XASTRO: a formalised framework for the modelling of space systems

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2. Introduction

XASTRO is an ESA study to develop a general framework, based on the open standard technologies of UML/XML to describe space systems and the information that lives within those systems. An original XASTRO study was performed from spring 2002 to spring 2003, under ESA's Innovative Technology initiative. This study was proposed in response to the widely accepted opinion that data exchange and management of many space missions is less than optimal. There are a number of factors in most of today's space missions that hamper an efficient data transfer process throughout a mission, including the following:

- Huge quantity of information in the space domain.
- Wide range of information types represented in a diverse range of formats.
- Many organisations geographically distributed.
- Information is generally document driven and the data content is tightly coupled to how the data is presented.

The main objective of the XASTRO activity was to define an XML based data exchange framework by which space programs could more effectively exchange system engineering information between customer, contractors and suppliers throughout the life cycle of a mission. The output of this study was a prototype XASTRO framework, which is an XML based meta-language and focused on the modeling of the space segment. The framework is described in UML 1.4 and captures a number of basic engineering concepts, such as multi-disciplinary viewpoints, hierarchical decomposition, behavior, etc. The XML Schema specifies the valid content of an XASTRO model document and is automatically generated from the UML model.

In the autumn of 2003, a follow-on XASTRO study, called $XASTRO_2$ but referred to as XASTRO for the remainder of this paper, was proposed by ESA. The objective of the study is to use the same techniques and tools developed in the original XASTRO study and apply them to the modeling of ESA's ground systems. The purpose is to define a standardised approach to information management in order to reduce the cost of ground systems development, operation and maintenance. The XASTRO study is part of a larger initiative within ESA to improve ground system interoperability through the definition of reference architecture in which common ground system services and information models are specified.

There are currently a number of organizations that are promoting standards. These include the Consultative Committee for Space Data Systems (CCSDS), OMG Space Domain Task Force (SDTF) and in Europe, the European Co-operation for Space Standardisation (ECSS). These bodies have made great strides in the introduction of standards to the space domain, particularly in defining cross support services between agencies. The XASTRO study can therefore be viewed as complimentary to these efforts, focusing on the development of a reference architecture and associated modelling language.

The main objective of the XASTRO is therefore to develop a formal language that can support other standards when describing common services and information within ground systems. The purpose is develop a framework in which models can be developed that are not only viewed as design artifacts, but can be used throughout the full life-cycle of the mission, including the configuration of the real system.

3. Architectural Methods and Standards

We now present a discussion of current architectural standards upon which XASTRO is influenced. Even if many use it, the term “architecture” has no well-established definition. Nevertheless, there is no shortage of more or less overlapping definitions. This has been the cause for development of a consistent set of definitions targeting architectural descriptions for software-intensive systems, namely the IEEE Std 1471-2000 [RD-3], the IEEE Recommended Practice for Architectural Description of Software-Intensive Systems. This recommended practice is becoming a common frame of reference within which to codify common elements between different architectural description initiatives, and has become influential and used as a baseline for architectural description frameworks, for instance within OMG. It reflects generally accepted trends in practices for architectural description and provides a frame of reference within which future developments in software architectural technology can be deployed.

A system has an *architecture* and this can be described in an *architectural description*. Note the distinction between the architecture of a system, which is conceptual, from the description of this architecture, which is concrete. Architecture is defined to be “the fundamental organisation of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution”. On the other hand, architectural description is defined as “a collection of products to document an architecture”.

The architectural description can be divided into one or several *views*. Each view covers one or more stakeholder concerns. View is defined as “a representation of a whole system from the perspective of a related set of concerns”. A view is created according to rules and conventions defined in a *viewpoint*. Viewpoint is defined as “a specification of the conventions for constructing and using a view. A pattern or template from which to develop individual views by establishing the purposes and audience for a view and the techniques for its creation and analysis”. A view expresses those concerns of a system architecture that are defined in its viewpoint definition. This is reflected in Figure 2-3.1, which shows that a viewpoint acts like spotlight that illuminates a view of the model that only exposes the concerns of the viewpoint.

