# Multi-Perspective Approach to Integrate Domain-Specific Semantics into the System Model

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### Abstract

Space System Engineering is an iterative process in which various domain-specific viewpoints are integrated to present the final mission. This multi-disciplinary character of digital space systems creates interoperability issues. To deal with these issues, European Space Agency (ESA) initiated the OSMoSE project (**O**verall **S**emantic **Mo**delling for **S**ystem **E**ngineering) to promote the digital continuity and interoperability among the involved stakeholders. OSMoSE provides a top-level space system ontology (OSS) and domain-specific ontologies. This paper aims at proposing a framework to create domain-specific ontologies for space systems. The concept of Perspective is proposed to define the system from the viewpoint of different engineering domains. This approach help us to identify all important information for each discipline as well as identifying interfaces between sub-systems. The proposed approach is presented by means of an example from a simulated earth observation mission (EagleEye) and the ontology is made using NORMA ORM (Object-Role Modelling) tool.

### Keywords

Space system semantic model, Domain Ontology, Multi-perspective model, OSMoSE

## 1. Introduction

According to the European Space Agency (ESA) Agenda 2025, ESA will 'digitalize its full project management, enabling the development of digital twins, both for engineering by using Model Based System Engineering, and for procurement and finance, achieving full digital continuity with industry"[2]. Based on this agenda, the Digital Spacecraft is derived to promote the digital transformation of the space system collaborative development and its operation throughout the full project lifecycle. In doing so, the "full data integration into a single consistent concept covering all aspects related to a spacecraft" is crucial [1]. In this context, the OSMoSE initiative (**O**verall **S**emantic **Mo**delling for **S**ystem **E**ngineering) proposes a top-level ontology called Space System Ontology (SSO) which promotes the digital continuity and interoperability among stakeholders which are using different tools and methods.

In order to cover all related engineering domains, creating various modular domain ontologies, called Universe of Discourse (UoD), and integrating them into the ESA top-level SSO is a promising solution. However, the main challenge is that each UoD focuses on one discipline's semantics without considering its requirements towards other disciplines. This means interfaces and data exchange with other disciplines will be missing which leads to interoperability problems between different domain ontologies as the core concept of the digital continuity. In order to deal with this issue, this paper proposes a multi-viewpoint approach to extract and model the semantics of the space systems from the various domain Perspectives (presenting various aspects of a sub-system). By means of adopting a modular ontology design approach, domain-specific ontologies for each sub-system are created taking into account the domain experts knowledge and space domain references. From the beginning, the System of Interest (SOI) and external systems as well as data exchange between them are defined. This

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[2] https://download.esa.int/docs/ESA_Agenda_2025_final.pdf

contributes to the digital continuity in space systems by proposing a framework for domain knowledge modelling which can be easily integrated into the high-level ontology. The modelling tool is NORMA ORM (Object-Role Modelling). The proposed approach is presented by means of an example from an earth reference mission (EagleEye)[3].

The remainder of this paper is organized as follows. Section two provides a theoretical background on the system semantics and semantic modelling approaches. Section three sets the main foundations of the ontology-based framework referring a space system model. The discussion and proposal for the future work is drawn in section four.

## 2. The Theoretical Background

Systems Engineering (SE) supports a wide range of activities from "characterizing the existing system" to the "concept formulation, design synthesis, and integration" of the system [2]. SE is a knowledge-centered iterative process that can be fulfilled by means of various models from multiple viewpoints [3]. By linking and integrating domain specific models, SE generates a common understanding of the system to support the collaborative system development [2]. In this matter, representing a common description is an essential pillar that supports consistency between all viewpoints. In doing so, models are often used to present the integration of all sub-systems, equipment, and components in the global system.

In this context, breaking down the system into the simple parts and reassemble these parts is the best way to understand the system [4]. However, this approach increases the risk of missing the "emergent properties" of isolated parts and giving a wrong understanding of a complex system as a whole [4]. To deal with this issue, knowledge modelling frameworks integrate semantic concepts representing the core content of the domain and a set of relations between these semantic concepts to define the whole "problem of interest" or UoD. In this context, modelling the system with a semantic approach considering the multiple interconnected viewpoints is crucial.

