# Development of Tooling to Support Fact-Oriented Modeling at ESA

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**Abstract.** Developing space systems implies complex activities involving many parties who are widely distributed in location and time. Such development therefore requires efficient and effective information exchange during the complete lifecycle of the space system. This can only be achieved by realizing semantic interoperability between all involved parties. Semantic interoperability can be achieved if the applications involved share a set of conceptual definitions. To achieve this goal, the concept of a global conceptual model that has the potential to embrace the complete lifecycle of a space system is analyzed. Realizing the full potential of this approach requires methods and tools not only to support the formal specification of such a conceptual model and their tailoring for producing application specific conceptual models, but also to support the development or adaptation of applications resulting in needs to support the 3-level data model hierarchy and the ability to specify domain-specific conceptual models based on the global conceptual model. This paper describes the tools that are under development to support the above described objectives.

**Keywords:** semantic interoperability, fact-oriented modeling, ORM, ESA, ECSS, global conceptual model.

## 1 Introduction

Developing a space system implies complex activities involving many parties who may be widely-distributed both geographically and in time. Each involved party makes use of information systems for capturing and maintaining the information required for developing and operating the elements of the space system of their responsibility. Due to this distribution, both in time and in space, efficient and effective information exchange has to take place during the complete lifecycle of the space system.

Through the years and in absence of standards and common definitions, each party has had the freedom to specify how the required information is structured and used. Due to these historical reasons, sharing information between the involved parties is difficult and potentially even impossible. Moreover, reusing the information provided by one of the involved parties presents a potential threat to the successful sharing of information due to the inherent risk of semantic misinterpretation of the supplied information by another party.

R. Meersman, P. Herrero, and T. Dillon (Eds.): OTM 2009 Workshops, LNCS 5872, pp. 714–722, 2009.

Successful sharing of information during the whole lifecycle of the space system implies that the information has to be exchanged between the sharing parties without a mismatch of information or a loss of semantics. This can only be realized if the involved parties share the same semantics and have means to derive their own representation from this shared semantics.

## 2 Semantic Interoperability

Any process within the development of a space system uses and produces data. These processes are supported by many different information systems, each of which has a data repository to provide the persistent data storage. Information exchange can thus be considered as the exchange of data between database applications. Taking into account that it is impossible (and undesirable) to standardize the database applications that are used across space industry and agencies, standardization of the data has to be achieved at the semantic level.

In order to achieve semantic interoperability, it is necessary to model the data and express the results in a formal way. It is desirable to use as much as possible a modeling approach that provides repeatability and traceability. The approach promoted by this paper complies with the 3-level hierarchy of data models, namely:

1. A conceptual data model,
2. Logical data models,
3. Physical data models.

A conceptual data model specifies the semantics of the data relevant to the domain; it defines the data of significance to the end-users, its characteristics and the associations between the data, the meaning and the rules that apply. A logical data model is developed (derived) from the conceptual data model, expressed using a specific data modeling notation, like the Entity-Relationship notation. A physical model is developed (derived) from a logical data model and is used for e.g. permanently storing the data objects on a computer.

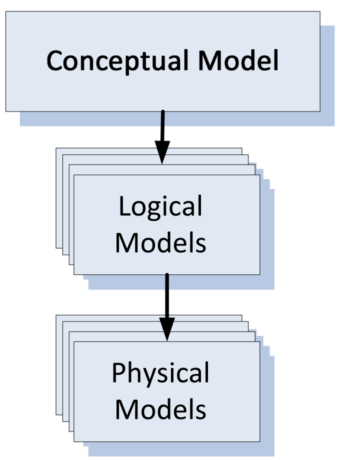


**Fig. 1.** The 3-level hierarchy of data models

Taking into account that a conceptual model specifies the semantics of the data relevant to the domain, semantic interoperability can be achieved if the involved database applications implement globally-consistent conceptual definitions. To achieve this objective, developing a "domain-specific" conceptual model (i.e. for a given application) requires considering the overall community, i.e. *the* system, represented by *the* global conceptual model. Such a constraint implies the following activities:

1. Identifying, within the existing population of the global conceptual model, those conceptual definitions of local interest, potentially defining additional derivation rules for mapping to and from this local view;
2. Adding to the global conceptual model the missing conceptual definitions in a way that satisfies the potential users of these definitions, i.e. *the* system, for example by applying standards, by ensuring that *the* system is involved in the modeling of additional definitions.

