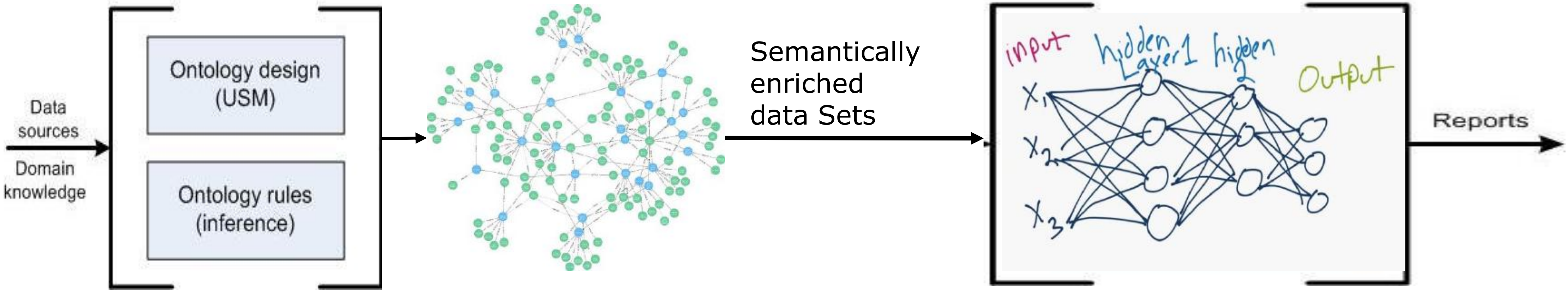
Motivations	Benefits	Tools
Solving semantic interoperability Need for a common source of knowledge Capitalization of engineering knowledge (static & dynamic) Visualization of linked information (triplets) Separation of domain knowledge from proprietary systems	Ontology Network Ontology Reasoning Ontology Reuse	Protégé TopBraid Composer Anzo Stardog Linkurious …

- **Scattered data in several sources, systems and services**
- **Different actors with multidisciplinary skills**