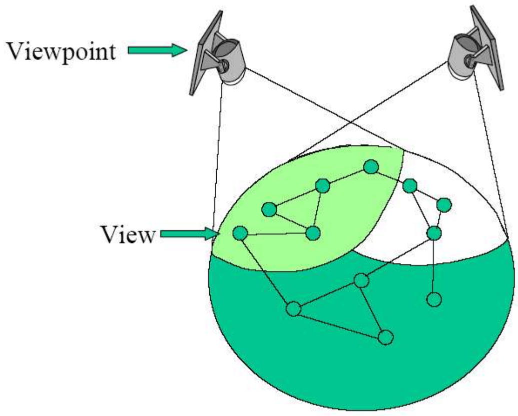

Figure 2-3.1 Architectural Views and Viewpoints [taken from RD-3]

An architectural description selects one or more viewpoints for use. This choice depends on the concerns of the stakeholders that need to be addressed by the architectural description. Although finalised earlier than IEEE Std 1471-2000, the Reference Model of Open Distributed Processing (RM-ODP) follows the same lines in specifying architecture and viewpoints, which justifies taking the definitions in IEEE Std 1471-2000 as the normative reference for terms used within architectural specification.

The Reference Model of Open Distributed Processing (RM-ODP) was a joint effort by the international standards bodies ISO and ITU-T to develop a co-coordinating framework for the standardisation of open distributed processing (ODP). The model describes an architecture within which support of distribution, interworking, interoperability and portability can be integrated. The RM-ODP framework defines ODP concerns using five “viewpoints” (abstractions), namely enterprise, information, computational, engineering, and technology. A set of concepts, structures, and rules is given for each of the viewpoints, providing a “language” for specifying ODP systems in that viewpoint. RM-ODP defines the following five viewpoints:

- Enterprise Viewpoint (purpose, scope and policies)
- Information Viewpoint (semantics of information and information processing)
- Computational Viewpoint (functional decomposition)
- Engineering Viewpoint (infrastructure required to support distribution)
- Technology Viewpoint (choices of technology for implementation)

A ground software system is basically a distributed processing system and therefore the concerns addressed by RM-ODP are very much the same concerns as a ground software system. This is one of the prime reasons why RM-ODP has been chosen by the CCSDS System Engineering Working Group in defining a reference architecture for ground systems – Reference Architecture for Space Data Systems (RASDS). The XASTRO framework will also apply the concepts of RM-ODP and will therefore be aligned with RASDS.

Another standard of relevance to XASTRO is the Model Driven Architecture (MDA) of the Object Management Group (OMG). The MDA process places formal system models at the core of the interoperability problem. What is most significant about this approach is the independence of the system specification from the implementation technology or platform. The system definition exists independently of any implementation model and has formal mappings to many possible platform infrastructures (e.g., CORBA, Java, .NET, XML, or SOAP). The XASTRO framework applies the same principles as the MDA, where system specification is modeled independent of an implementation technology or platform.

Figure 2-3.2 shows the relationship between XASTRO and other existing standards. It shows that XASTRO applies the principles of both MDA and RM-ODP within its framework.