Such an approach results in modeling a local conceptual model as a subset of the global conceptual model.

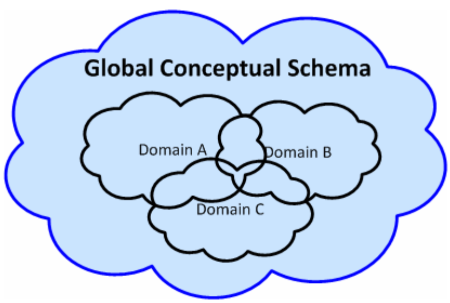


**Fig. 2.** Domain-specific conceptual models as subsets of the global conceptual model

## 3 One Objective, Two Functions

Analyzing above overall objective reveals that a supporting tool has to implement two major functions, namely the function:

1. To support the production of database applications and their related components, and
2. To support the exchange of database products on the basis of the global conceptual model that comprises the globally-consistent conceptual definitions.

### 3.1 Function 1 – Supporting the Production of Database Applications

Database applications are generally applications consisting of several data related components, such as those depicted in figure 3. Realizing function 1 means that the tool should support the development of each of these data related components. This forms the scope of the "Enhanced FOM (Fact-Oriented Modeling) tool".

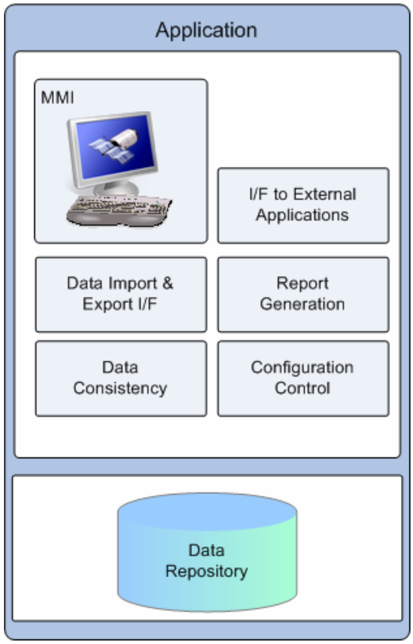


**Fig. 3.** A database application and its typical data related components

### 3.2 Function 2 – Supporting the Exchange of Database Products

Exchanging database products implies semantic-adequacy of the interpretation of the data by both suppliers and customers. Realizing function 2 means that the tool should ensure the adequacy of the exchanged data for all of its users. This implies that function 1's conceptual modeling is compliant with system conditions as depicted in figure 4. This forms the scope of the "Ontology definition FOM tool".

