Ontology-Based Design of Space Systems

ISWC 2016 Emerging Applications Paper
20 October 2016

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Hennig, et al., 2016. Ontology-Based Design of Space Systems.

State of the Art in System Modeling in European Space Engineering

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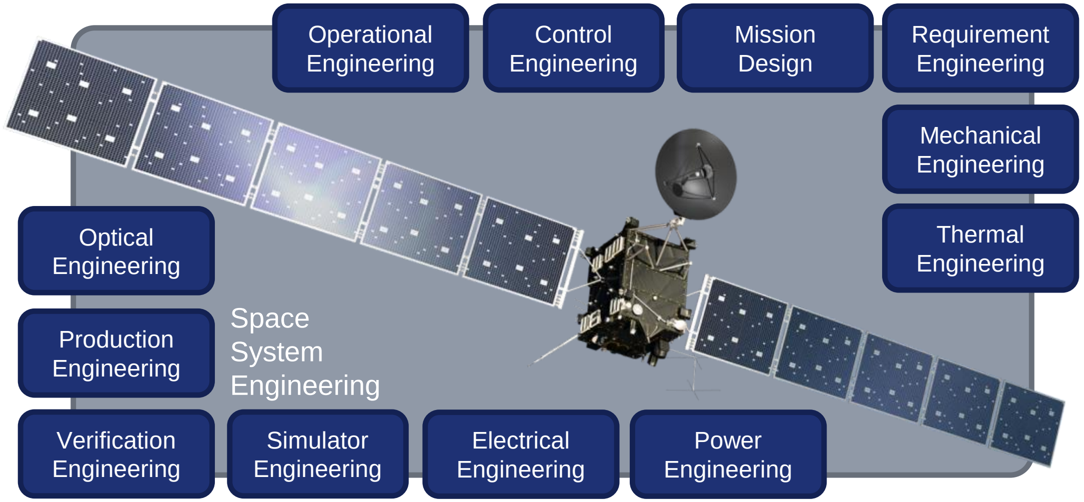
Realization of interdisciplinary design process through Model-Based Systems Engineering (MBSE)

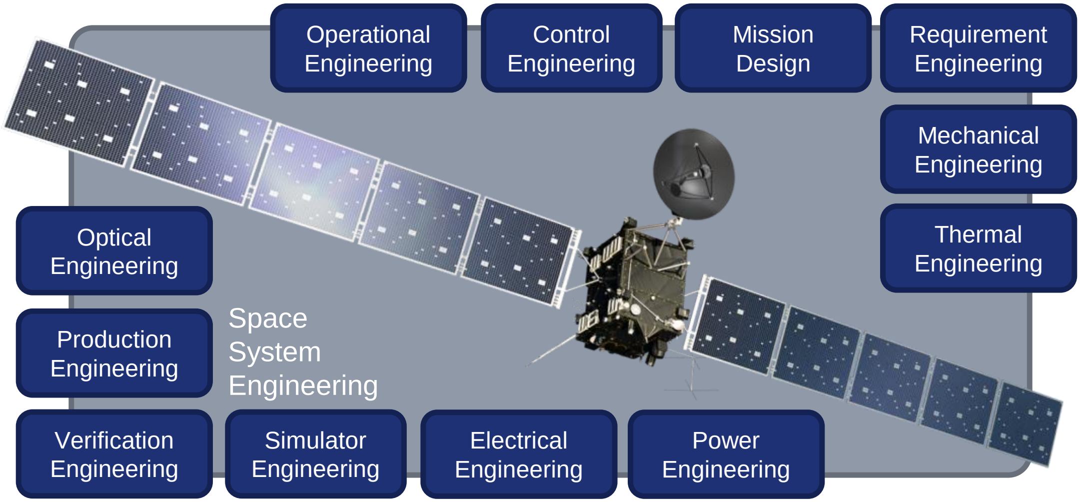


Design of space systems with strong multi-disciplinary characteristic

Hennig, et al., 2016. Ontology-Based Design of Space Systems.

Realization of interdisciplinary design process through Model-Based Systems Engineering (MBSE)

Realization through Model-Based Systems Engineering (MBSE), with a central database acting as data versioning and exchange hub



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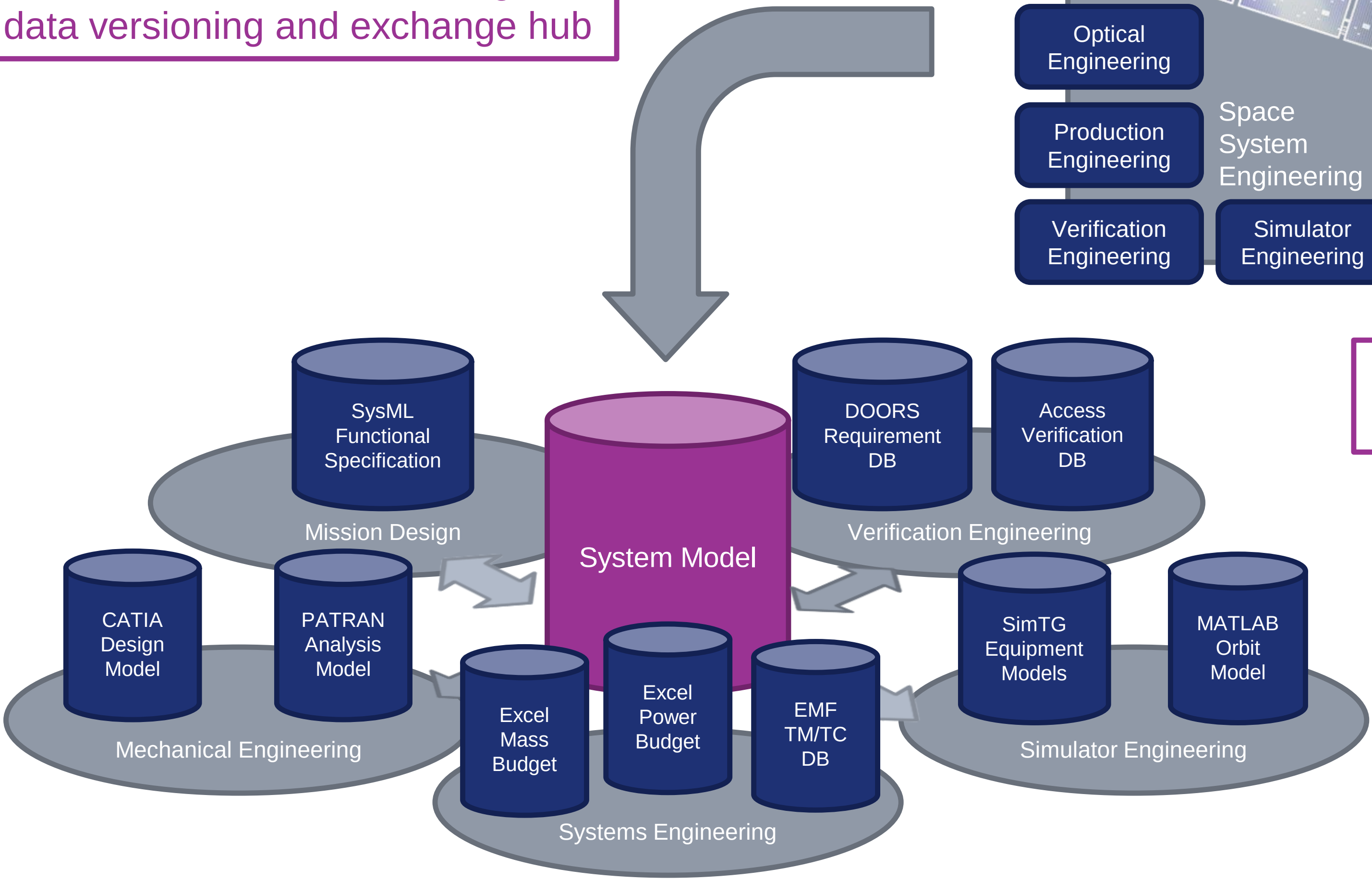

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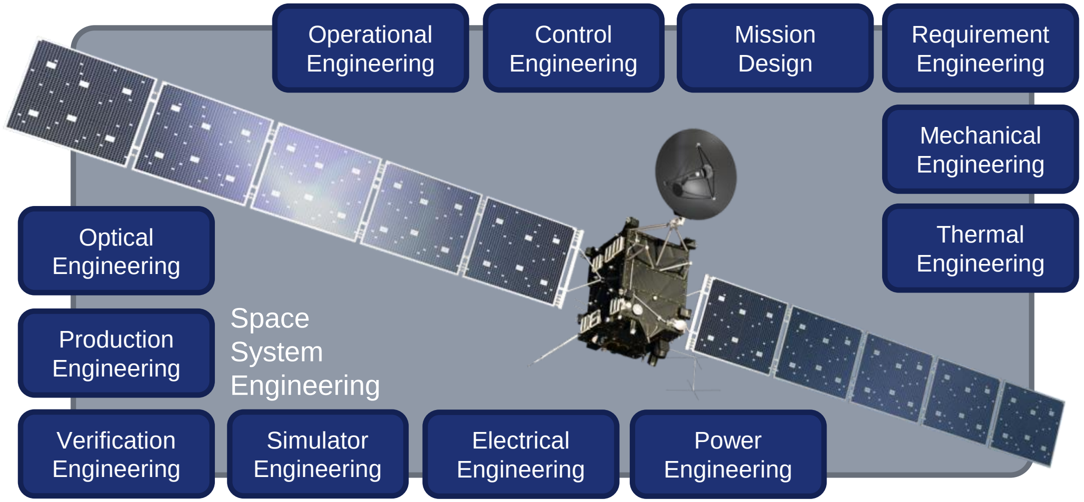

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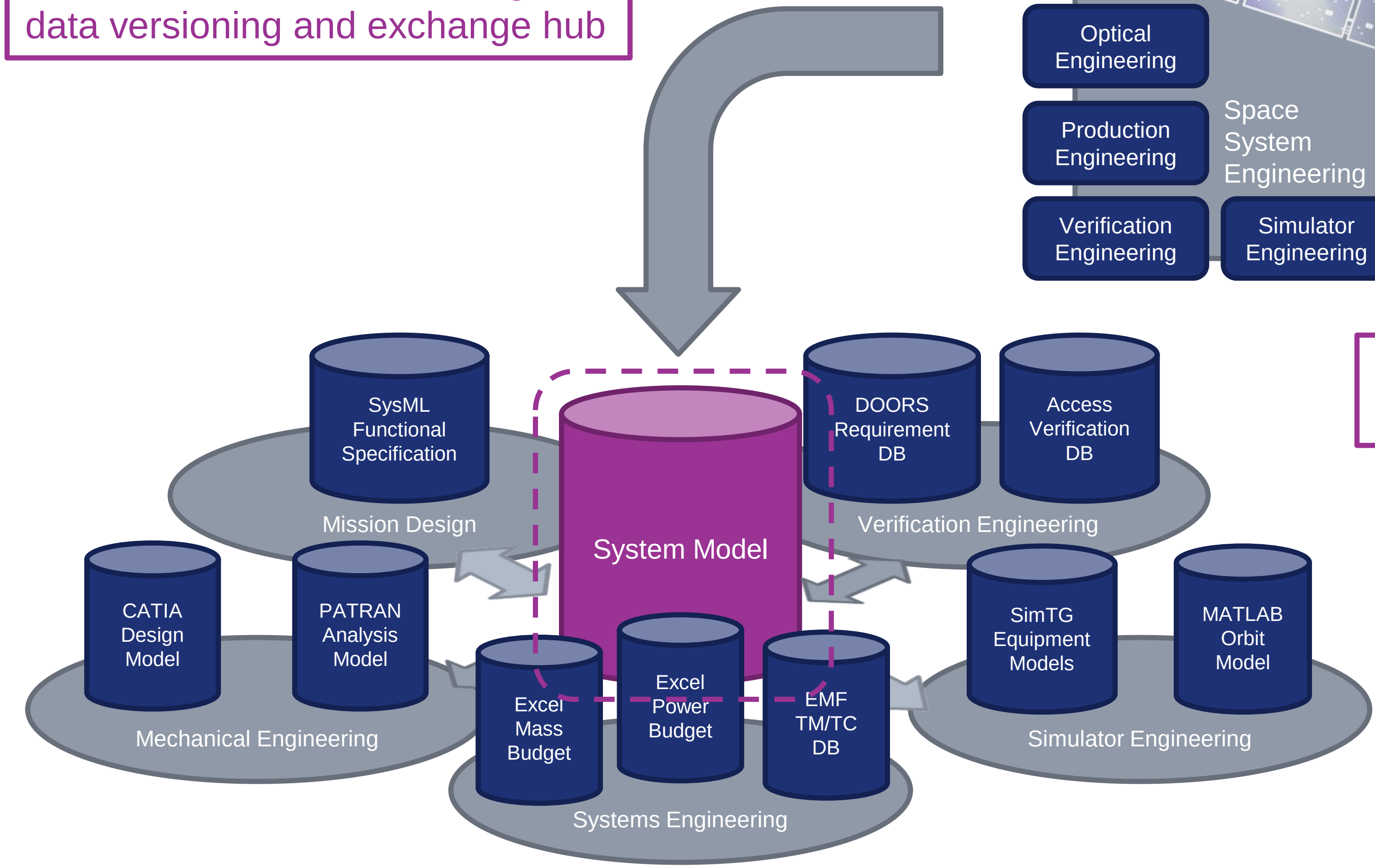