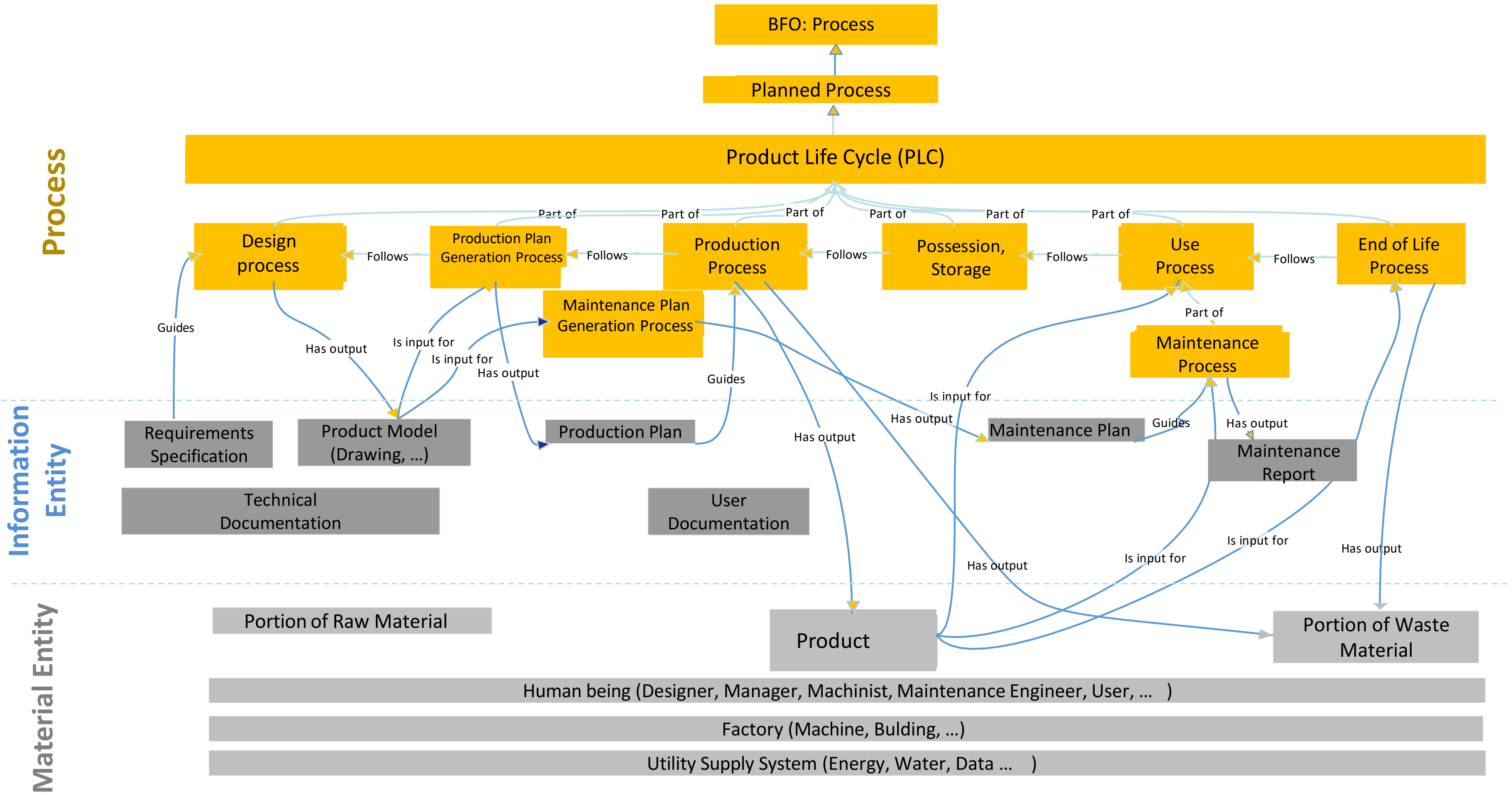
Semantic modelling module

Knowledge Graph

Data Analytics module



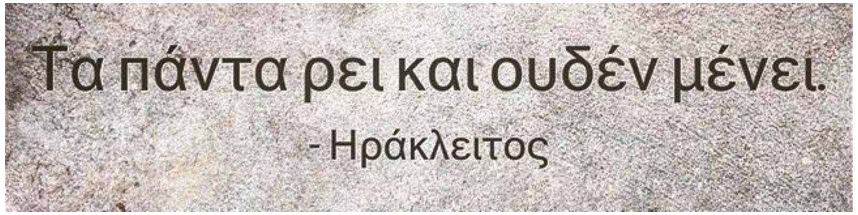
Poduct Life Cycle Ontology



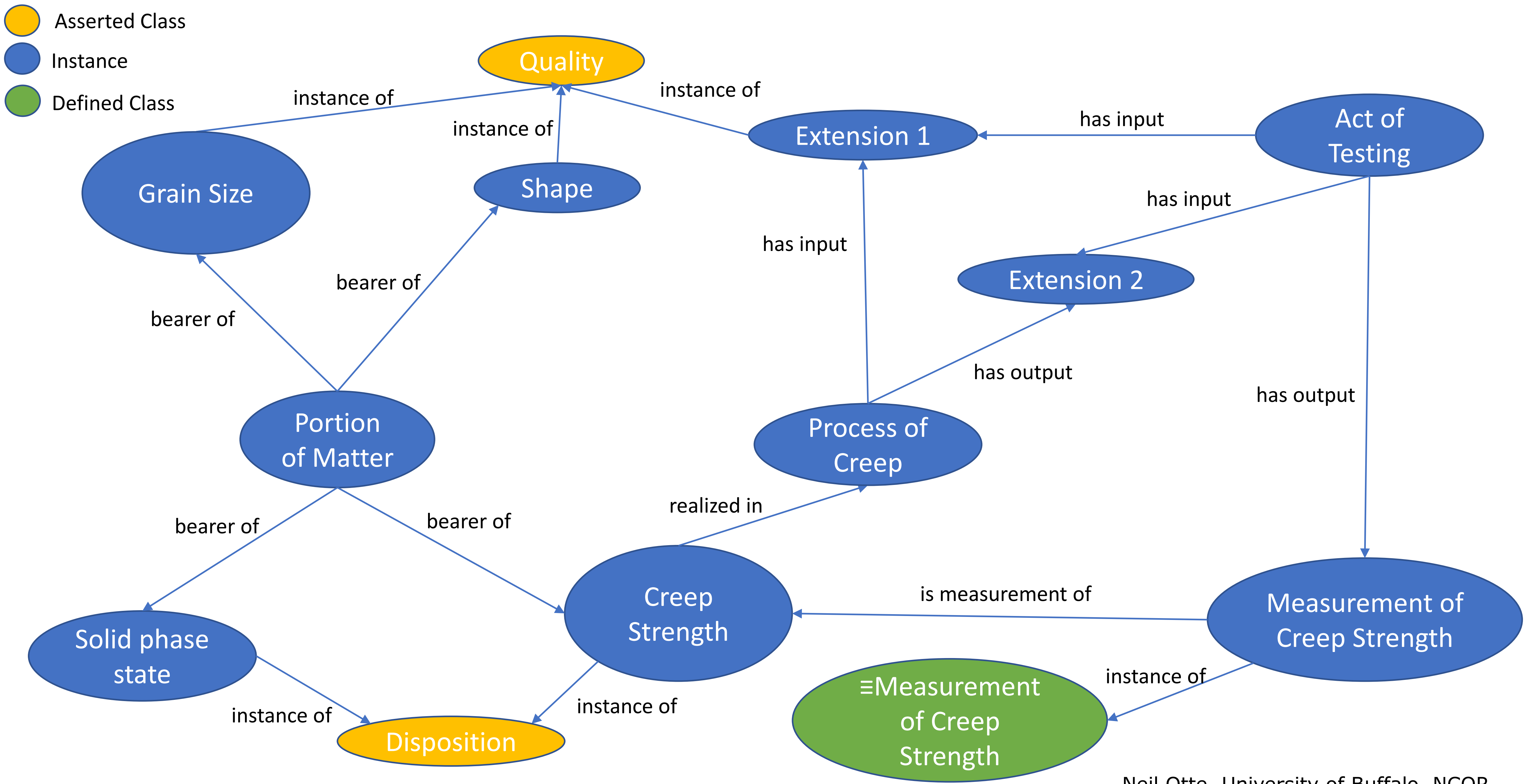
Bring together the Physical (**Real**)–Cyber (**Digital**)–Bio (**Human/Cognitive**) worlds

Material Entity

We need to deal with the fact that the end-of-life process normally occurs not merely after some process of use, but after long sequence of processes of use or after a long time period has elapsed covering the complete lifecycle of a product.



Material Analysis



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MatOnto: A suite of ontology modules based on BFO