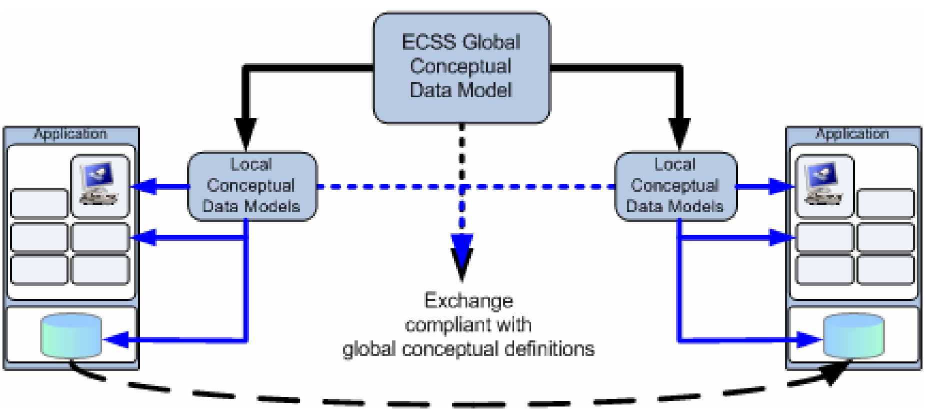


**Fig. 4.** Development of applications compliant with system conditions

## 4 The Enhanced FOM Tool: A Global Overview

The Enhanced FOM tool is responsible for implementing the requirements stemming from function 1, as depicted in figure 5.

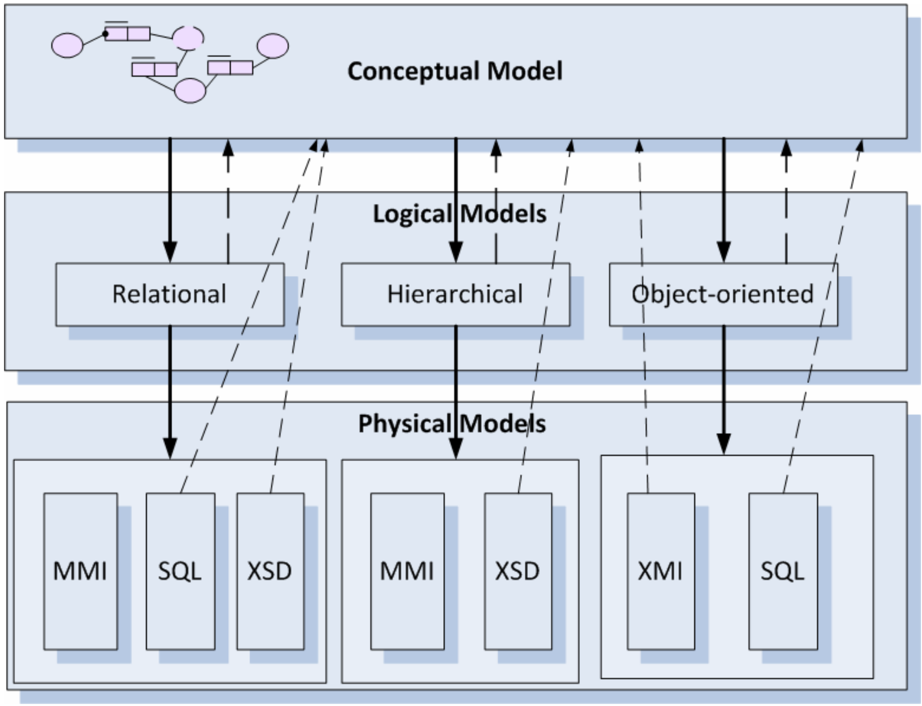


**Fig. 5.** Overall overview of the Enhanced FOM tool

The three-layer architecture of data models is supported by the Enhanced FOM tool. The conceptual model forms the first, top, layer of this architecture and is the basis for the logical models which can be derived from this conceptual model. Three types of logical models are under analysis, namely the relational model, the hierarchical model and the object-oriented model. Mapping from conceptual to logical, and further on from logical to physical model, is done by means of mapping algorithms. However, because there is not one optimal (for all application domains) mapping from conceptual to logical and physical (of given types), customization for each mapping is provided.

The relational model is an abstraction and transformation of the conceptual model, showing the underlying relational structure as supported by relational databases. In other words, the relational model is a set of tables and relations between these tables.

The hierarchical model is an abstraction of the conceptual model allowing scoping (based on the existence-dependencies relations) and reusing conceptual definitions in order to produce tree-like structures using parent/child relationships. This hierarchical model is adapted to users' views on the data and offers means to develop facilities such as man-machine interfaces and hierarchically structured data exchange files.