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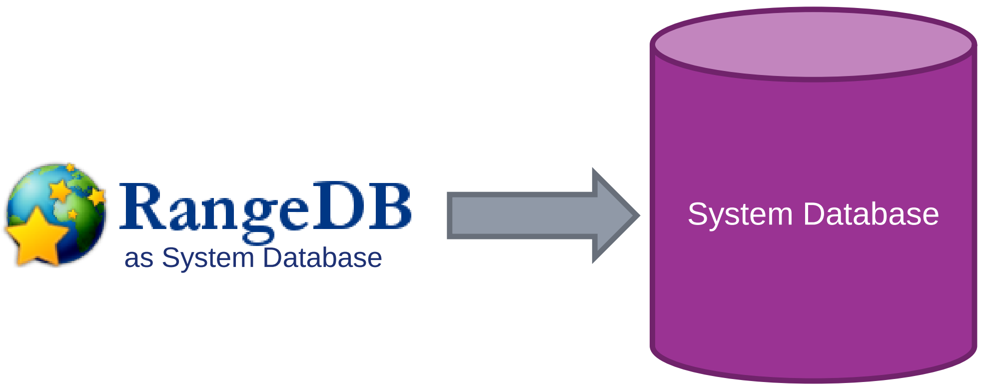
RangeDB developed by Airbus DS as engineering data management solution: Object-oriented database based on UML data specification



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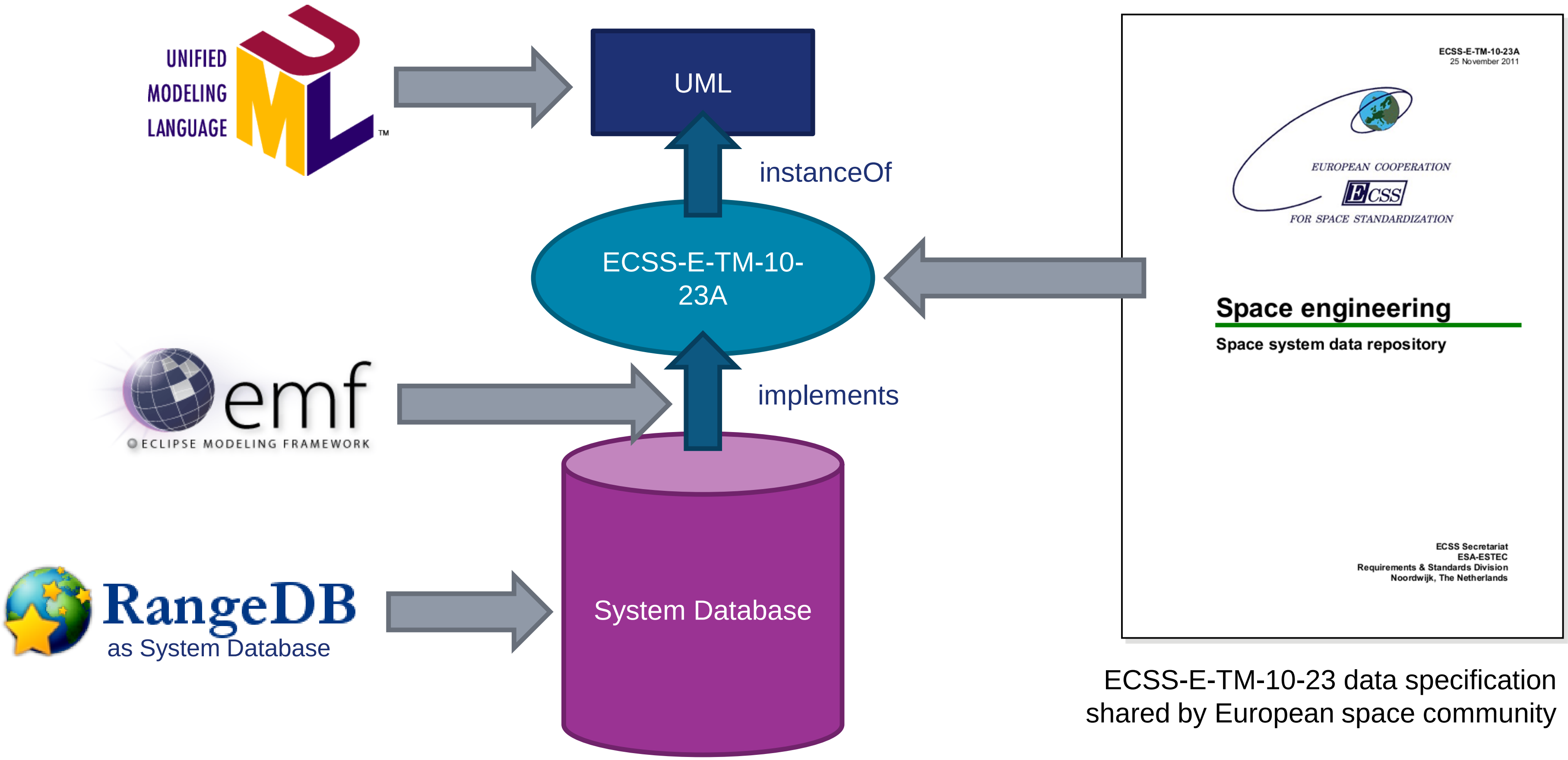

ECSS-E-TM-10-23 data specification shared by European space community

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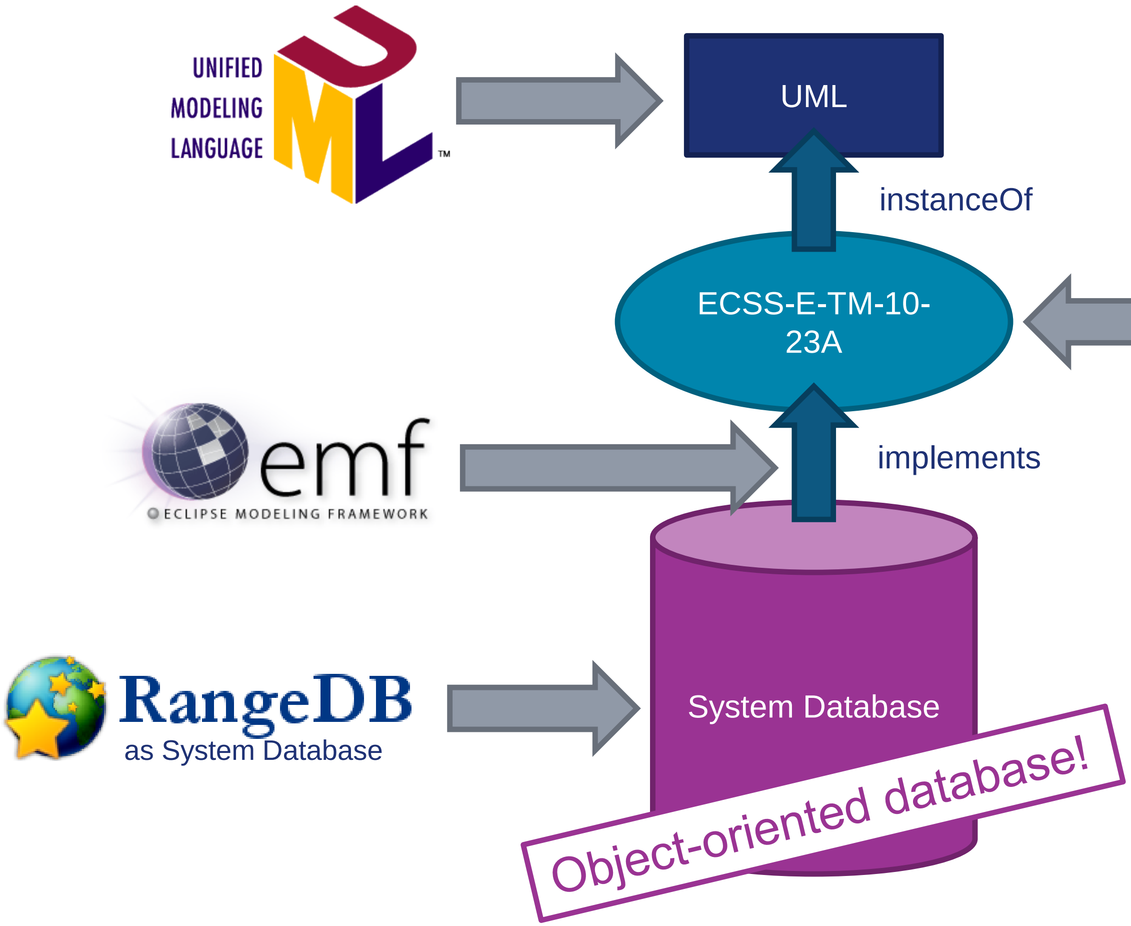

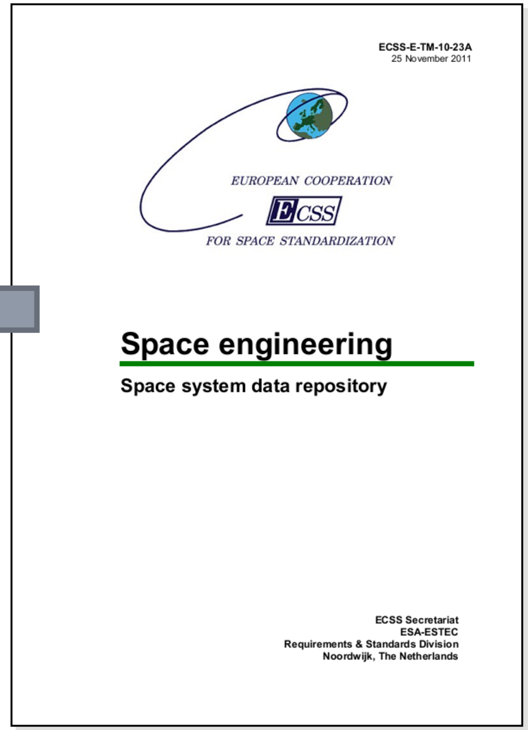
ECSS-E-TM-10-23A
25 November 2011
EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space engineering

Space system data repository

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

ECSS-E-TM-10-23 data specification shared by European space community

Hennig, et al., 2016. Ontology-Based Design of Space Systems.

Current approach with a number of shortcomings

- SC1: Necessity for cost-efficient deployment of system modeling application often leads to using generic structures for CDM implementation, weakening semantics of defined concepts
- SC2: Inadequate tailoring support, resulting in re-deployment of s… …ific projects
- SC3: No explicit discipline context inform… …out on further supporting the interdisciplinary nature of the system design pr…
- SC4: No real exploitation … …g system design data, as the main focus is on data versioning and exchange and concepts required for associating real semantics to CDM concepts are missing
- SC5: No existing capture and application mechanism for operational knowledge

In essence: A lot of data exists, but the underlying data structures do not allow its full exploitation.