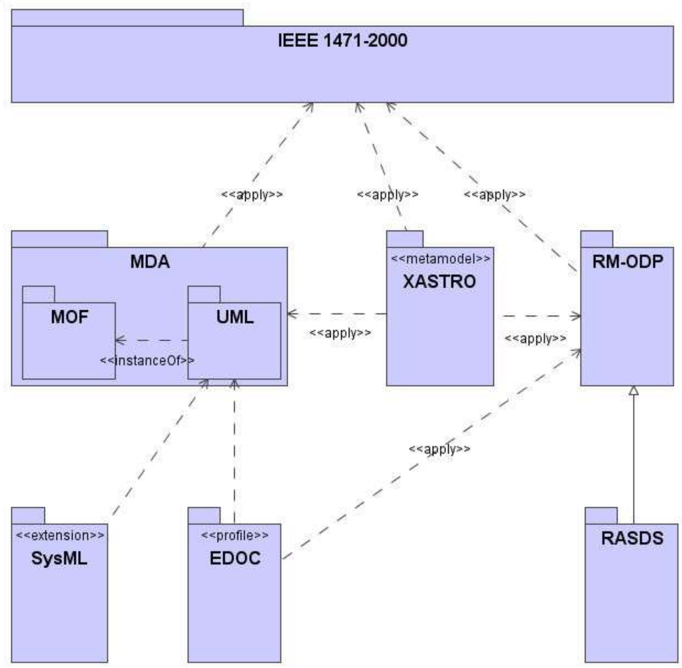

Figure 2-3.2Relationship of XASTRO to other standards

The Figure 2-3.2 also shows two other standards that are related to XASTRO. The first is the Enterprise Distributed Objects Computing (EDOC) specification. The EDOC is a UML profile that applies the concepts of RM-ODP and therefore has been considered as the basis of the XASTRO framework. The EDOC is however difficult to use, mainly due to the limitations of UML 1.4, and it is likely that we shall define an XASTRO metamodel.

The second is the Systems Modeling Language (SysML) [RD.8]. SysML is an extension of a subset of the core UML 2.0 metamodel and addresses the concerns of the system engineer. SysML is in the early days of development and therefore will not be used by the XASTRO study.

4. XASTRO Concepts

We now present some of the main concepts of XASTRO. XASTRO comprises of the following elements:

- The *XASTRO Framework* is the modelling language used to define entities within a system and is independent of any space specific features. The XASTRO framework is analogous to the UML modelling language. This language provides supports a consistent approach to modelling all aspects of a distributed processing system.
- The *Ground System Information Model (GSIM)* contains models of entities and information within a ground operations system. The GSIM contains standardised descriptions of system elements, such as ground stations, missions controls systems, etc. It contains descriptions of standard interfaces and services, such as SLE data services. It also contains standard

descriptions of ground operations system information, such as monitoring and control data. The GSIM is the level at which ground system standard services and a standardised data model are defined.

- The *Mission Information Model (MIM)* is a mission specific model of a space ground segment. The MIM is composed of instantiations of standard system elements, services and information defined in the GSIM. As part of the XASTRO study, the CryoSat ground system will be modelled

Figure 3-4.1 shows how XASTRO conforms to the four meta-level approach of the MDA.

M3	(MOF)	Language of Languages	
M2	Framework	Modelling Language	[UML Class Model] XML Schema
M1	GSIM	Ground Station Type	XML
M0	MIM	Perth Ground Station	XML

Figure 3-4.1XASTRO Modelling Layers

The XASTRO framework is a metamodel, like UML, and therefore sits at level M2. The GSIM consists of instances of the XASTRO framework constructs and therefore sits at level M1. The MIM consists of instances of the GSIM and therefore sits at M0. In principle, any MDA metamodel should be defined using the Meta-Object Facility (MOF), which supplies the constructs for defining metamodels. MOF is very closely aligned with UML and it is possible to express a MOF metamodel using a UML class model. XASTRO takes the same approach and the framework is specified as a UML class model. XASTRO however is currently not fully aligned with MOF and the mapping of the metamodel to XML is different, although in the future these differences may be removed and the concrete XML syntax of the XASTRO framework would become based on XMI.

As previously mentioned, the XASTRO framework will evolve to incorporate the concepts of RM-ODP. This is shown in Figure 3-4.2, which shows that the framework incorporates the viewpoints specified in the RM-ODP standard.