Ontology-based modelling is a well-known approach to support knowledge integration and interoperability between IT systems to facilitate data exchange between engineering activities during the collaborative design [5]. Ontology is defined as an "explicit specification of a shared conceptualization that holds in a particular context" [6]. In other words, it provides the vocabulary for a domain and uses formal language to explicitly represent complex models [7]. To cope with the complexity of the engineering knowledge, modularity in ontology design is proposed as a promising approach. Modular ontology development proposes that rather than having a massive ontology to cover a domain, it is necessary to abstract and generalize concepts into separate ontologies [8]. This will allow better reusability, flexibility, and maintainability [9]. From the ontological viewpoint, four types of ontology based on the level of the generality are:

1. **Top-level or foundational ontologies** propose a formal representation of general concepts which are "independent of a particular problem or domain" [10] serving as a "common understanding of terms across various domains and thereby help to exchange structured data domain-independently" [8].
2. **Domain independent reference ontologies**, define general common concepts like "time, geospatial, or unit of measure" [9].
3. **Domain-specific ontologies** define the vocabulary of general domains or tasks or activities, by "specializing the terms introduced in the top-level ontology" in which users can chose related modules [8][10].
4. **Application ontologies** describe concepts in a particular domain or task, which are often specializations of top-level and domain-specific ontologies [10].

The commonly accepted approach for structuring the domain knowledge is constructing domain ontologies [11]. The concept of various semantic models for domain-related knowledge has been developed by Jin [6] to present it from different view-points as process, interface, tasks, or object types

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[3] https://indico.esa.int/event/329/contributions/5544/attachments/3927/5631/1720_-_Presentation_-_MBSE_demonstrator_CDF_study_results_-_EagleEye_Reference_Mission.pdf

in the form of Meta-level, Application-level, and Context-level [6]. The concept of the “Linked Product Data” provides “domain-specific modules, a core schema that serves as the product descriptions basis, and uniform linking methods for individual modules to enable switching the applied domain ontologies or schemas” [8]. Considering the development of ontology, two approaches are proposed by the literature which both rely on human intervention: 1) the top-down approach in which the semantic consistency is guaranteed, and 2) the bottom-up approach in which up-to-date ontologies are guaranteed [9].

## 3. The Proposed Framework

This paper proposes a framework to create domain-specific ontologies for space systems. The modelling tool is NORMA ORM (Object-Role Modelling) which is a modelling approach for “designing and querying database models at the conceptual level”[4]. ORM is formalized, graphical, fact-oriented, and attribute-free. By means of the automated verbalization in ORM the domain semantics can be easily extracted, “modelled in terms of controlled natural language”, and easily understood by non-technical users [12]. This enhances the “semantic stability” which makes it more adaptable to “changing business”, facilitates the communication between stakeholders, and supports the modelling of the “large-scale industrial application” [12][13]. One of the strongest features of ORM is that it can “automatically generate a relational model from a conceptual ORM model” and NORMA facilitates the graphical express of conceptual schema as well [14]. Comparing to OWL, ORM has “high expressive capabilities, and implements the node-link paradigm”, and its meta-model is simplified [15].

The ontology development in this project is highly dependent on the domain-expert knowledge and different levels of abstraction to define each domain. The main challenge is the extraction of semantics from different domain’s viewpoint. This needs a top-down approach to develop the ontology to ensure the consistency in ontology. The capability of ORM in easy verbalization of semantics facilitates this collaborative modelling by making semantics unambiguous and easily understood by the domain expert (who are non-technical in semantic modelling). As a result, OSMoSE considers ORM as “the best technical solution to develop the Space System Ontology”[5].

The proposed framework is presented in Figure *1*. In this paper, the domain of Interest or UoD concept is adopted similar to the domain ontology. According to ISO/IEC 15288 standard, the SOI is the final result of the development process [4]. All other interacting disciplines are external systems. In order to present this approach, the concept of Perspective is adapted from the engineering vocabulary. In this framework, the Perspective is the viewpoint of each engineering discipline involved in the system design. Each Space Mission contains Item which are presented by Perspective. Two kinds of perspectives are proposed as SOI Perspective and External System Perspective. The SOI has requirements towards external systems. To fulfil these requirements, the SOI Perspective provides information (Provided Interface) and shows the related data of the system/mission from the SOI requirement viewpoint. The External System Perspective provides the requested information (Requested Interface) to realize the SOI. Each Item has Characteristic which is a wide range of parameters (such as mass, weight, temperature,…). These parameters are categorized and presented for each Item by means of Perspectives.