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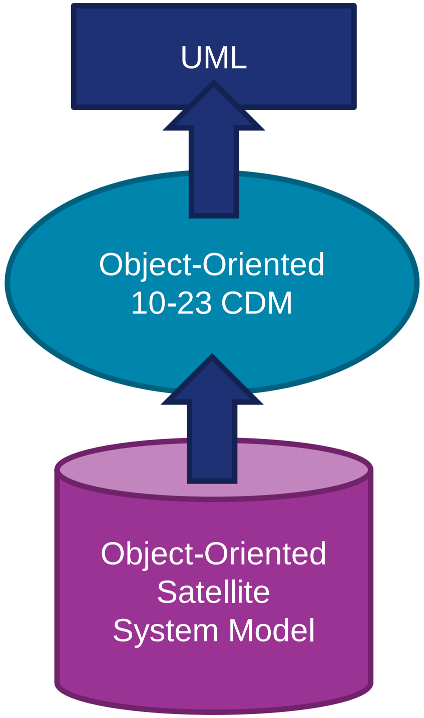
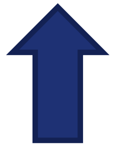
Usage of OWL 2 for improving identified shortcomings

Approach: Re-hosting of existing Data Model and System Model in OWL 2, additional formalization of operational knowledge





instance of

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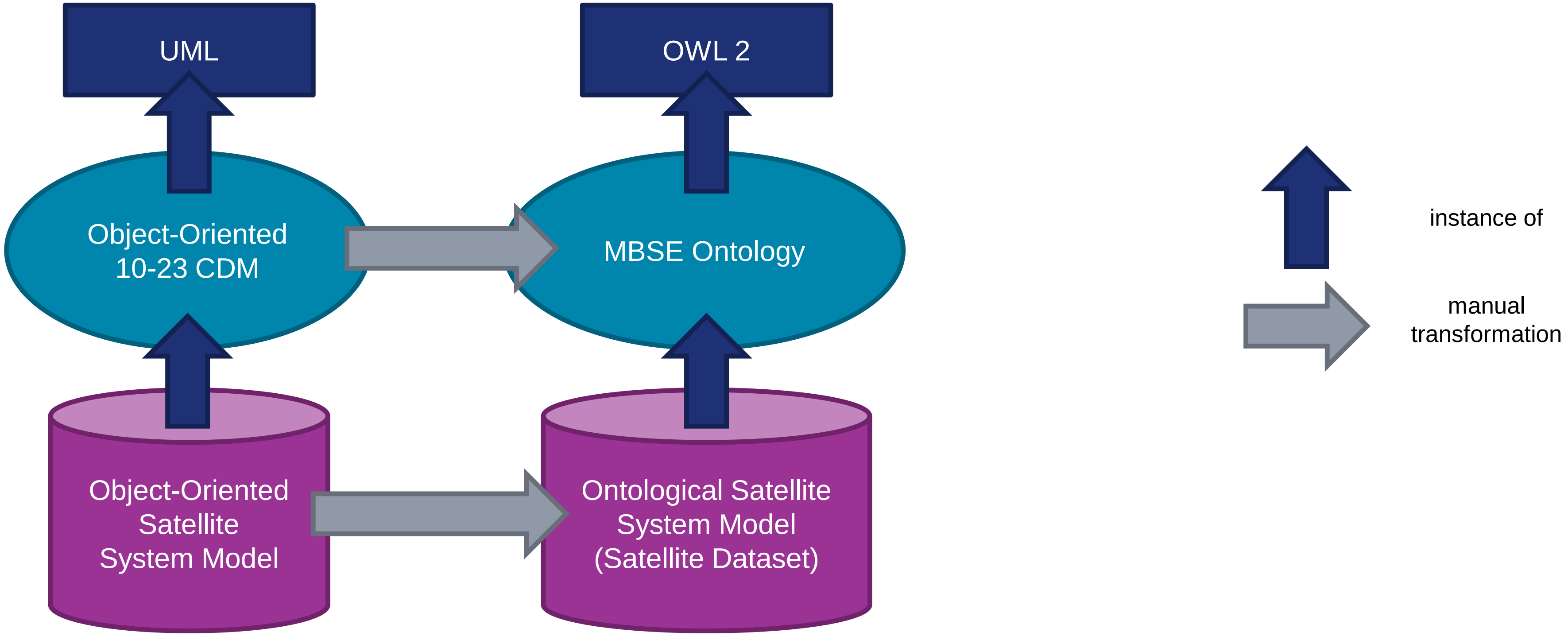

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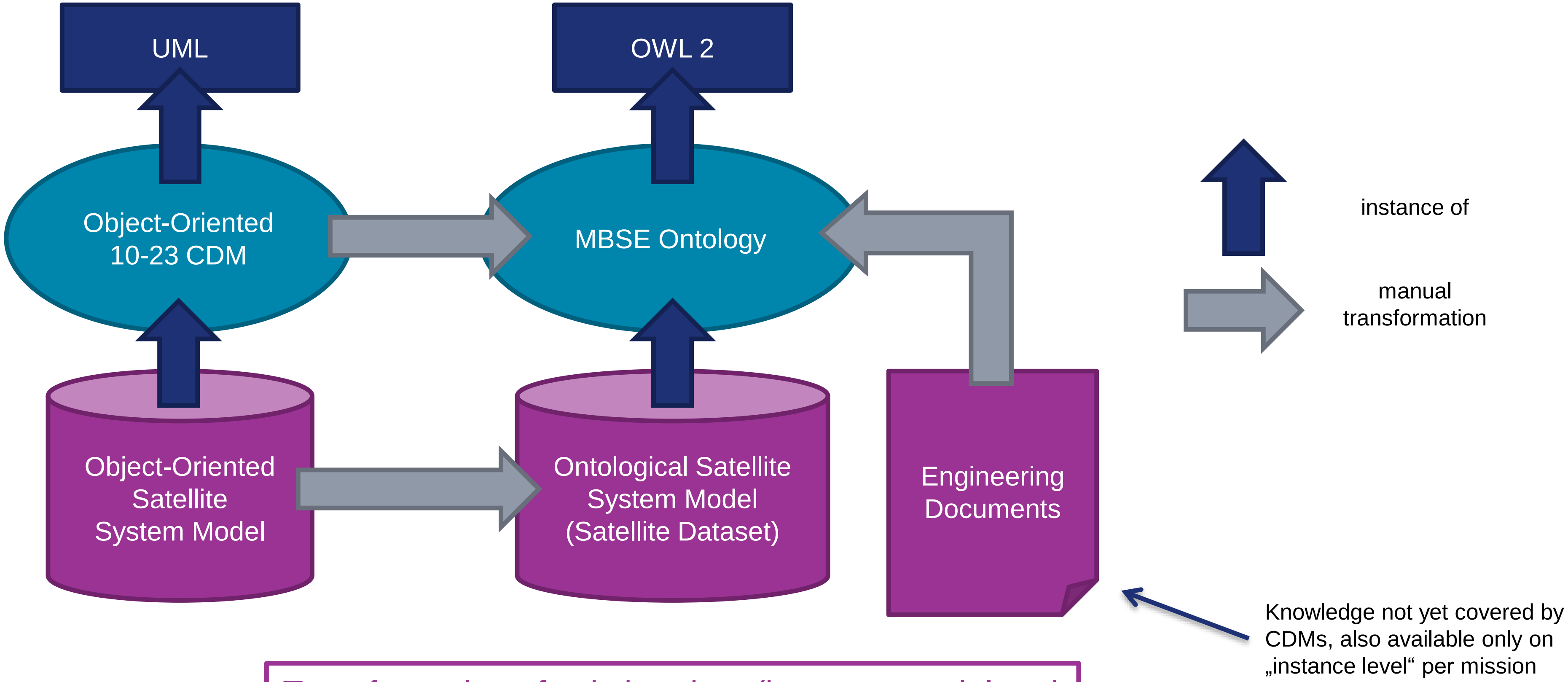

Transformation of existing data (instance model and data model) into an OWL 2 description

Hennig, et al., 2016. Ontology-Based Design of Space Systems.

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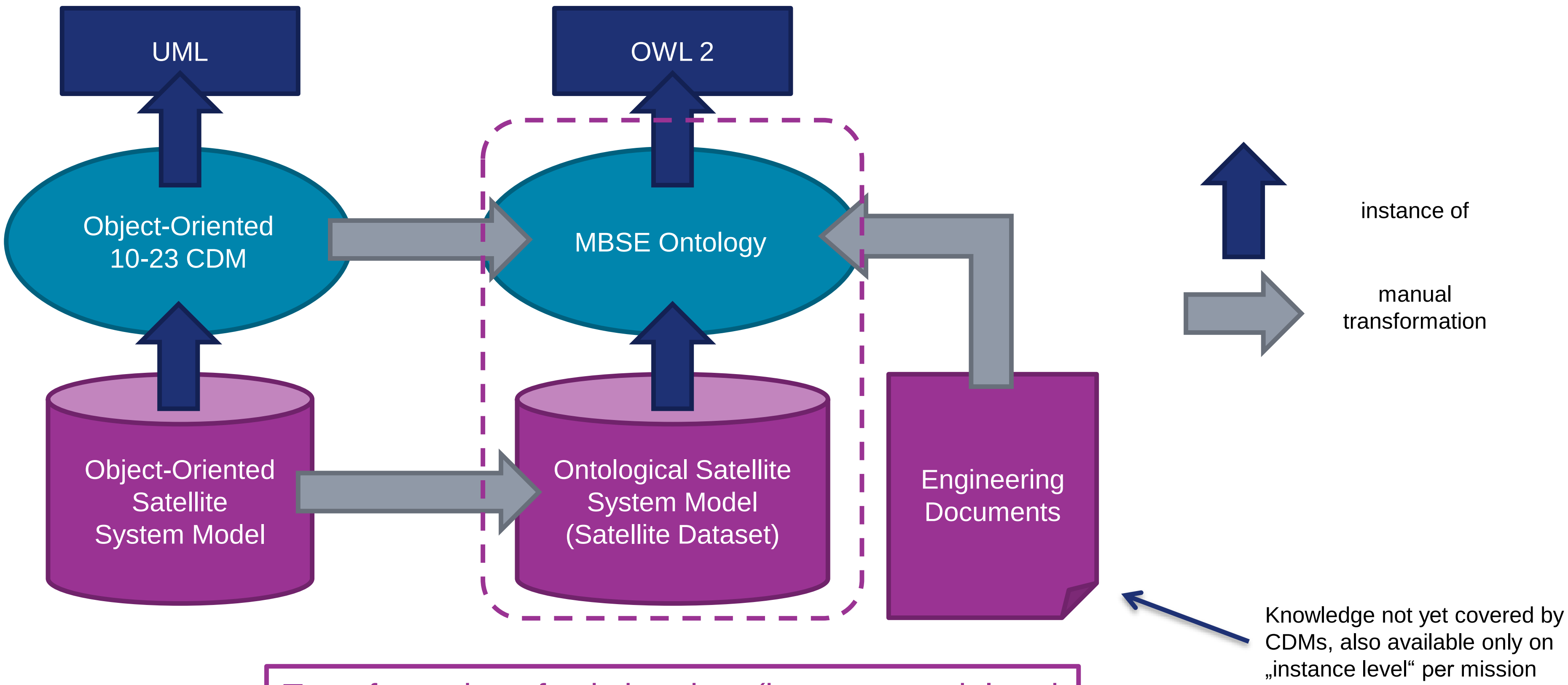

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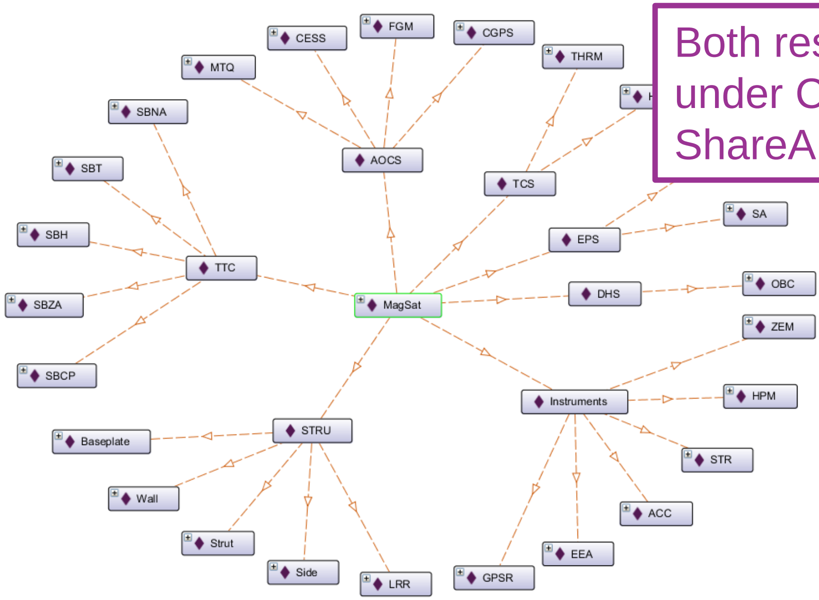
MBSE Ontology and Satellite Dataset freely available

	MBSE Ontology	MagSat Dataset
Axiom count	1632	1102
Logical axiom count	946	779
Declaration axioms count	664	301
Class count	360	14
Object property count	93	0
Data property count	30	0
Individual count	181	280
Expressivity	SROIQ(D)	



Both resources available at Zenodo under Creative Commons Attribution-ShareAlike (CC BY-SA) license

http://dx.doi.org/10.5281/zenodo.57955
http://dx.doi.org/10.5281/zenodo.57957

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Contributions

- Outlining of shortcomings of the established industrial data management practice used in space system engineering.
- Delivery and application of an ontology for model-based space systems engineering for supporting numerous activities involved in a satellite's design.
- Critical discussion on how OWL 2 can fit into current industrial data management and model-based systems engineering settings.