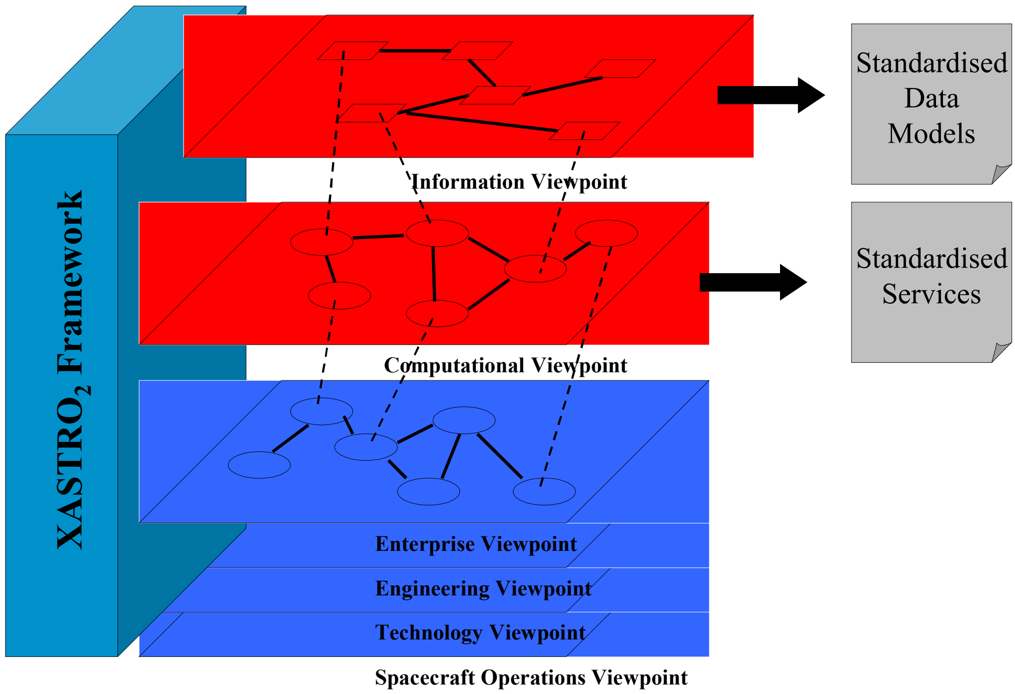

Figure 3-4.2XASTRO Framework Viewpoints

The viewpoints separate the concerns of the ground system. For example the computational viewpoint is where standard services are defined. The information viewpoint is where standard information and the semantics of the information processing are defined. In addition to the RM-ODP viewpoints, XASTRO will also investigate the definition of other viewpoints that focus on the concerns of the end user of the system.

As previously discussed, the XASTRO framework is a new metamodel. There is however considerable interest in the use of UML 2.0, which is currently being finalised by OMG. UML 2.0 incorporates many of the concepts required by XASTRO that were not included in UML 1.4 and was influenced in its development by OMG's EDOC which incorporates many of the concepts of RM-ODP. XASTRO shall therefore consider alignment with UML 2.0 and the possibility to define the XASTRO framework as a UML 2.0 profile. A "metamodel + profile" strategy is attractive as it provides the possibility to utilise UML 2.0 tools once they become available, while also allowing the use of custom tools that have a tight domain focus and do not expose the user to all the modelling possibilities offered by UML.

5. XASTRO Tool Support

The *XASTRO Framework Applications* are a set of tools that support the development of models conformant with the XASTRO Framework. This includes the creation and editing of GSIM and MIM models and the generation of domain specific languages.

A prototype editor was developed, as part of the original XASTRO study and this will be evolved to support the new features of the XASTRO framework, particularly in respect to support the viewpoint languages. Figure 4-5.1 shows a screenshot of the prototype XASTRO editor.