- Initiated under Obama 'Materials Genome' project

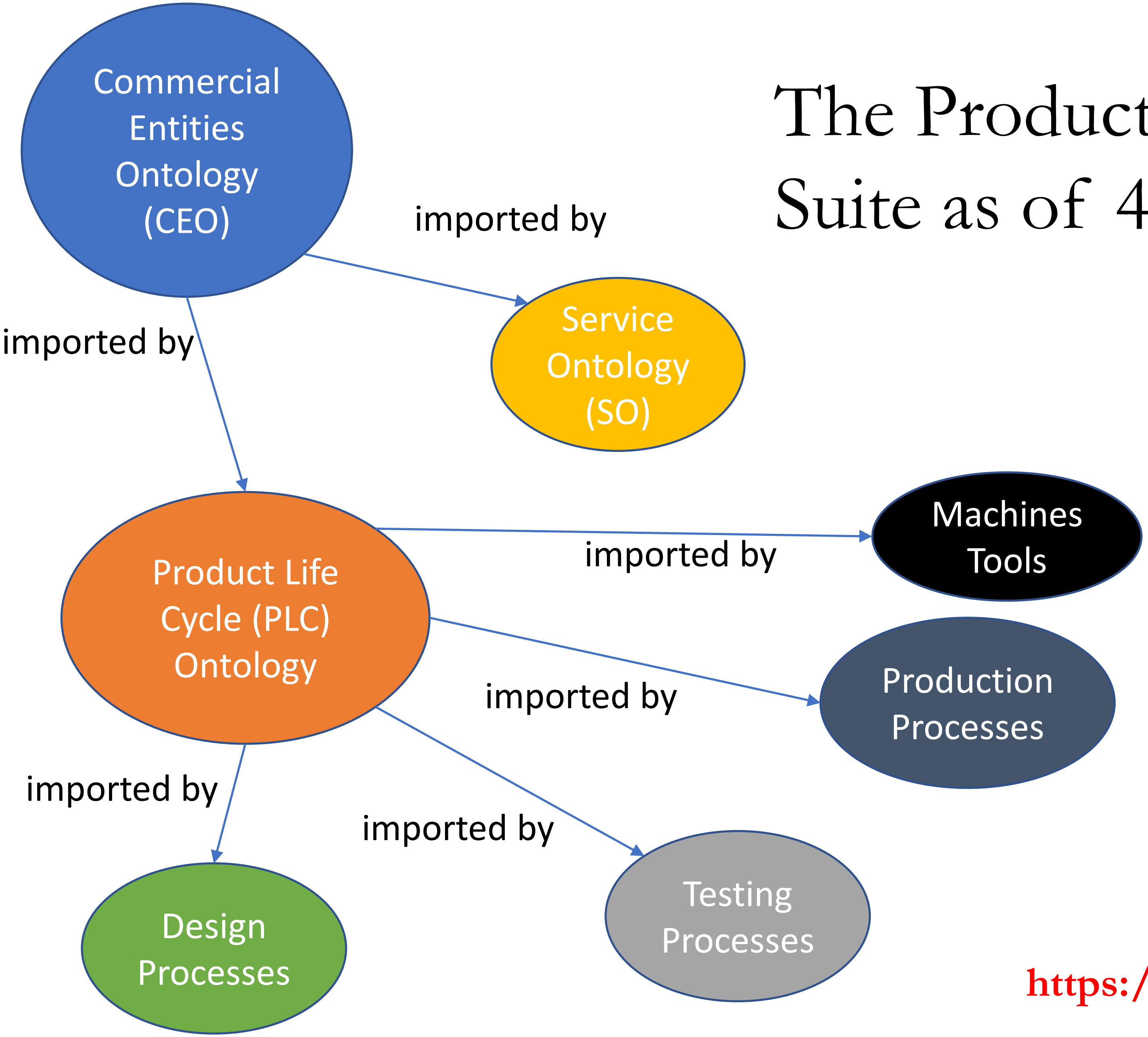
- Now under direction of Clare Paul (Air Force Research Lab)

- Existing ontologies in process of being re-engineered to be BFO-conformant:
  for **Laminated Composites**: SLACKS (UMass)
  for **Functionally Graded Materials**: FGMO (NCOR, Milan Polytechnic)

- Existing ontologies already BFO-conformant:
  for **Polymers**: CHEBI (EBI)

See: http://ncorwiki.buffalo.edu/index.php/MatOnto_Ontology_Meetings

The Product Life Cycle Ontology Suite as of 4/24/18



https://github.com/NCOR-US/CHAMP

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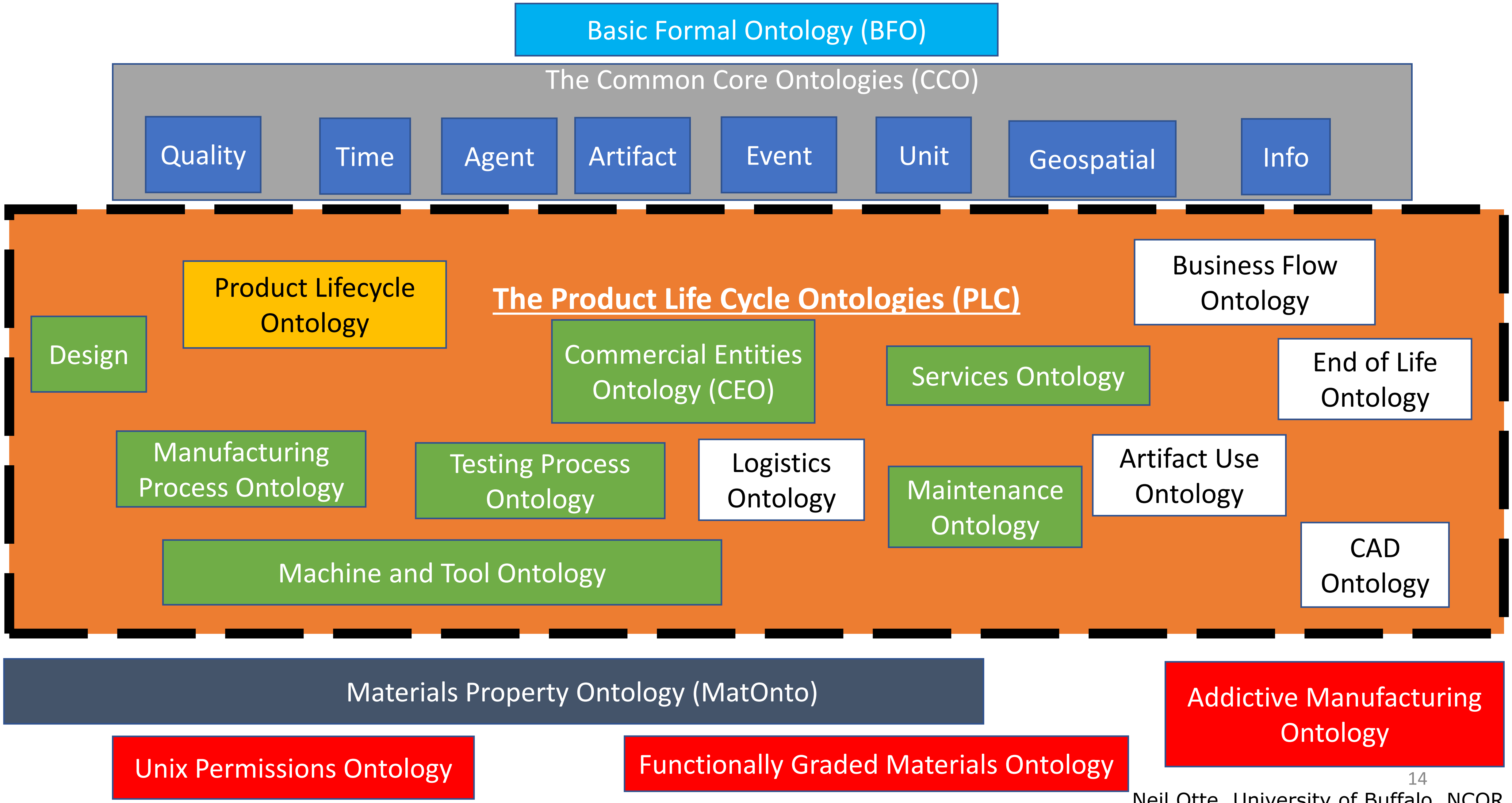
The PLC Ontologies