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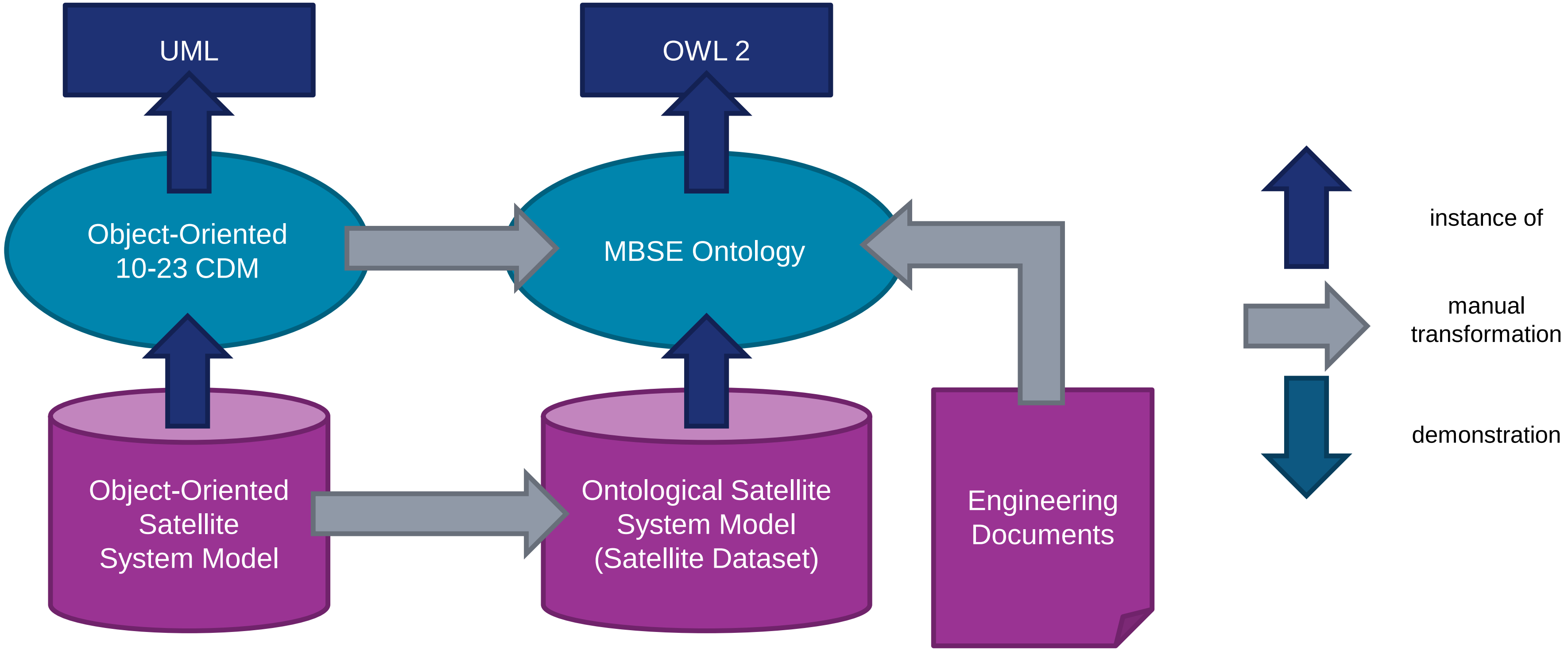
Approach: Re-hosting of existing CDM and System Model in OWL 2, additional formalization of operational knowledge



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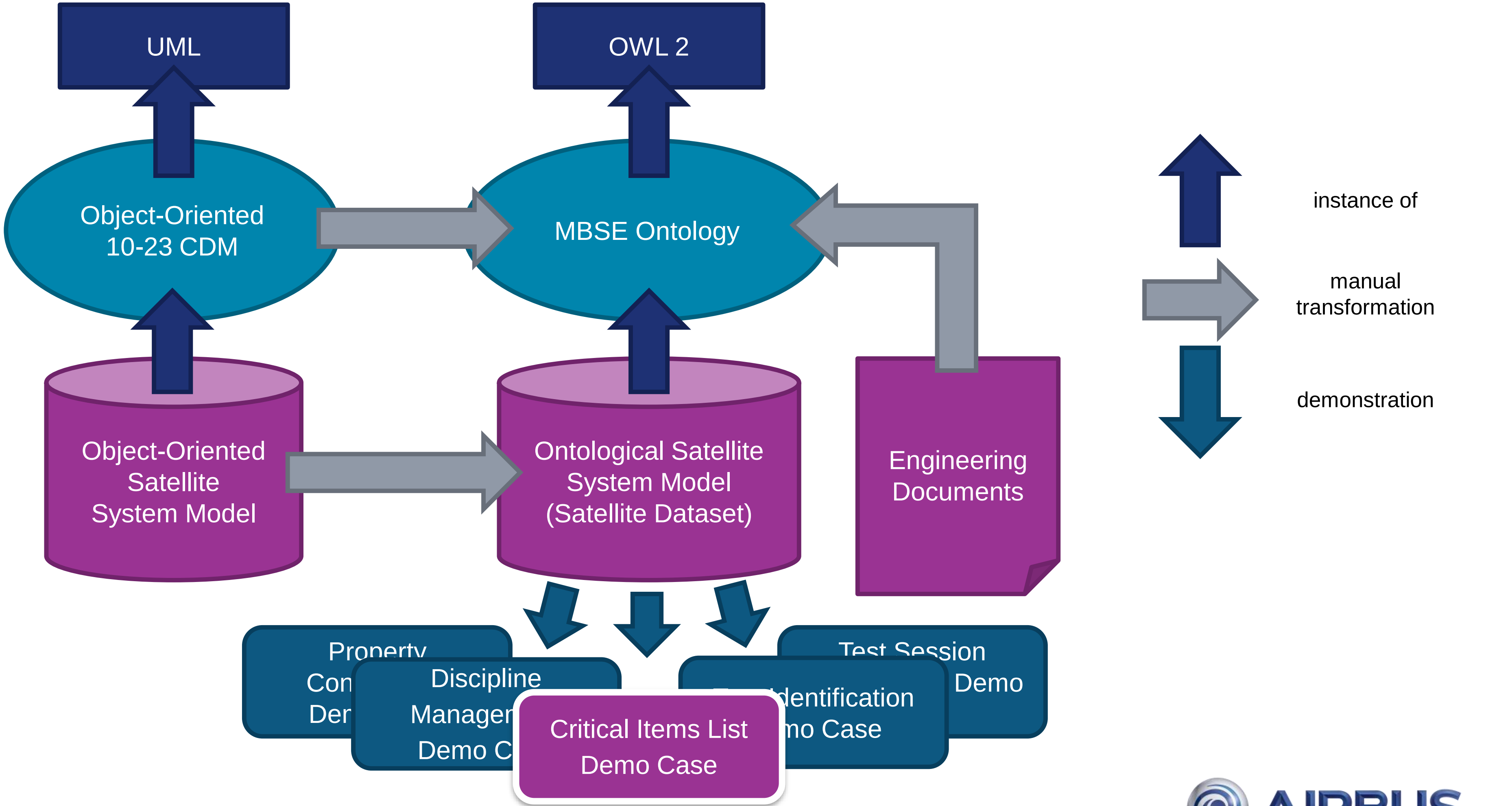
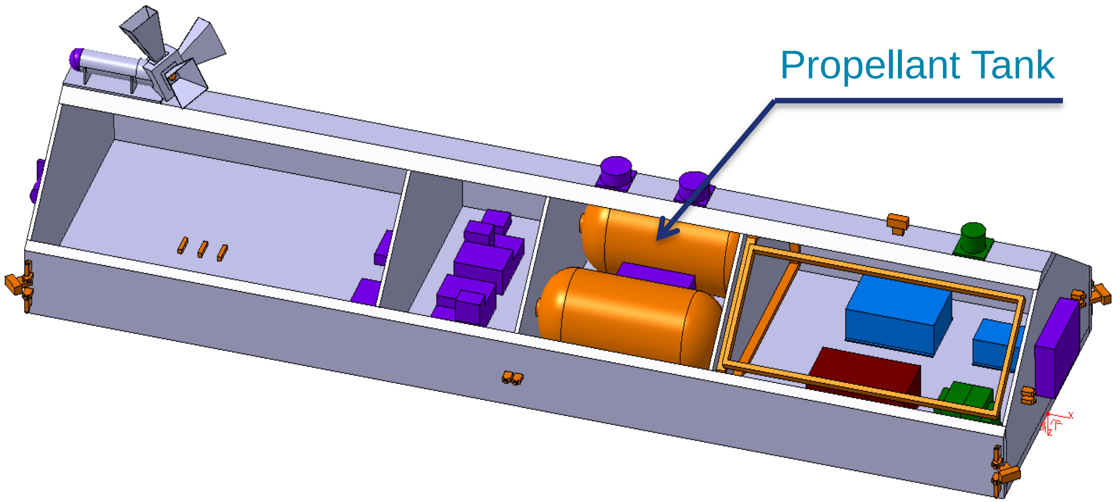


Hennig, et al., 2016. Ontology-Based Design of Space Systems.

Current manual process

Generation and Administration of the Critical Items List (CIL) as currently established (roughly)



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Current manual process

Generation and Administration of the Critical Items List (CIL) as currently established (roughly)

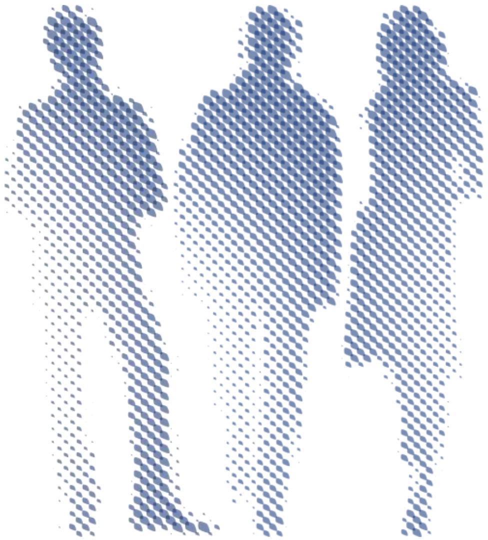
Technology critical item? Safety critical item?

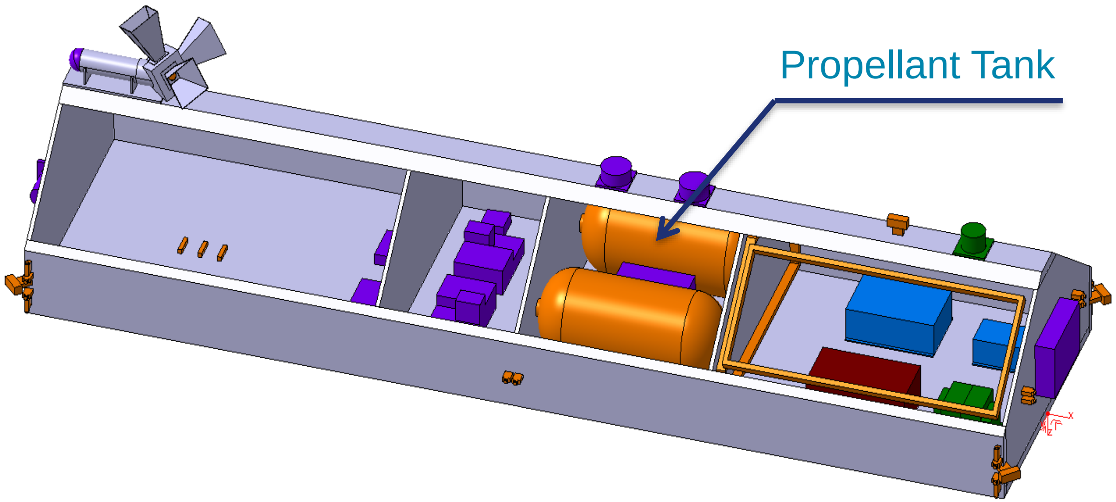
Single point of failure? …?

Life limited item? Item with non-recoverable errors?

Contamination critical item?

Does the element exhibit any kind of criticality?





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Technology critical item? Safety critical item?