The final users of this framework are the domain-ontology experts who are creating the SSO. As explained before, SSO is the top-level space ontology in which domain-specific ontologies will be integrated. Each domain ontology focuses only on the data from the SOI. They do not distinguish between different perspectives and at the end they map the semantics to SSO. Integrating different domain ontologies are not considered in these works. This framework is useful during the domain-ontology creation as well as during this integration phase. In order to use it, first, the domain-specific semantics should be extracted in different disciplines and populated in ORM. These populated semantics will be automatically presented as “Examples” in the verbalization form. Next, during the integration phase, the common semantics between the domain ontology and SSO will be mapped.

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[4] http://www.orm.net/

[5] https://mb4se.esa.int/OSMOSE_Space%20System%20Ontology.html

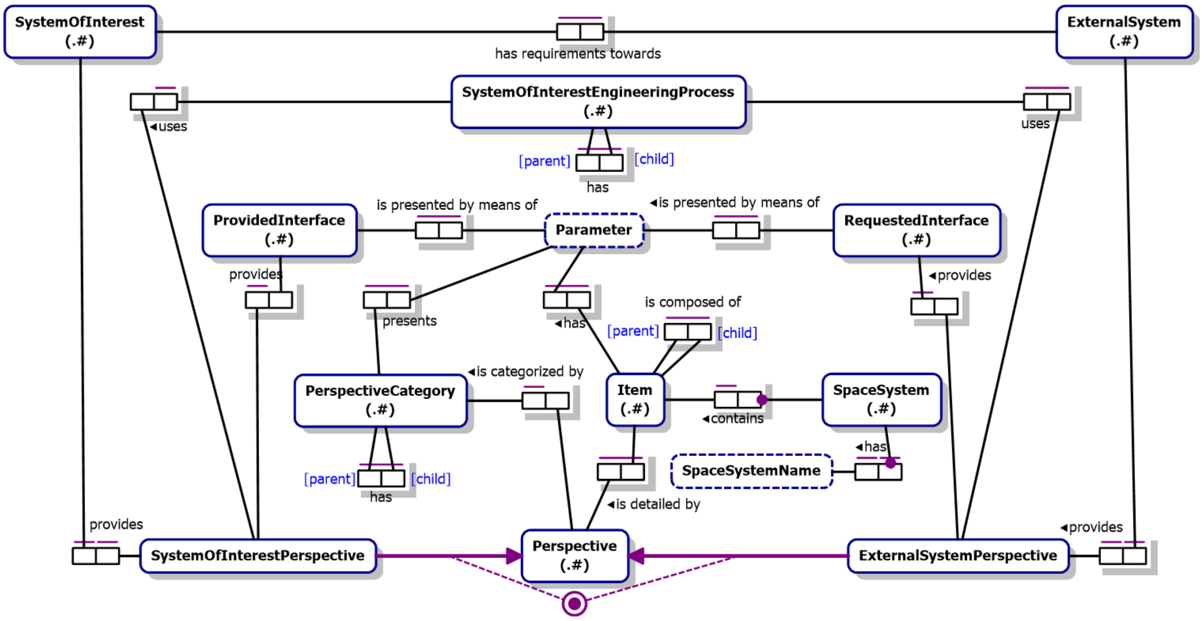


*Figure 1 The proposed framework focusing on Perspectives in the domain specific ontology (UoD)*

To show the proposed approach in a space system, a simulated earth observation mission (called EagleEye) is selected. The objectives of this mission is to collect earth and ocean data for climate change observation. This mission consists of Space Segment as SOI and various external systems (Ground Segment, Launcher Segment, Customer, and Environment) (Figure 2).