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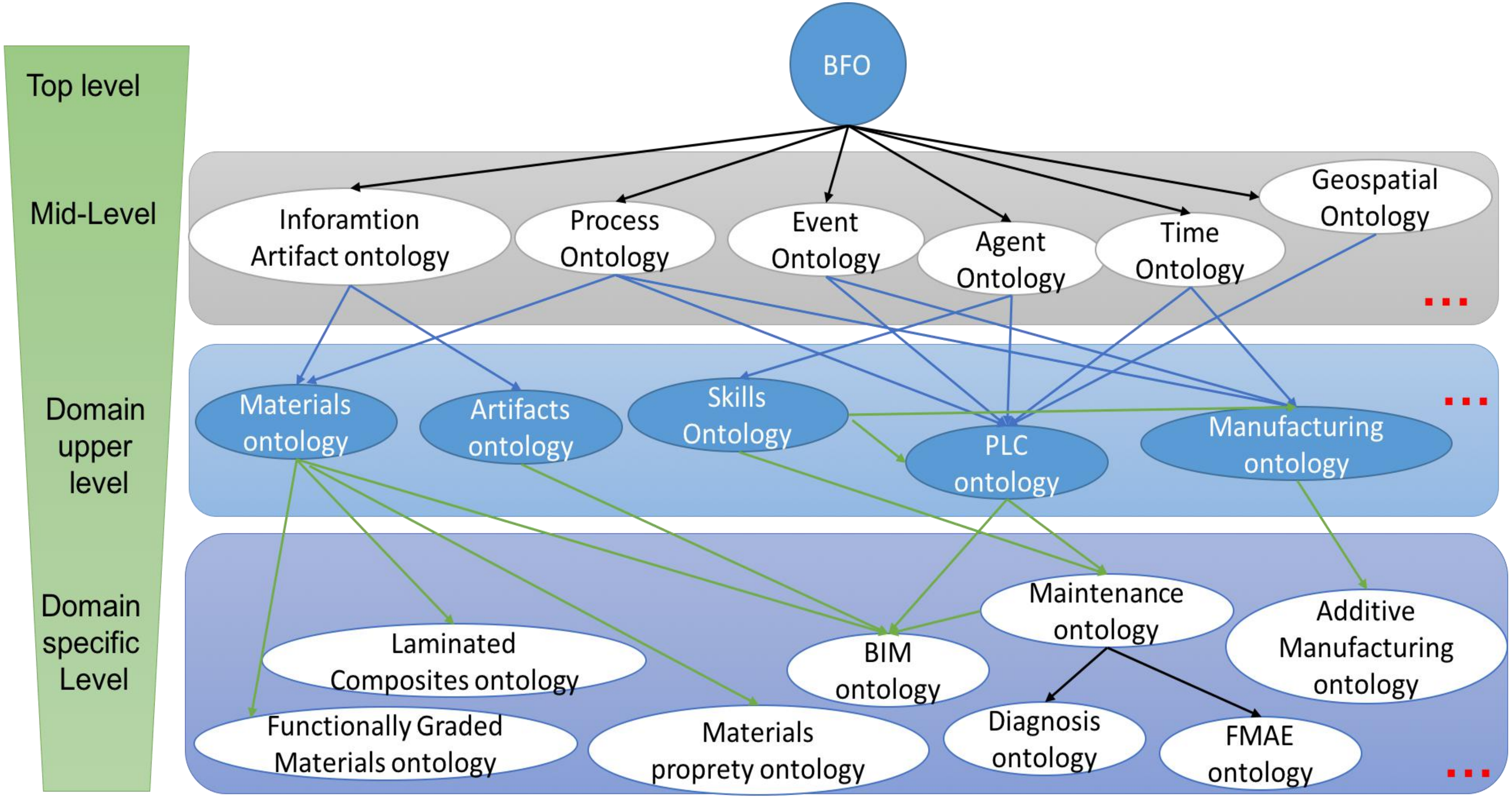
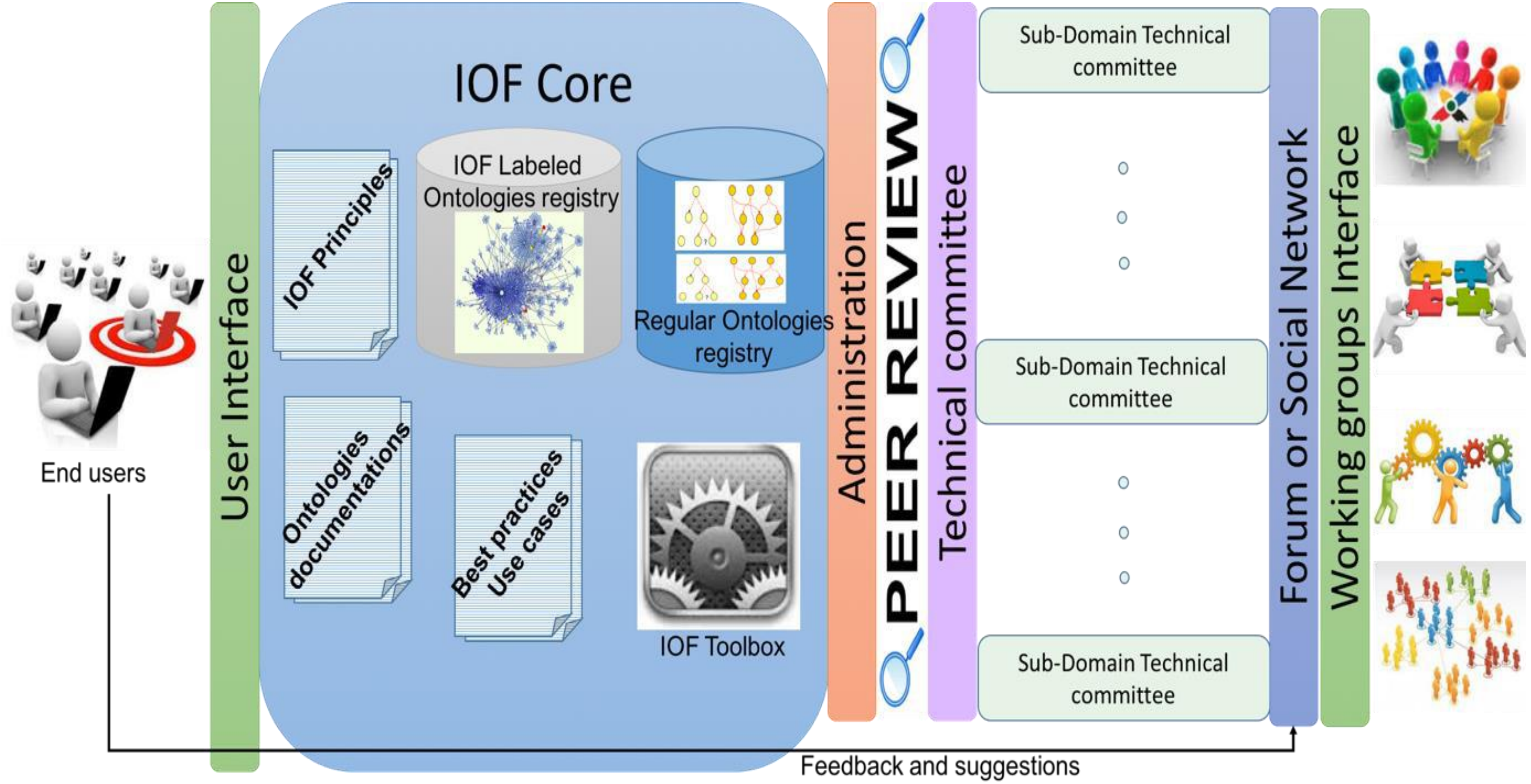