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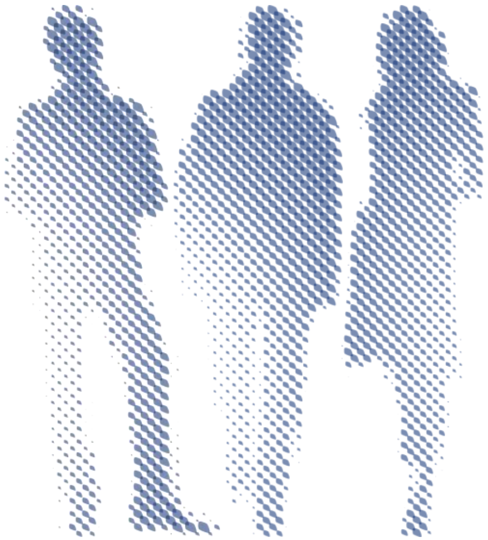
Contamination critical item?

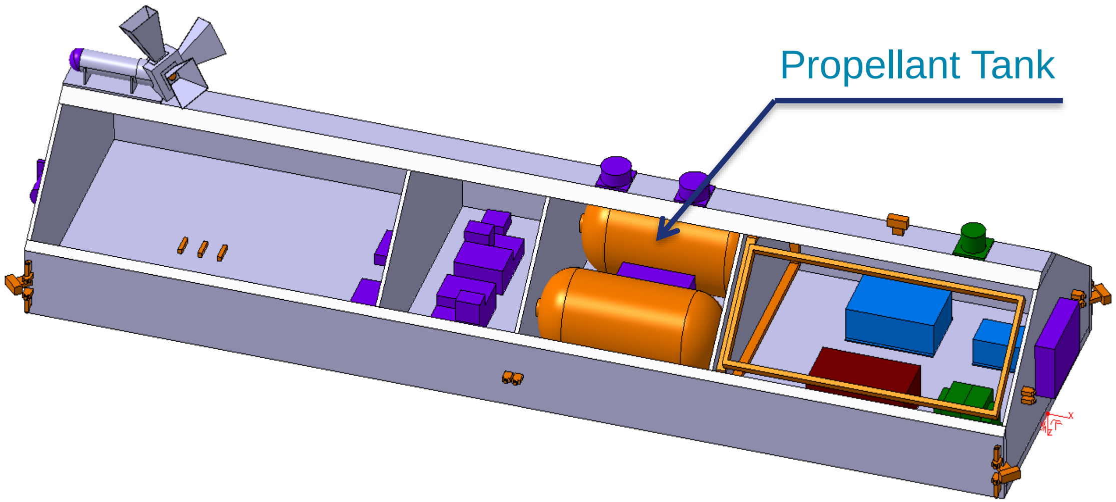
Does the element exhibit any kind of criticality? → **What are the effects of the criticality?**

Fill/vent cycles lead to material wear

In case of rupture during test injury to personnell

In case of rupture during flight loss of spacecraft





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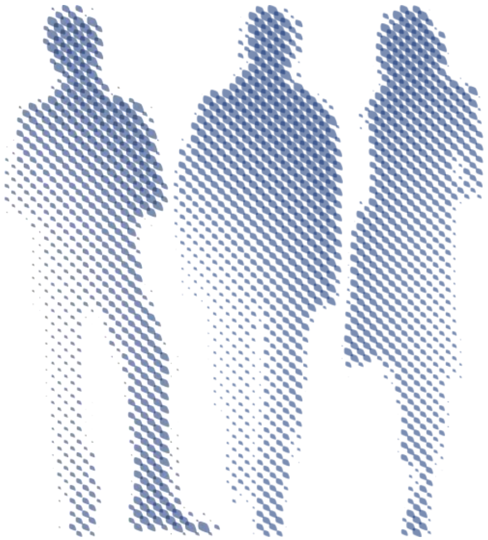
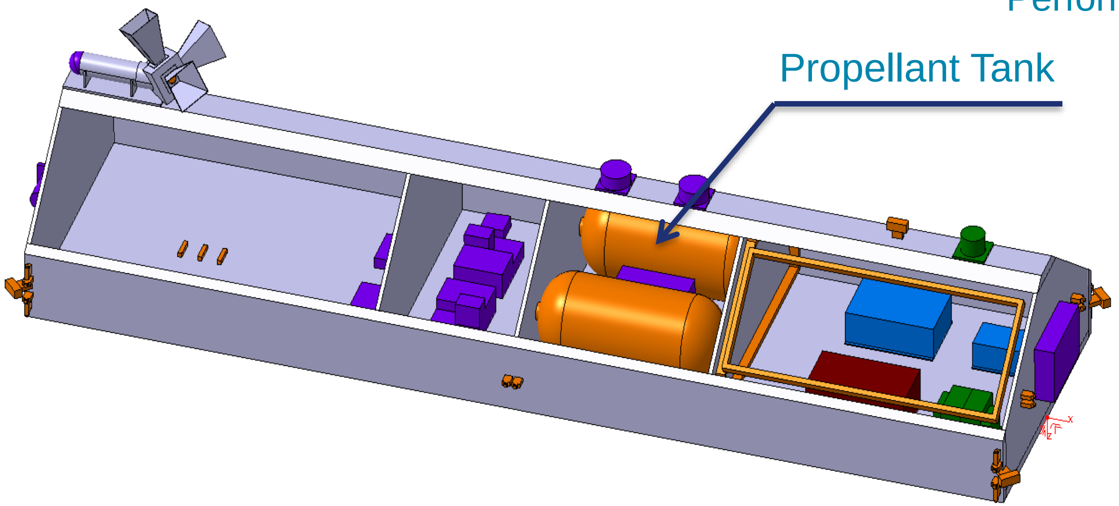
Safety critical item?
Single point of failure?
…?
Life limited item?
Item with non-recoverable errors?
Contamination critical item?

Does the element exhibit any kind of criticality? → What are the effects of the criticality? → What are risk reduction measures?

Fill/vent cycles lead to material wear
In case of rupture during test injury to personnell
In case of rupture during flight loss of spacecraft

Follow leak before burst design
Perform burst test
Perform proof pressure test
Perform dye penetrant flaw detection
Limit number of cycles
Include design margins





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Current manual process

Generation and Administration of the Critical Items List (CIL) as currently established (roughly)

- Activity performed by experienced experts
- Has to be done for each component
- Potential to miss out on critical item assertions
- Highly formal work, but also a lot of thinking required
- Maintenance of list required during all project phases

Technology critical item? Safety critical item?

Single point of failure? …?

Life limited item? Item with non-recoverable errors?

Contamination critical item?

Does the element exhibit any kind of criticality? → What are the effects of the criticality? → What are risk reduction measures?

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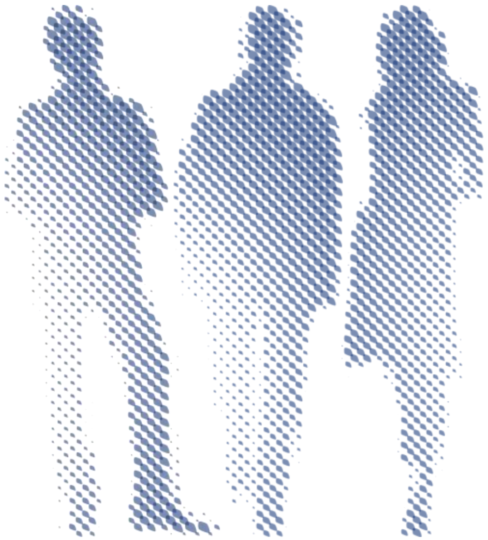

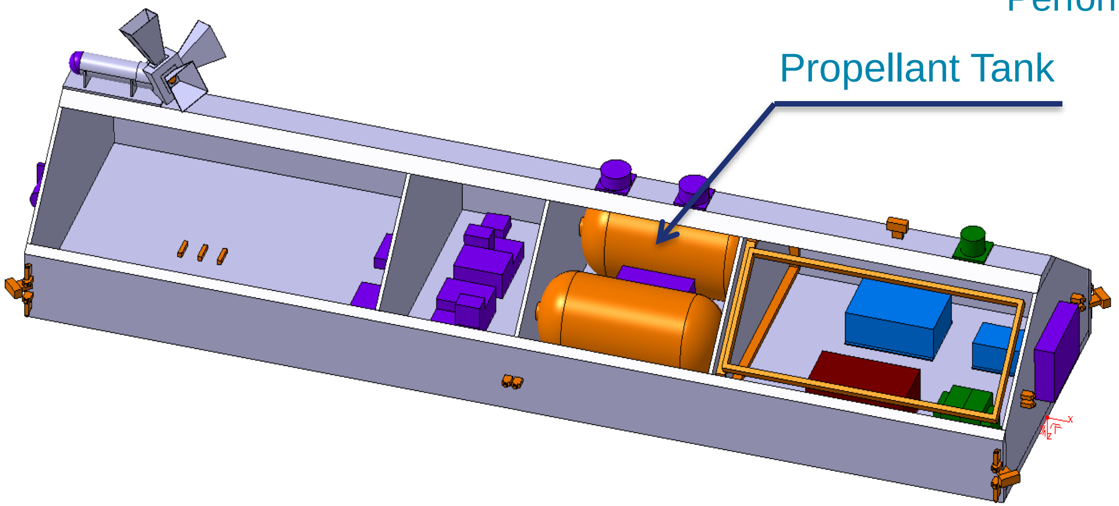

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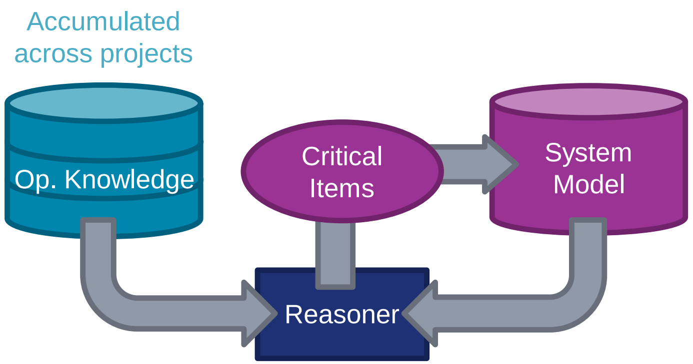
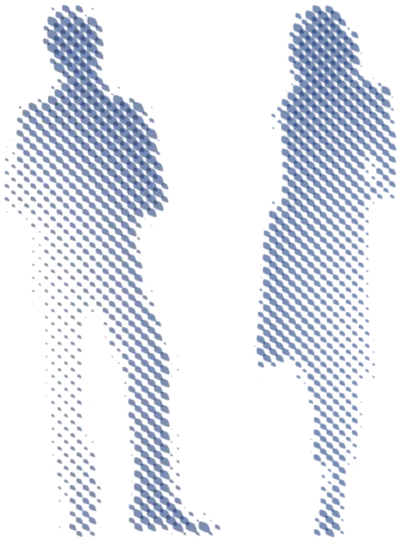
Automated, ontology-driven process

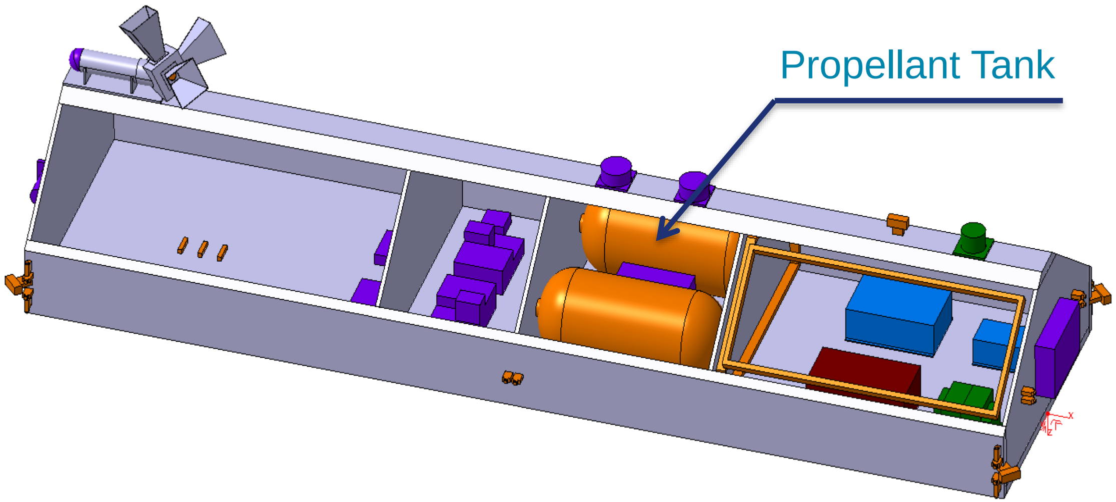
Generation and Administration of the Critical Items List (CIL) ontology-supported approach