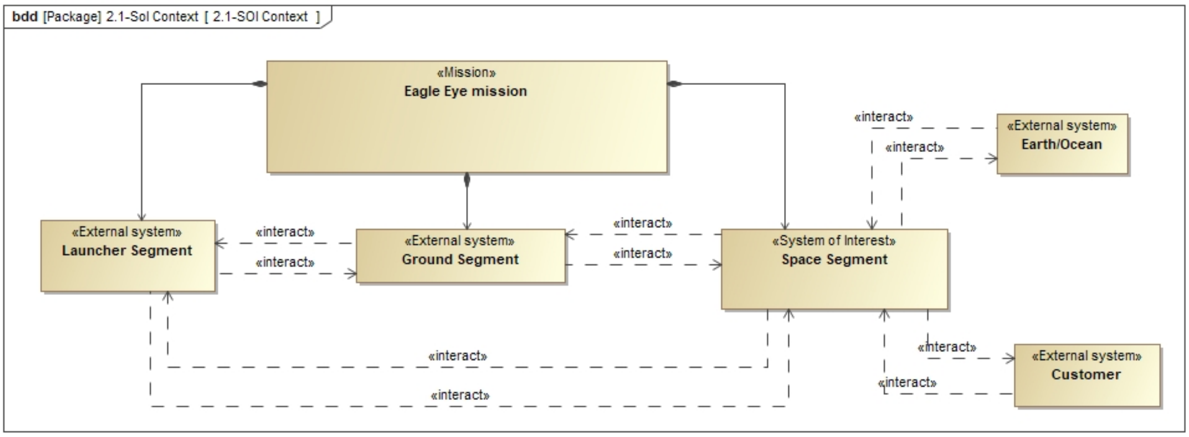
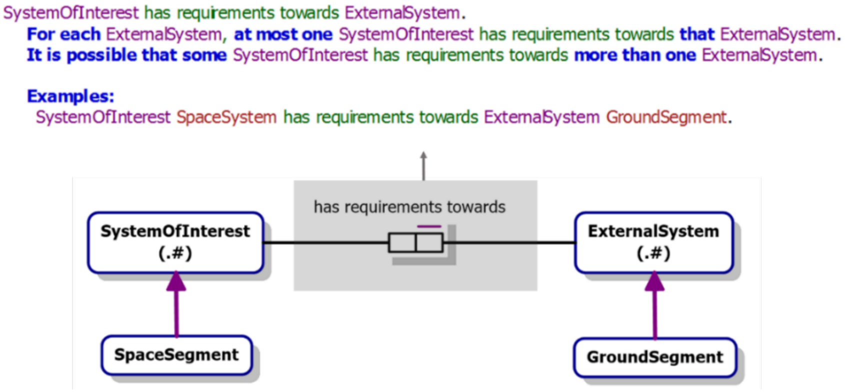


*Figure 2 The SOI and External Systems in an earth observation mission*

In this paper, populated examples are the Space Segment (as the SOI), and the Ground Segment (as one of the External System) are selected to visualize the proposed approach. Figure 3 shows an example of the verbalization from the SOI and the External System requirements towards each other. The verbalization shows that each System Of Interest has requirements towards more than one External System. It also shows that the Space System is a population of System Of Interest, and the Ground Segment is a population of the External System. These populations facilitate the verbalization of the model while at the same time add the related semantics to the model. It means that for each object and each role the semantics are presented from the domain specific population. This first modelling in which the multi-perspective approach is shows the data exchange and interfaces between Space Segment and Ground Segment.

Figure 4 presents the system from the Space Segment (SOI) point of view. The SOI engineering process is the Solar Array Deployment. In doing so, the Item from this Mission is the Solar Array. The data exchange with the Ground Segment is the received and sent data of the Solar Array such as its Rotation per day. From this phase, interfaces and data exchanges between space and ground segments and their requirements towards each other are identified. In Figure 4, the dark color concepts are the populated concepts from the proposed schema (the white ones). As proposed above, the item is the solar array. The process to deploy solar array uses command and control data from the ground segment (requested interface) and provides the control feedback (provided interface). The SOI perspective (from the space segment) provides data on solar array rotation per day, and the external system perspective (from the ground segment) presents (solar array dynamics validation). It should be considered that, the perspective presented here for SOI and external system is not a presentation of the whole SOI or external system. It is only one of many data from their viewpoints on the solar panel deployment.