https://sites.google.com/view/industrialontologies/home

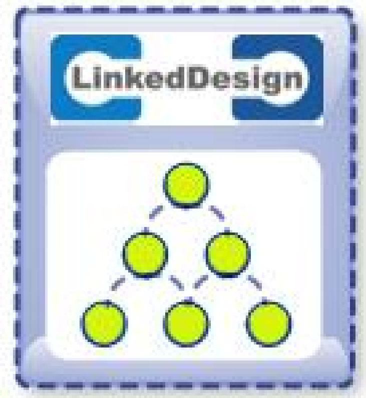
Drawn by Hedi Karray

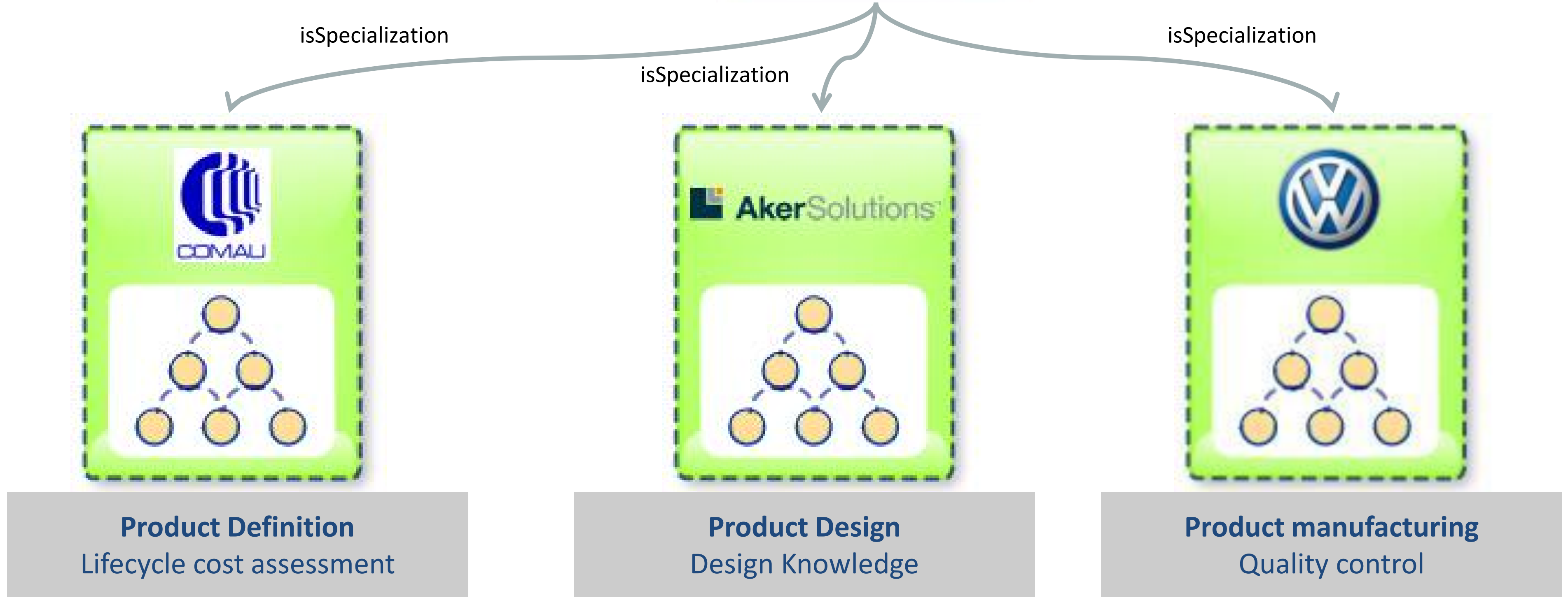
IOF Archtecture



Drawn by Hedi Karray

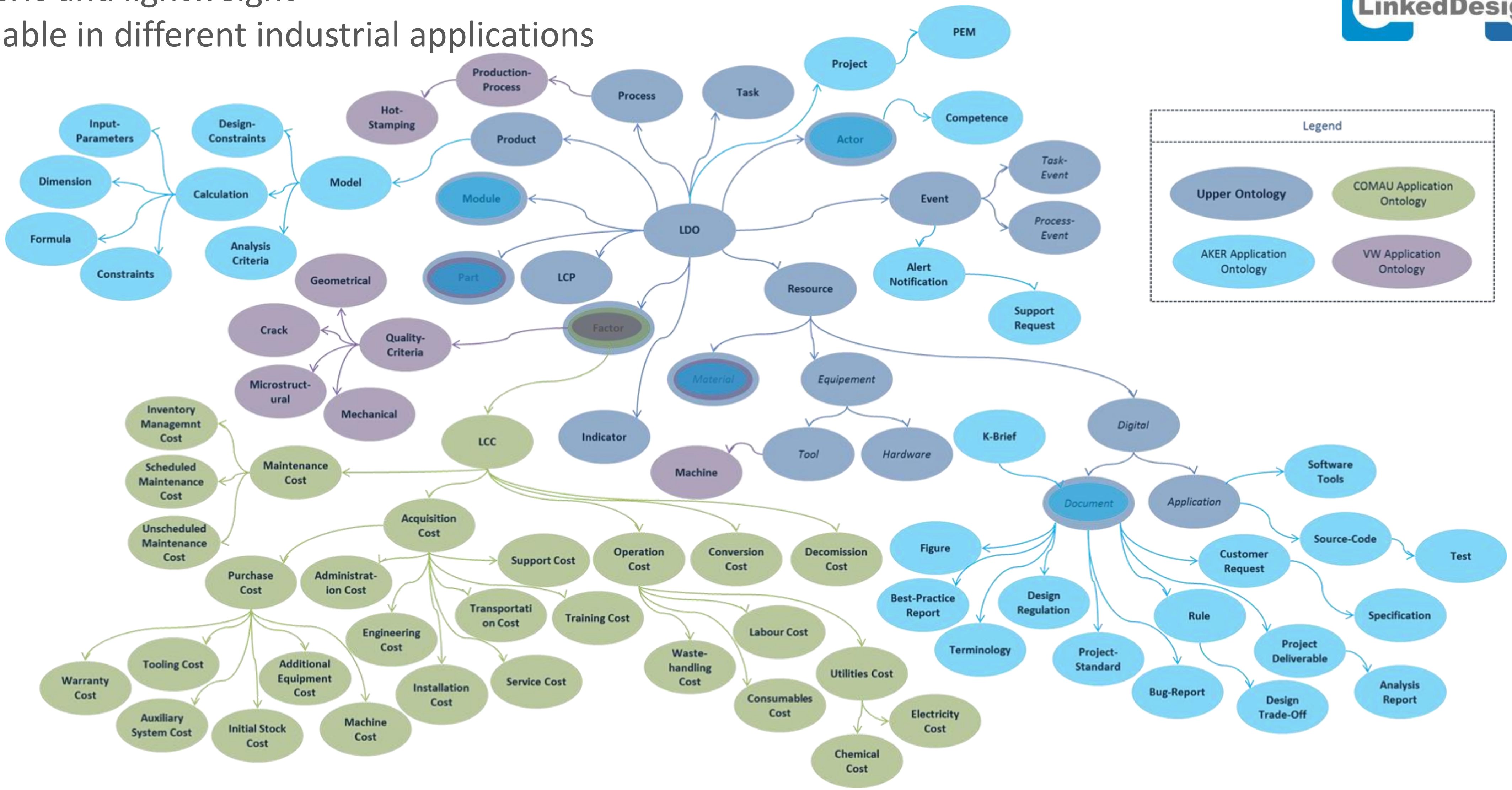
- ✓ Enable context-driven and collaborative access to data, information and knowledge in engineering and manufacturing
- ✓ Data stored in structured and unstructured information sources