Inferred Statements

PropellantTank : LifeLimitedItem
PropellantTank hasFailureEffect MaterialWear
PropellantTank hasRiskReductionMeasure LimitNumberOfCycles
…
PropellantTank : SafetyCriticalItem
PropellantTank hasFailureEffect InjuryToPersonnell
PropellantTank hasRiskReductionMeasure FollowLeakBeforeBurstDesign
…





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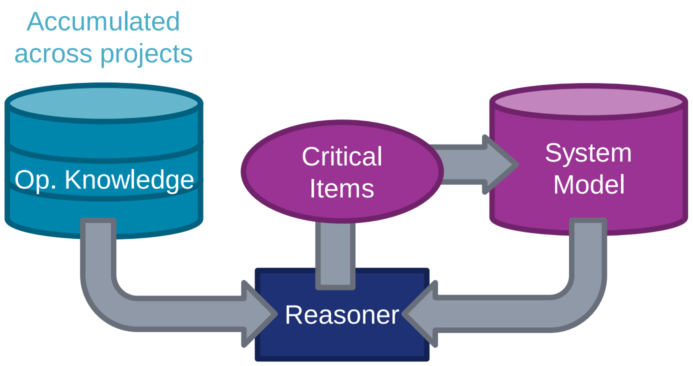


Asserted Statements:

StarTrackerBootLoaderMemory : PROM

StarTrackerBootLoaderMemory contains StarTrackerBootLoader

StarTrackerBootLoader : StartupSoftware

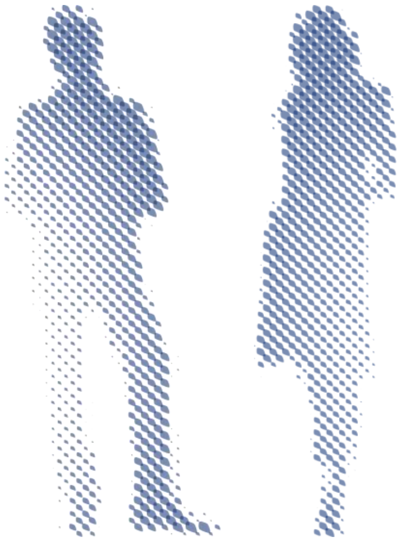
Inferred Statements:

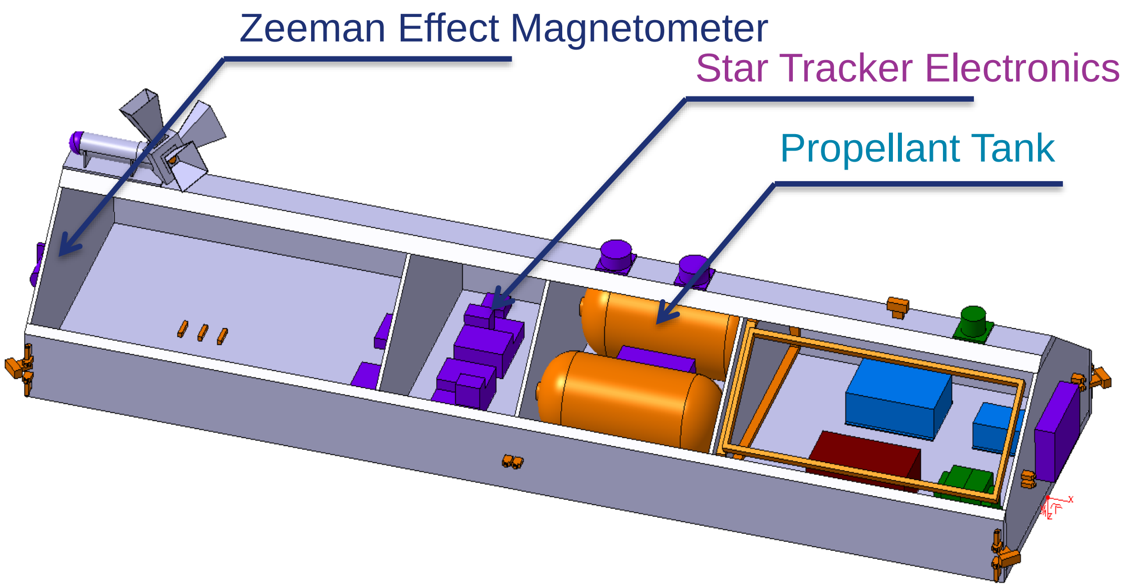
StarTrackerBootLoader : UnpatchableStartupSoftware

StarTrackerBootLoader hasFailureEffect SofwareBugMayLeadToBootFailure

StarTrackerBootLoader hasRiskReductionMeasure HighDegreeOfQuality

StarTrackerBootLoader hasRiskReductionMeasure CodeInspectionRequired





Lessons Learned and Conclusion

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The usage of OWL 2 in the MBSE context draws an ambivalent picture

Good deal of helpful functionality introduced by usage of OWL 2

- Classification of individuals based on modeled information
- Ability to infer new property assertions on individuals based on asserted types
- Explanation of made inferences
- Ability to ensure semantic consistency of a multi-classification environment

Ambivalent aspects that behave „differently“ compared to existing engineering data management applications

- Nonunique Naming Assumption
- Possibility to manage data in the ABox that is not scoped by the TBox

However, also problematic aspects were introduced

- Lack of built-in part-of/containment/composition semantics
- Shortcomings when reasoning with numeric values
- Lack of closed world behavior, no possibility to employ negation as failure

Conclusion

- Direct replacement of current system models with ontologies not feasible, too much in contrast to established modeling and working approach
- However, ontology-based system models introduce functionality benefical to system design quality, system development cost, and time required, that cannot be ignored
- Exploration of hybrid architectures that offer both object-oriented and ontological semantics on system level

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Generation and Administration of the Critical Items List (CIL) - Conclusion

	Total classes	Modeled classes	Inferred critical item assertions	Inferred total effects	Inferred total measures
Contamination critical items	3	3	4	4	4
Life limited items	12	5	6	7	13
Magnetic cleanliness items	10	7	11	11	10
Safety critical items	31	22	27	45	64
Total	**56**	**37**	**48**	**67**	**91**

No satisfying solution found for modeling the class of Single Points of Failure, due Open World Assumption

This demonstration case deals deals with SC4 (Inadequate exploitation of existing system design data) and SC5 (No notion of knowledge base)

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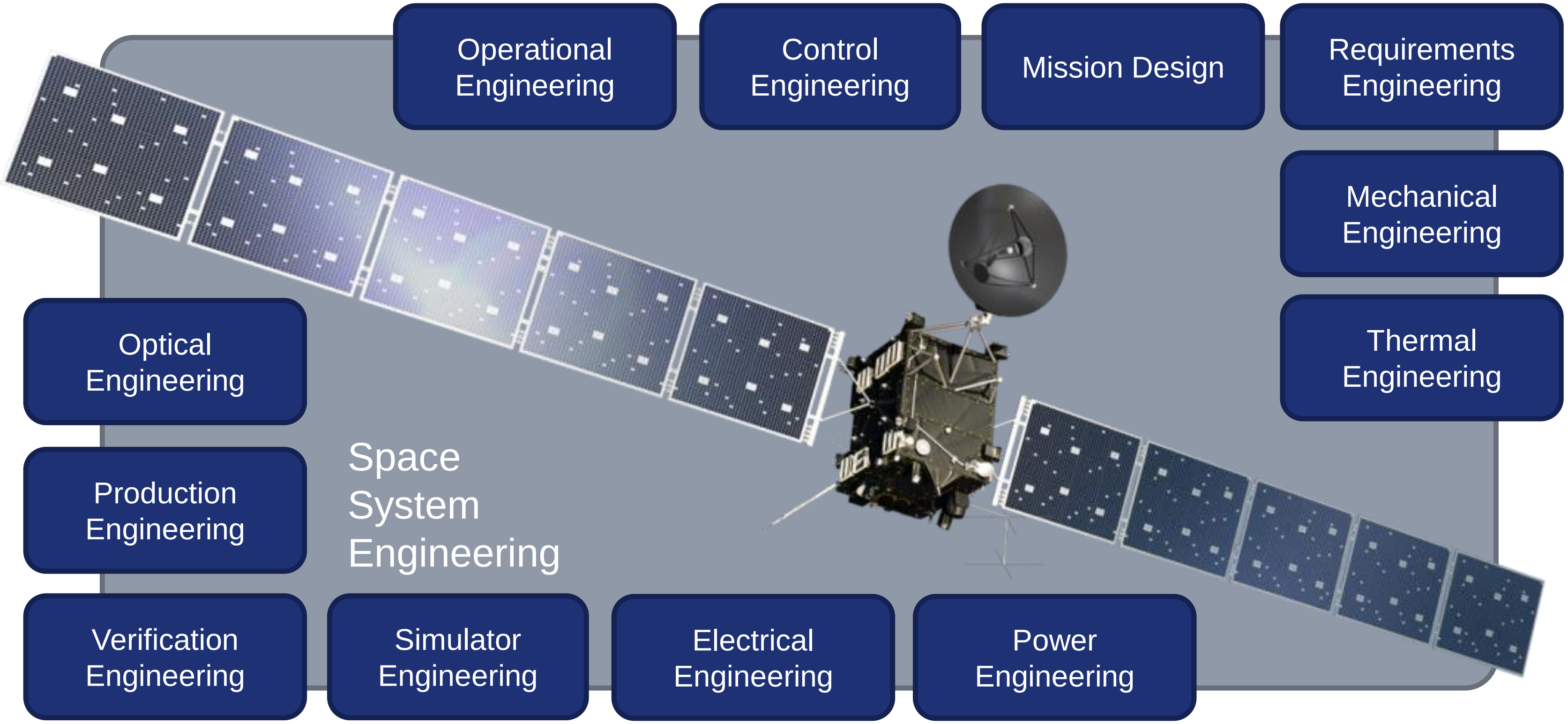

- Systems engineering is a means to manage complexity and coordinate disciplines
- First usage in the 1940s at Bell Labs
- First large-scale employment during development of the Atlas ICBM, key success factor in Apollo space program
- Spreading into other domains, such as automotive, healthcare, infrastructure

Image credits: European Space Agency, "ESA Science & Technology: Rosetta," 2015. [Online]. Available: http://sci.esa.int/rosetta/

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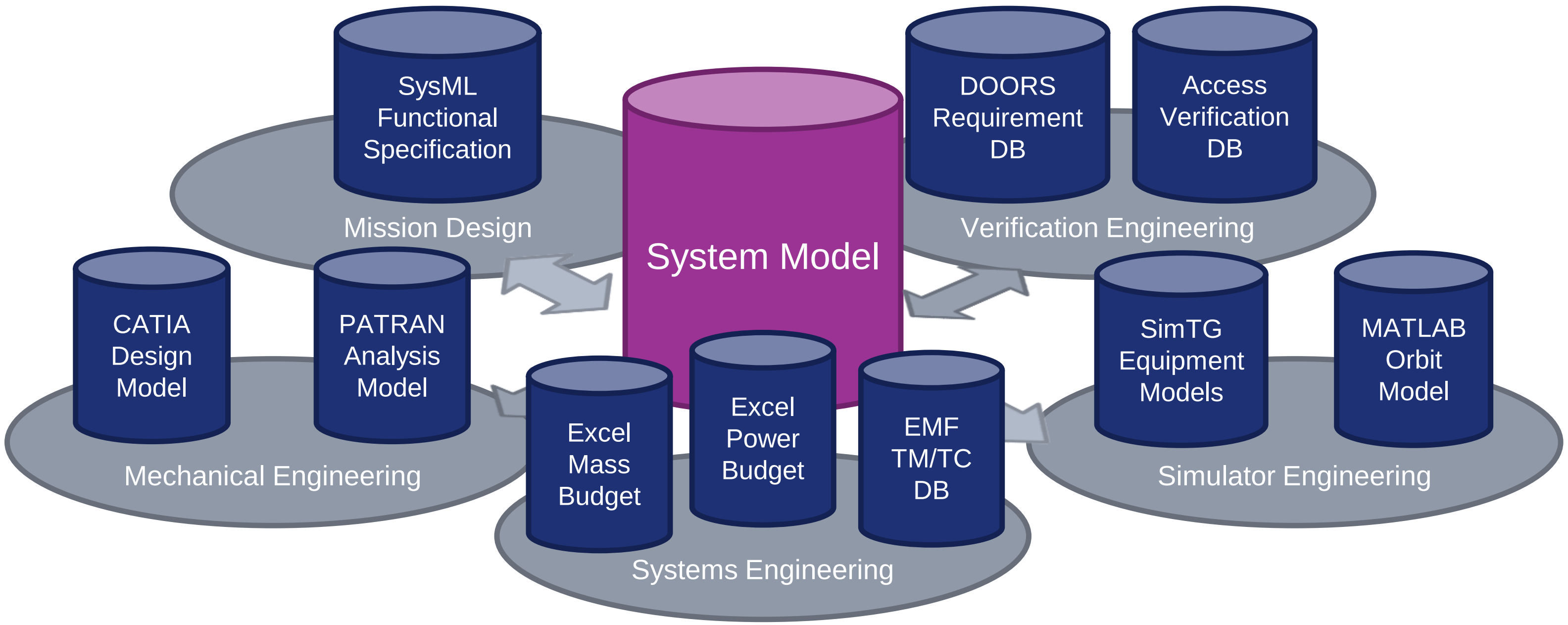
System model as a central hub for data management and exchange in the approach of „Model-based Systems Engineering“ (MBSE)