The object-oriented model is an abstraction and transformation of classes and relationships between these classes.

Based on the logical models, physical models are derived taking into account the software needs (derived from user needs), and given technologies. Assessing the implications of given logical and physical models implies identifying those conceptual definitions that are required for developing a given solution. This means not only those already covered by fact-oriented modeling but also additional ones. For this purpose, as shown in figure 5, assessing MMI development, XSD and XMI is included taking into account the user needs and environmental constraints (such as security):

- The man-machine interface modeling acknowledges the existence of (so-called) "data-model-independent MMI model", i.e., including software requirements derived from user needs and environmental constraints as well as architecture issues of a given technology. The latter physical models provide "data requirements" as derived from the conceptual and logical models that configure the model-independent specification which is the basis of the data-model-independent MMI model.
- Trade-offs are made for the modeling of the data repository according to overall needs and technology characteristics, e.g. however relational SQL is adequate for human interactions, it might not be optimal for "between-software" interactions such as those having hard real-time access needs.
- XSD is used for example for exchanging data with external entities, e.g. import/ export.

## 5 Interaction with Other Methods and Tools

Interoperability does not mean having everyone following the same method, using the same tools. Complying itself to the interoperability objective, the Enhanced FOM tool promotes the need for exchanging conceptual models developed using other modeling methods and tools. As shown in figure 6, several information exchange points have been identified for ensuring interoperability of conceptual, logical and physical models.

Promoting the use of fact-oriented modeling for specifying conceptual models, baselines a FOM exchange schema that is proposed to the overall fact-oriented modeling community as standard means to exchange fact-oriented models. This exchange schema covers the essential concepts required for developing conceptual definitions according to the fact-oriented philosophy, namely ORM, CogNIAM, FCO-IM, SBVR or any other fact-oriented representation form. It also identifies additional conceptual knowledge needed to allow reusing, compiling and structuring fact-oriented models.

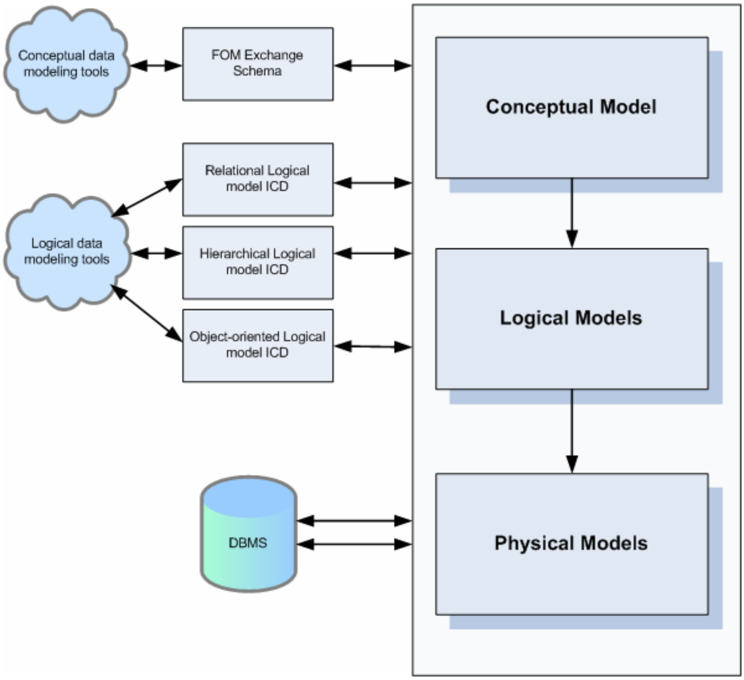


**Fig. 6.** Interaction between the Enhanced FOM tool and other tools

For interacting with other modeling tools, interfacing is proposed at the logical level according with existing or to-be-specified interface control documents (ICDs) that define the exchange format (e.g. XMI for object-oriented models).