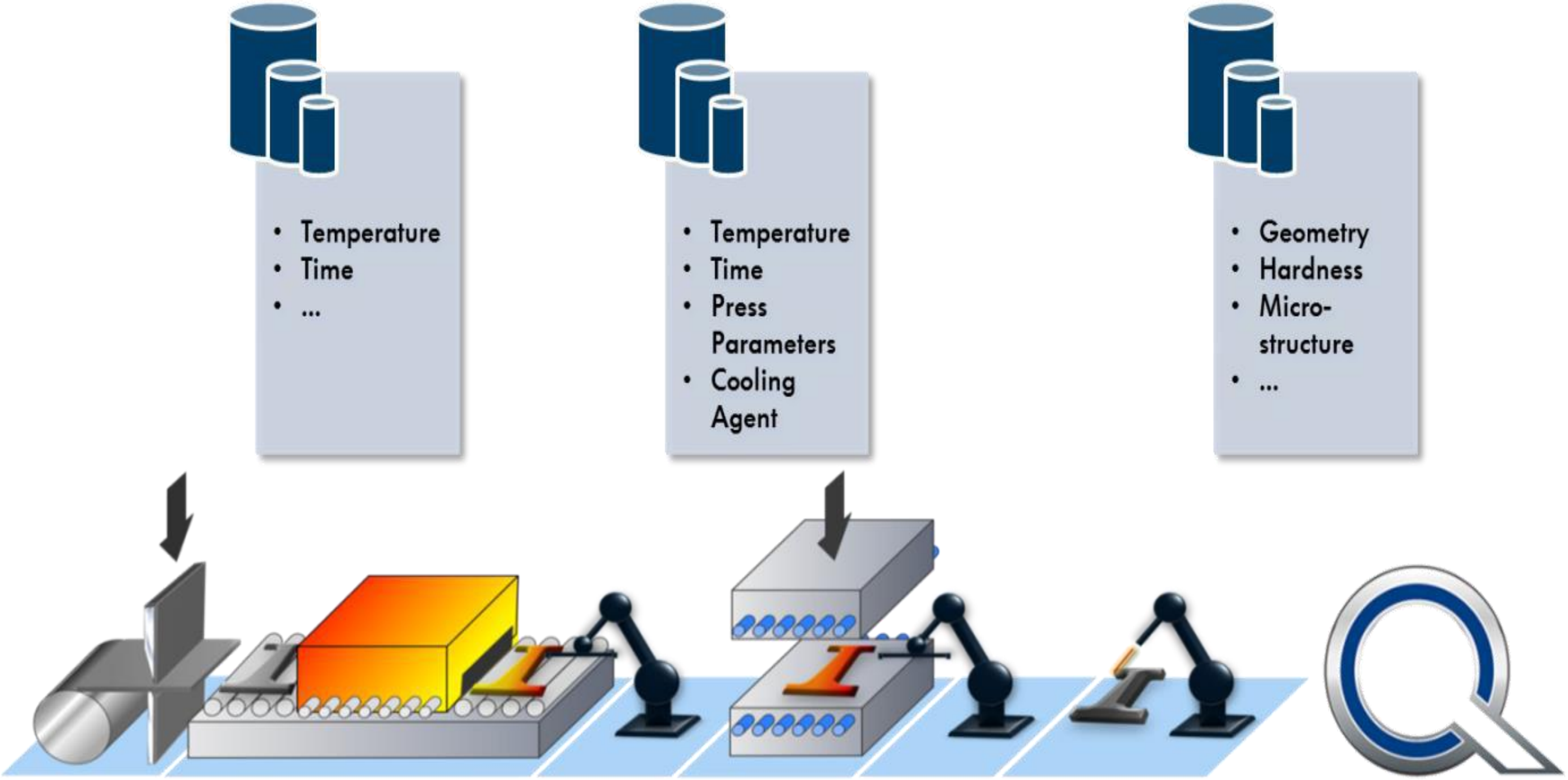


LinkedDesign Project

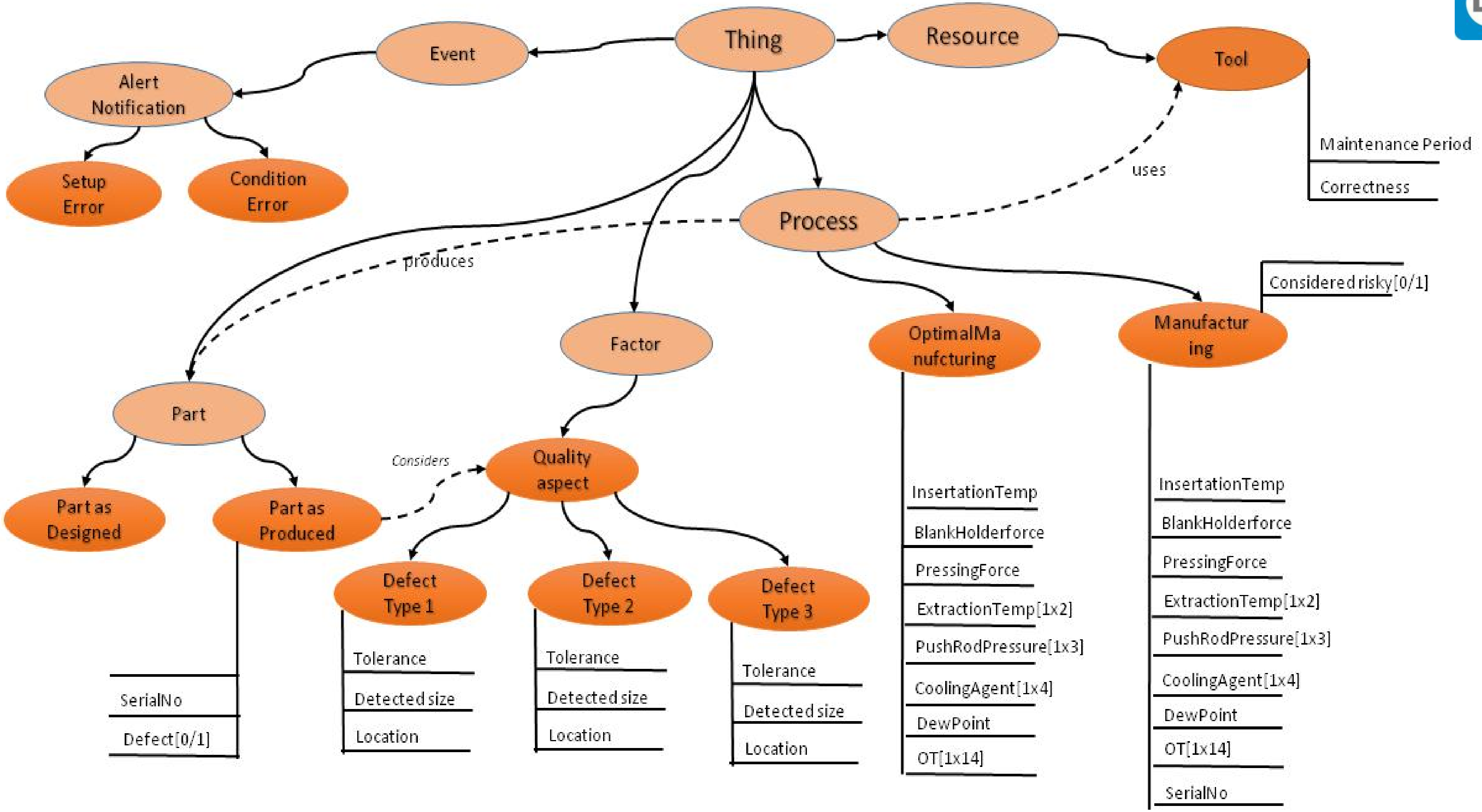
- ✓ Generic and lightweight
- ✓ Reusable in different industrial applications



Quality control use case



System testing – Quality control use case



System testing – Quality control use case

Value "No" of variable "Defect" can be predicted with 0.86 accuracy using Decision tree algorithm

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This paragraph reports correlations which are more than three standard deviations higher than mean of all correlations

Pair wise data correlation :