- Domains well covered by mature models and model chains
- System model as a facilitator for data management and exchange, and as container for system design
- Possibility to perform operations on the system design that required data from numerous disciplines

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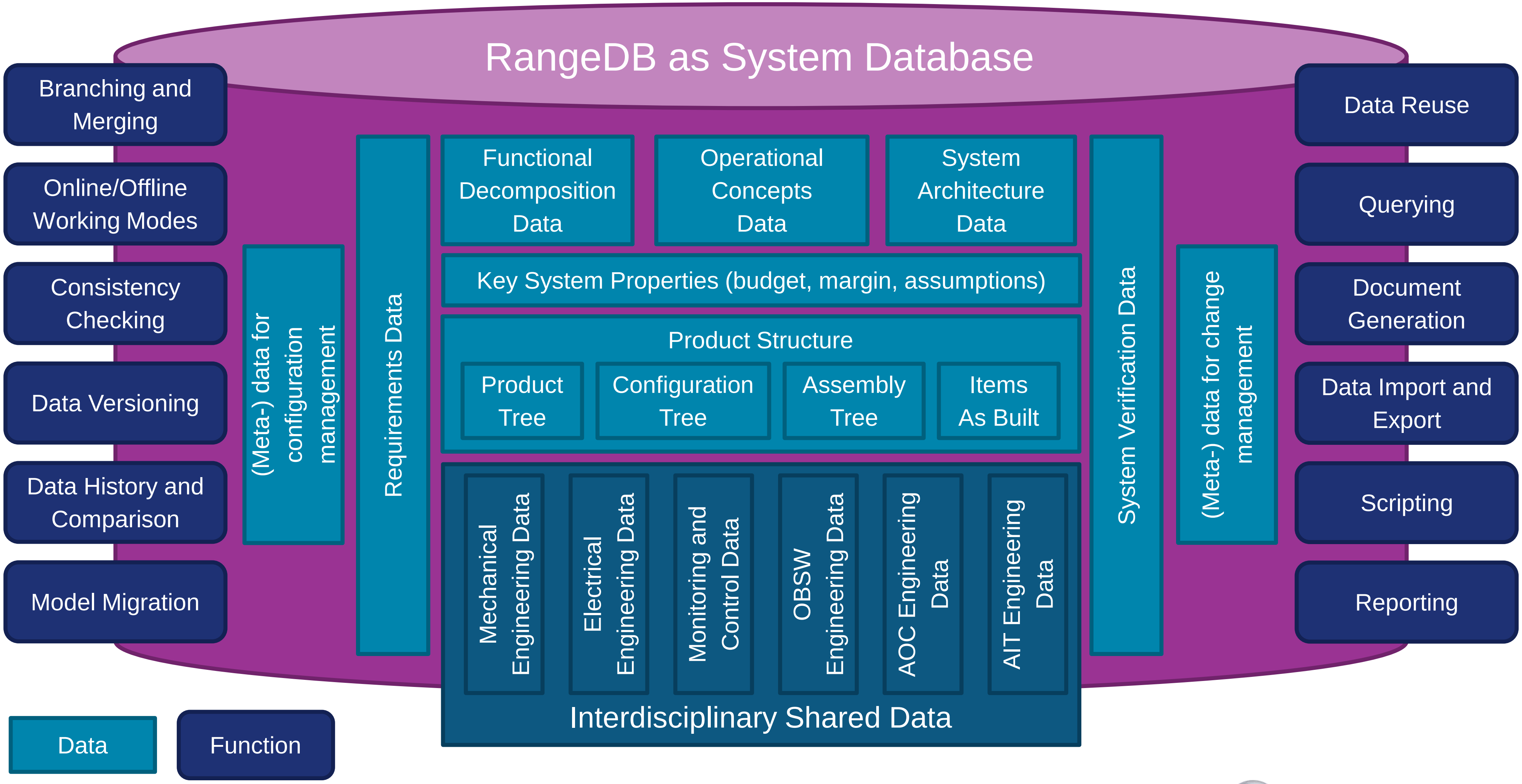
Implementation of the MBSE appraoch at Airbus DS with RangeDB



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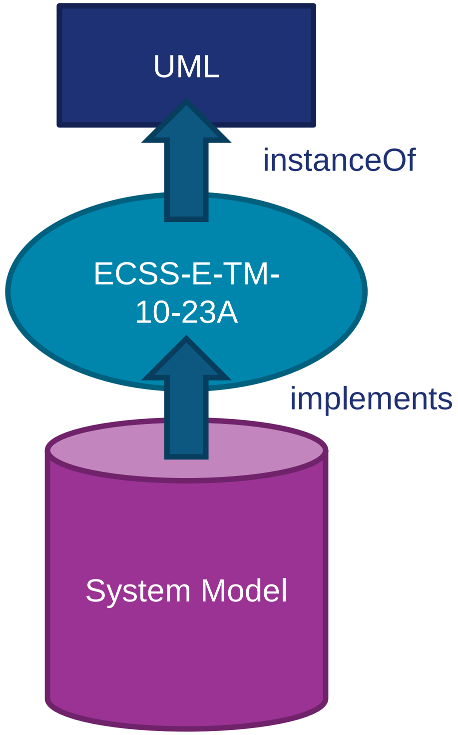
Technical background of data specification approach



Object-oriented database implementing a data specification shared by the community

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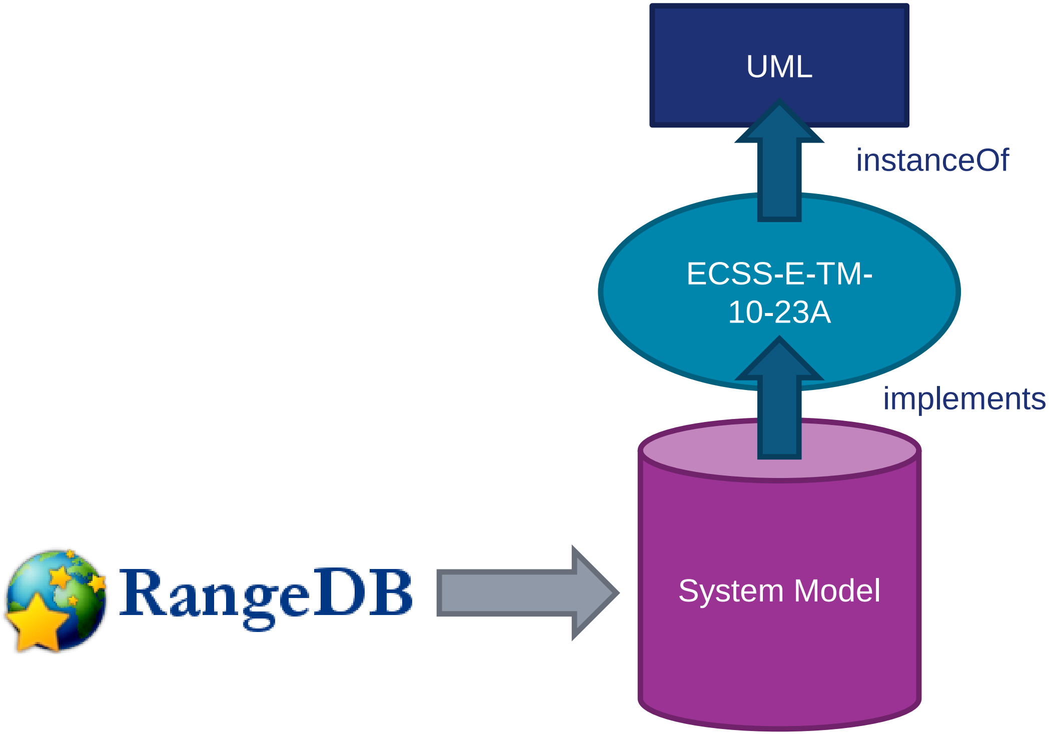
Technical background of data specification approach

M0
System Model



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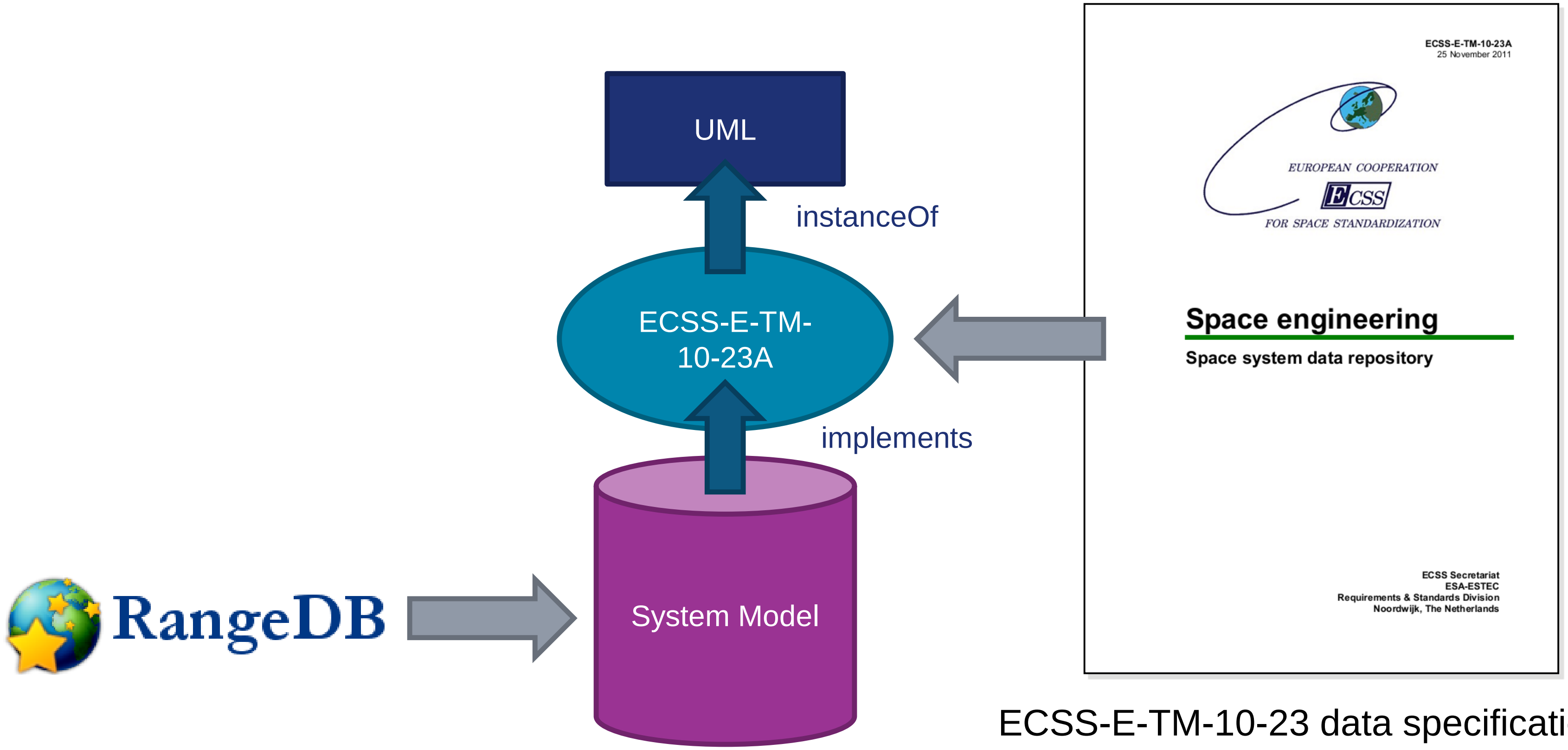
Technical background of data specification approach