SystemOfInterest has requirements towards ExternalSystem.
**For each** ExternalSystem, **at most one** SystemOfInterest has requirements towards **that** ExternalSystem.
**It is possible that some** SystemOfInterest has requirements towards **more than one** ExternalSystem.

**Examples:**
SystemOfInterest SpaceSystem has requirements towards ExternalSystem GroundSegment.

*Figure 3 The verbalization of the semantics of the ORM schema*

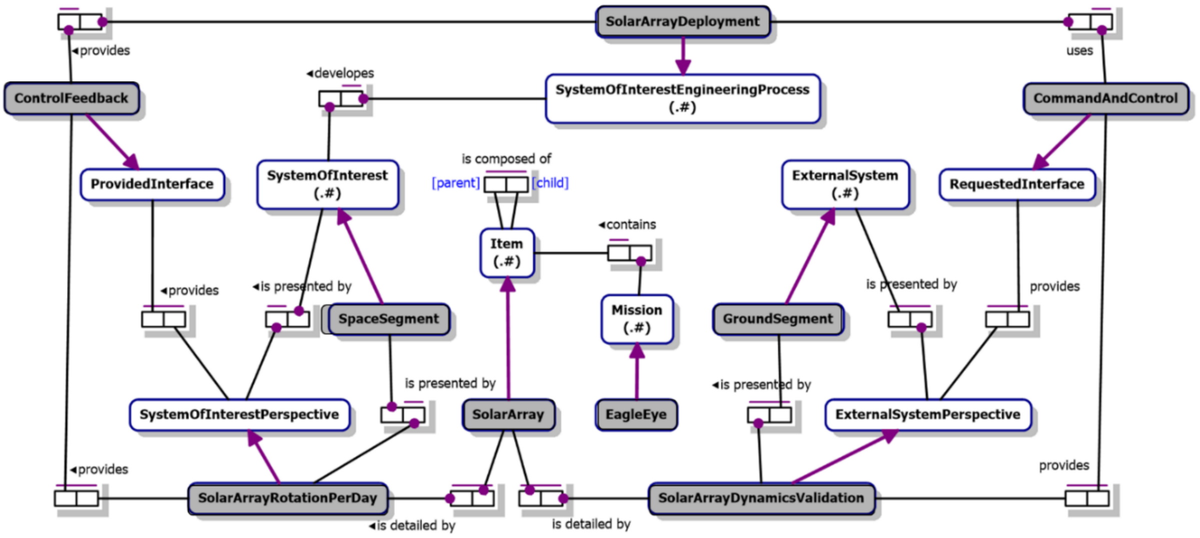


*Figure 4 Extracted semantics for the earth observation mission*

In order to integrate this ontology to the SSO, the system semantics of this ontology must be aligned with SSO. In doing so, the main common semantics will be mapped to SSO. OSMoSE is investigating different methods to automatically integrate UoDs to the SSO. However, the integration with SSO is out of the scope of this paper.

## 4. Discussion and Future Work

This paper has presented an ontology-based framework focusing on integrating various perspectives in System Engineering modelling. The needs of such developments have been identified by daily hands-on experience of systems engineering support to space projects that needs an interdisciplinary collaboration. To improve this multi-discipline and multi-stakeholders process, the digitalization of the space system engineering is gaining much attention is ESA. As a result, dealing with interoperability issues are of great interest as well. This primary proposition can greatly contribute to digitalization of system engineering activities and empowering support tools for Model-Based System Engineering (MBSE) by proposing a way to create domain-specific semantic models considering the integration of different perspectives from the early phase. Using such a framework for domain ontologies facilitates the digital continuity between engineering disciplines which is an important prerequisite for the digital spacecraft project.

The application of this approach in different engineering domain is undergoing. Intentions for future work concentrate on extending the domain ontology to cover different engineering domains and validating this proposal as a framework to create domain ontologies considering the interfaces with the other disciplines and the SSO. It will also include additional detailed features from the engineering process semantics. The prospect of being able to make an interoperable semantic model serving the ultimate goal of improving the end-to-end systems development process is a continuous incentive for future research. We share needs and ideas on how to shape the future with several stakeholders across the supply chain, which we regularly meet for focus discussion of ad-hoc points. Finally, full implementation and testing of this proposal for the whole space disciplines is in progress.

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