"ExtractionTemp1" and "ExtractionTemp2" show correlation of 0.96

"CoolingAgent1" and "CoolingAgent2" show correlation of 0.95

"CoolingAgent1" and "CoolingAgent4" show correlation of 0.94

"CoolingAgent2" and "CoolingAgent4" show correlation of 0.90

"CoolingAgent3" and "CoolingAgent4" show correlation of 0.87

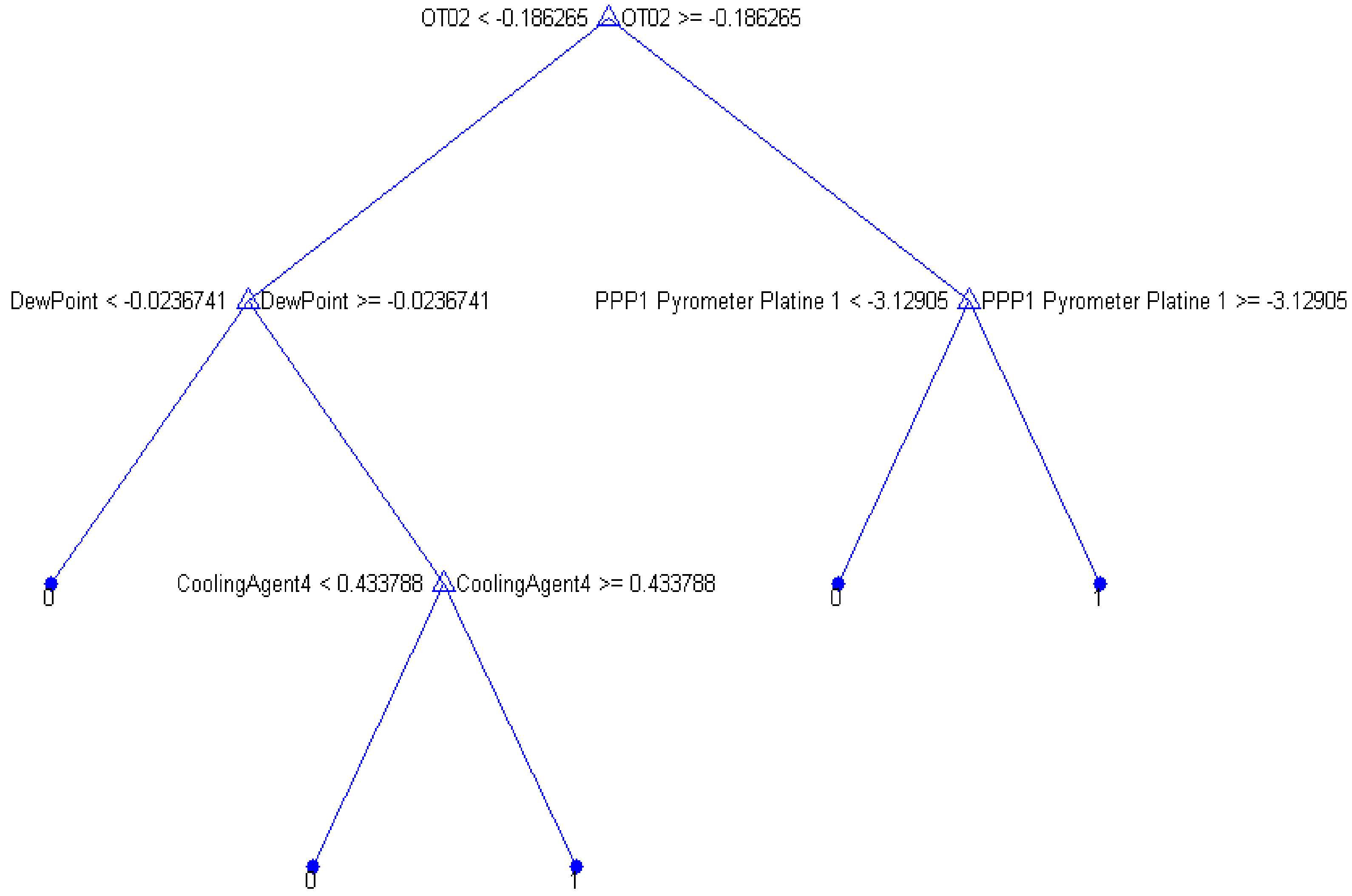
"OT01" and "OT02" show correlation of 0.85

"OT02" and "OT04" show correlation of 0.85

"OT03" and "OT04" show correlation of 0.91

"OT04" and "OT05" show correlation of 0.88

"OT09" and "OT10" show correlation of 0.87



OT02 < -0.186265
OT02 >= -0.186265
DewPoint < -0.0236741
DewPoint >= -0.0236741
PPP1 Pyrometer Platine 1 < -3.12905
PPP1 Pyrometer Platine 1 >= -3.12905
0
CoolingAgent4 < 0.433788
CoolingAgent4 >= 0.433788
0
1
0
1

Observed Limitations in Applying Ontology

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- ✓ There is still a relevant gap between scientific studies and industrial applications
- ✓ The development of an ontology-based system is particularly challenging because it asks for the collaboration between experts in knowledge engineering, ontology engineering, database management systems, and software engineering
- ✓ Real industrial applications require the management of large amount of data, this must be addressed taking into account the requirements for ontology storage (Graph Databases – Knowledge Graphs)
- ✓ Available solutions present limitations related to: operating system, implementation language, repository mechanism and performance, programming language for client connectors, query language, security, versioning, handling of binary data
- ✓ Very few programming environments provide multi-language support and high-level functionalities
- ✓ There is a strong need for more efficient and effective software environments to support the various phases of ontology-based system lifecycle engineering

Additional slides

Four fundamental objectives of ontology	
Objective 1	Ontology provides a structuring of entities, their properties, relations and axioms describing a specific domain
Objective 2	In this specific domain, the structuring remains entirely determinate regardless of the requirements of any system or of the changing requirements of a given system
Objective 3	Ontology captures domain entities and related information at different levels of focus and granularity
Objective 4	Ontology acts as a point of reference for designers to extract system specifications

Seven key roles of ontology	
Role 1	Trusted source of knowledge
Role 2	Database
Role 3	Knowledge base
Role 4	Bridge for multiple domains
Role 5	Mediator for interoperability
Role 6	Contextual search enabler
Role 7	Linked Data enabler

Use of ontology for dealing with research problems in PLM

Research challenges in PLM		Roles of ontology in dealing with research problems in PLM
Functional	Product definition	Ontology supports product definition by modelling and storing product-related taxonomies, product structure and facets
	Product design	Ontology supports product design and conceptual design stages through concepts and rules dealing with design constraints, or feature-based design
	Manufacturing process	Ontology supports product manufacturing-related issues through concepts and rules dealing with performance monitoring or quality control
	Use, maintenance, recycling	Middle- and end-of-product lifecycle-related semantics are not fully covered by existing product ontologies and applications
	Decision- making strategies	Ontology supports distributed and linked decision- making enabled through data integration coupled with reasoning mechanisms for knowledge discovery

Use of ontology for dealing with research problems in PLM

Research challenges in PLM		Roles of ontology in dealing with research problems in PLM
Technical	Semantic interoperability	Ontology supports cross-disciplinary collaboration through mapping several ontologies from different domains. It acts also as a basis for schema matching to support systems interoperability across multiple and heterogeneous systems
	Data integration	Ontology supports data integration through the application of Linked Data principles
	Data/ information exchange	Ontology encompasses the model and the data and thus can be seamlessly exchanged among different systems on a global basis based on standardised representation languages (OWL/RDF/ RDFS)
	Information modelling	Ontology enables information modelling of the product throughout its entire lifecycle and supports expressing a shared understanding of a domain as a common source of knowledge
	Knowledge engineering	Ontology supports capturing, storing and retrieving knowledge taking advantages from reasoning mechanisms to infer hidden and tacit facts