Finally, the Enhanced FOM tool also supports the mapping with implemented models as instantiated within database management systems.

## 6 The Ontology Definition FOM Tool: A Global Overview

Semantic interoperability requires not just any conceptual model but a conceptual model which is comprehensible to all involved stakeholders (see for early work on this [1], [2]), and which is expressive enough to capture everyone's need without conditioning the quality of everyone's solution. Achieving comprehensiveness between all stakeholders is realized by using Object Role Modeling. Achieving expressiveness is realized by extending ORM with structuring, packaging, conditioning conceptual definitions, conditioning assertions and derivations, etc.

Realizing the full potential of the global conceptual model requires tooling to support not only the development of the global conceptual model based on ORM, but also supports the 3-level data modeling hierarchy (conceptual, logical, physical) and the ability to specify domain-specific conceptual models based on the global conceptual model.

Currently, no fact-oriented modeling tool exists to support such extensive needs. The second overall objective of the research activity, initiated by ESA, is the study and development of a “space system ontology definition tool” based on the ORM methodology which is able to support the conceptual modeling of the overall space system knowledge in a way that baselines the conditions required:

- For producing database applications that comply with user needs, e.g. providing adequate structures, adequate interface specifications for maintaining and accessing data, adequate constraint specifications for ensuring data quality, adequate data lifecycle specification for ensuring data availability.
- For providing means to share and reuse data between applications, e.g. producing interface specifications for data exchange and transformations.

### 6.1 Using the Ontology Definition FOM Tool within ESA

The ECSS (European Cooperation for Space Standardization) System has been developed as a cooperative effort between the European space agencies and space industries. It comprises a comprehensive set of documents addressing all essential aspects of successful implementations of space programs and projects, covering:

- Project management,
- Engineering, and
- Product assurance.

With more than 100 standards, handbooks and technical memoranda, the ECSS system constitutes an “informal” specification of a space system ontology that is used by all actors involved in the overall development and operations of space systems.

The Ontology Definition FOM tool is developed with the objective to cover all modeling capabilities required to formally specify the ECSS system and to provide to ESA missions the capability to tailor these standardized definitions for project-specific and application-specific needs, as depicted in figure 7.

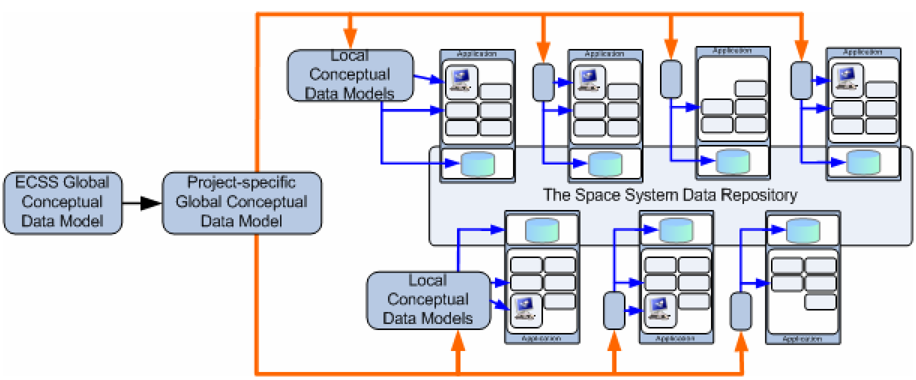


**Fig. 7.** Applying formal methods and tools for deploying the ECSS System

## Acknowledgements

Developing a tool that fulfils the above requirements is an ambitious task and requires a solid understanding of not only fact-oriented modeling, but also the problem domain and its particularities. Therefore, a consortium of three parties consisting of Space Software Italia, PNA Group and the NORMA team (consisting of Terry Halpin and Matt Curland) is working closely with ESA to realize the goals. Each party in this consortium brings in its own unique knowledge and its own unique view on the challenge at hand. We greatly appreciate the support of all the parties involved.


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