Conceptual
Data Model
M1

M0
System Model



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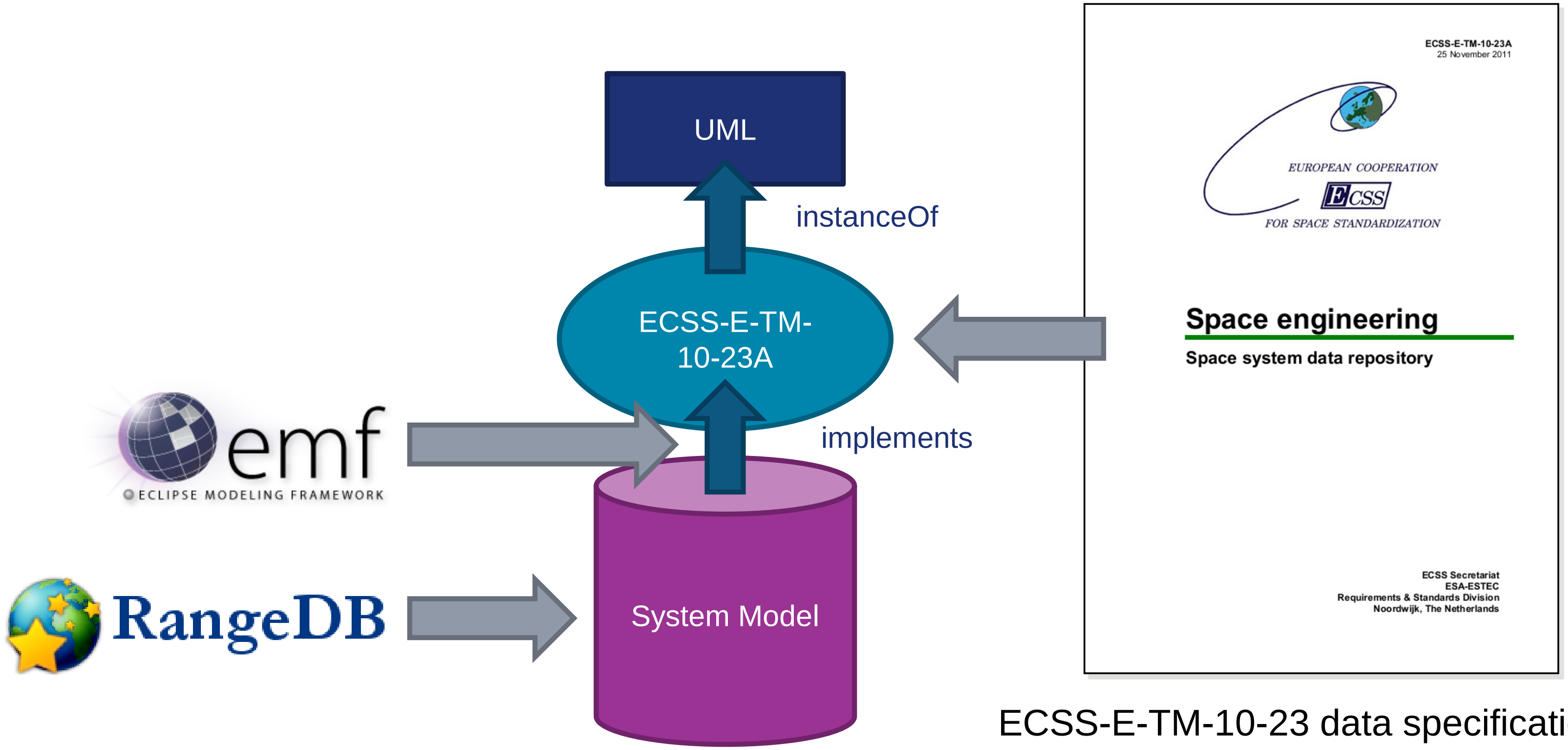
Technical background of data specification approach

Conceptual
Data Model
M1
Logical and Technical
Data Models

M0
System Model



ECSS-E-TM-10-23 data specification shared by European space community

Object-oriented database implementing a data specification shared by the community

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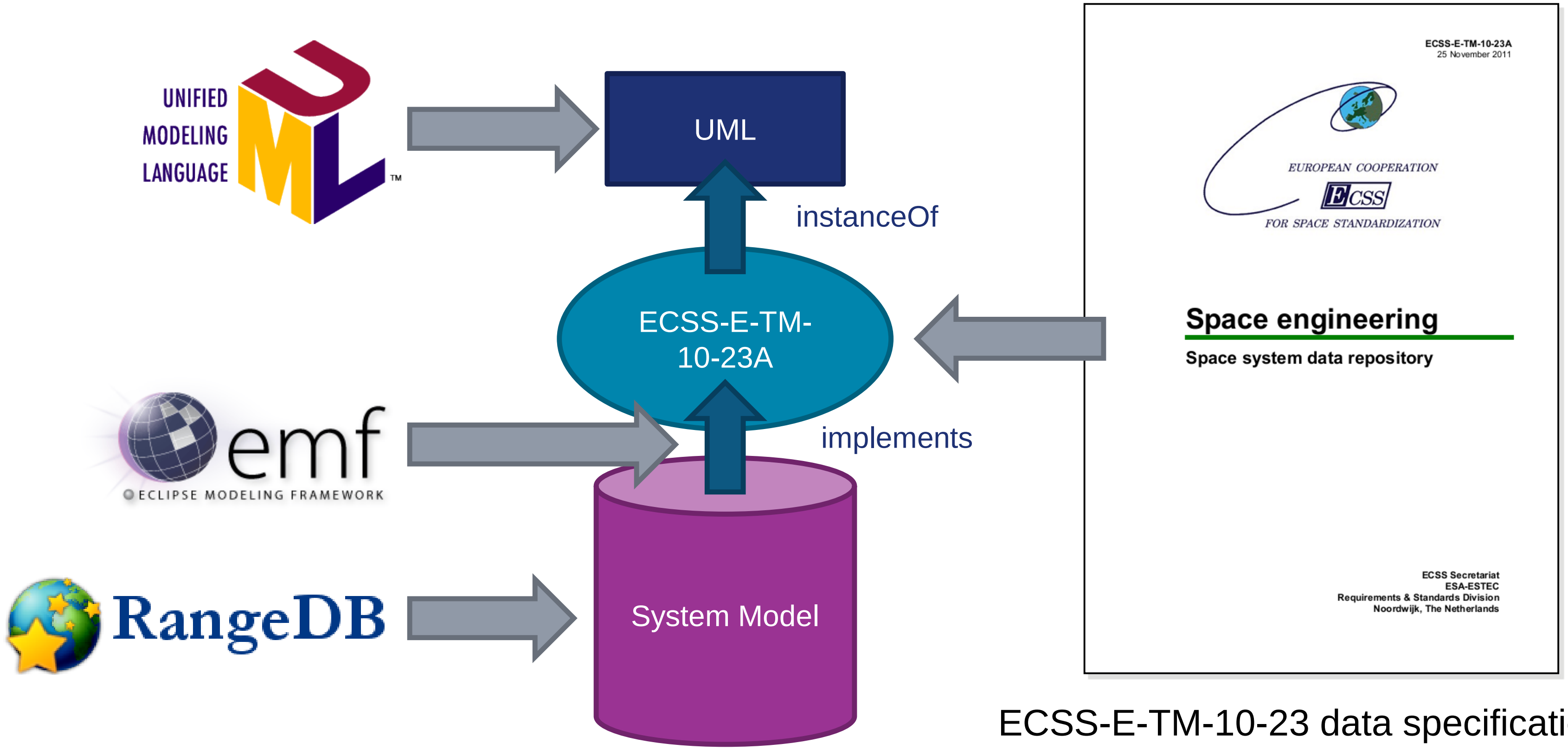
Technical background of data specification approach

M2
(Data) Modeling Language

Conceptual Data Model
M1
Logical and Technical Data Models

M0
System Model

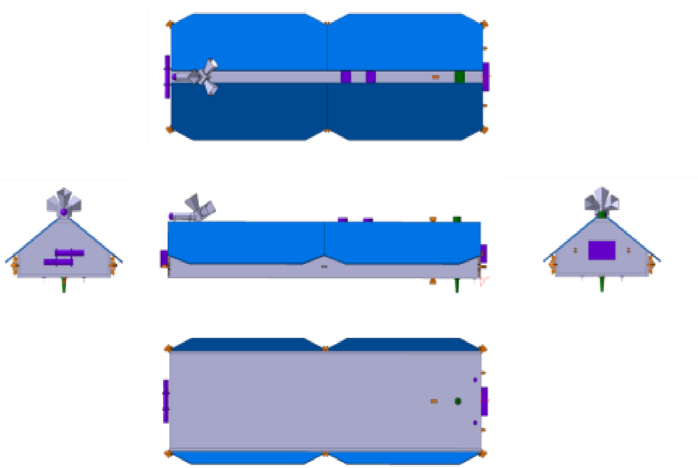


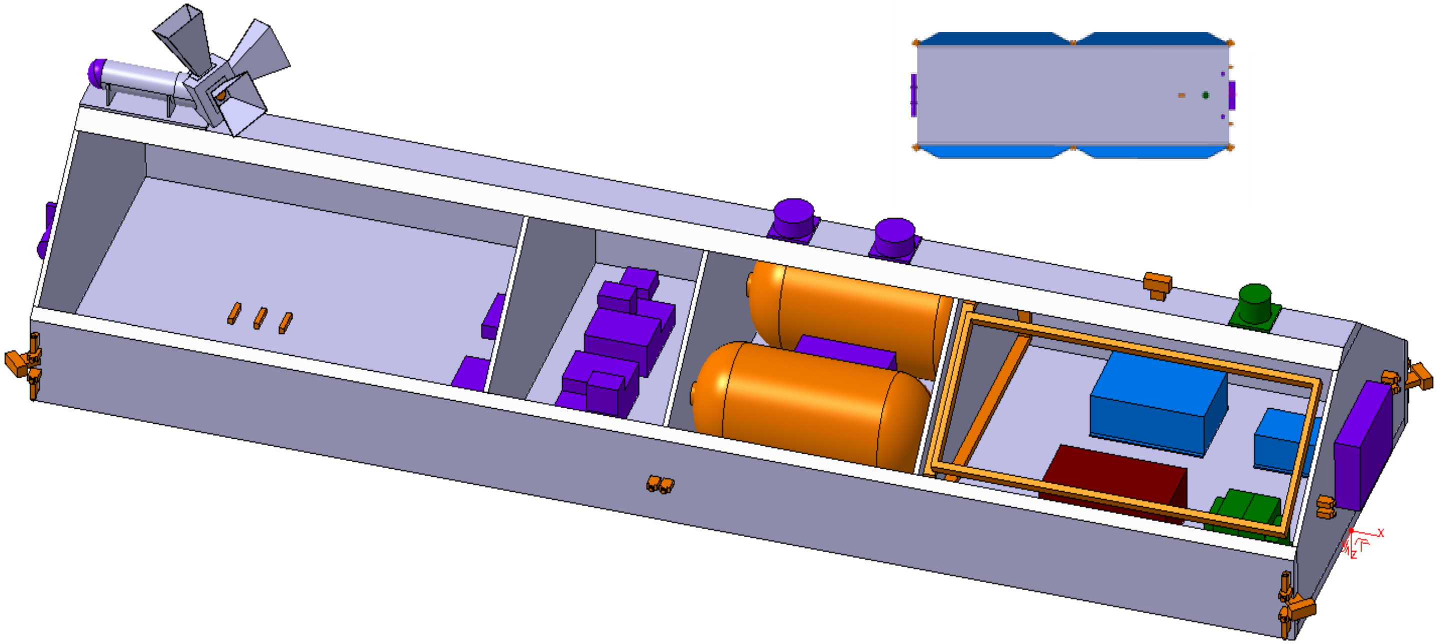
ECSS-E-TM-10-23 data specification shared by European space community

Object-oriented database implementing a data specification shared by the community

MagSat dataset as a representative example derived from project data

Structure
Electric Power Subsystem
Data Handling Subsystem
Telemetry, Tracking, and Telecommand Subsystem
Attitude and Orbit Control Subsystem
Instruments





- Representative data, derived from actual project
- Data subject to IPR issues left out
- System design close the Preliminary Design Review, extended at specific points for demonstration purposes

- System called MagSat
- Scientific satellite, main goal measurement of magnetic field
- 5.0 m x 1.4 m x 0.8 m (l x w x h)
- 600 kg wet mass

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