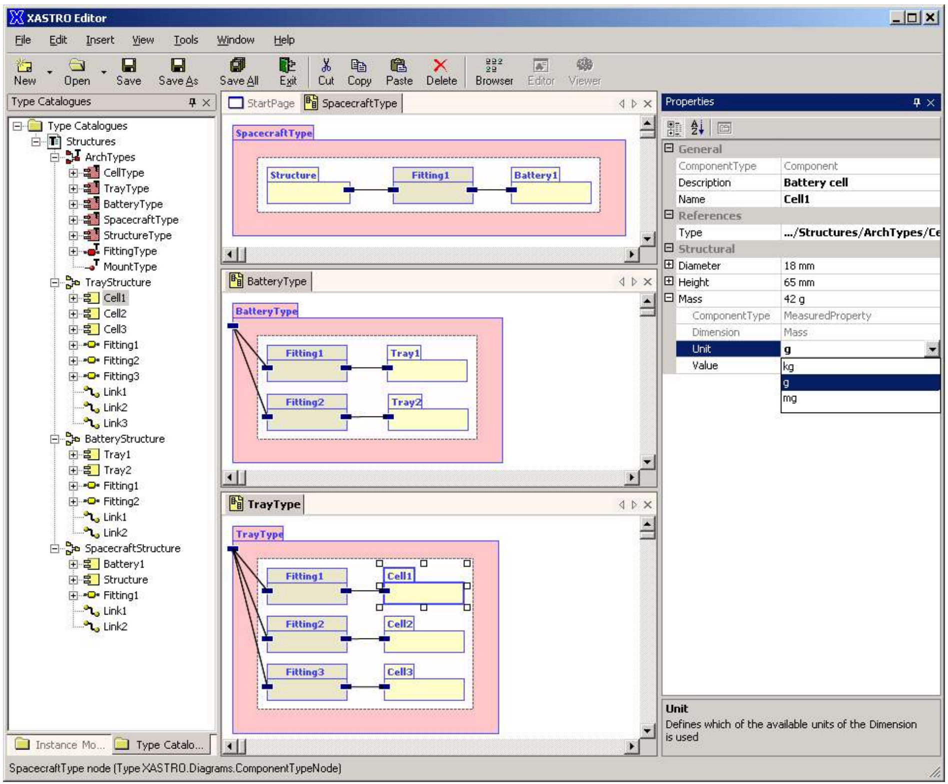

Figure 4-5.1XASTRO Editor Prototype

In addition to the XASTRO editor, a number of support applications shall be provided to support the management of models in the GSIM and MIM and the generation of ground system products, such as documents and configuration files. As the GSIM and MIM are independent of the implementation platform, the mapping of models to an implementation technology used by the Ground Software Systems is required and shall be provided as part of the XASTRO study. In the case of services, the mapping to CORBA interfaces will be defined. In the case of schema in the information viewpoint, a mapping to XML W3C Schema will be defined.

The models contained in the MIM can be used to drive the configuration of the real ground software systems. This promotes the use of models not just simply as design artifacts but through into implementation skeletons and deployment of the system.

6. Application of the GSIM and MIM

The GSIM is a model of standard components, information and services that comprise a space ground system. The MIM is a model of an actual space mission, based on the standard components, information and services defined in the GSIM. The MIM can therefore act as a central repository of project information related to the architecture of the system and improve communication between different stakeholders. The MIM can therefore be seen as a mechanism to capture knowledge about the mission, which is particularly important for long duration missions when loss of experienced staff becomes an issue. The MIM in this context could therefore been used as a training tool. To support this, the XASTRO study will use an XML server for storage of the models in a central repository that can be made available to a mission.

As the GSIM and MIM are stored in a machine-readable format, it is possible to automatically generate documentation. For example, an Interface Control Documents can be generated for the interfaces between components, based on the formal description of interfaces and the information passed between interfaces. This therefore lessens the problem of documentation being misaligned with the design (although it does require that the model is kept aligned with the real design). The XASTRO study will therefore demonstrate the feasibility of generating such documentation from the MIM.

In addition to the generation of documentation, another aim of the XASTRO study will be to demonstrate the feasibility of generating configuration files that can be used to configure the real system. This addresses a real problem currently found in ground system software, where configuration information is often stored in a variety of different formats and distributed throughout the system. Having a central repository of configuration information that lives in the MIM should help address this problem. It is however sometimes necessary to transform configuration information stored in XML in the MIM into a format that can used by the ground software component, which again will be investigated as part of the XASTRO study.

As already mentioned, the GSIM contains the definition of standard components, information and services. The XASTRO study will provide mapping tools to transform the platform independent models into platform specific models. In the case of information, the mapping to XML Schema will be supported and in the case of services, the mapping to CORBA IDL will be support. Having a repository of standard services and information definitions aids reuse and improves interoperability. It should be noted that it is not the purpose of the MIM to provide a detailed design of the system, but it can be used as input into the detailed design.

7. Conclusions

The XASTRO framework and supporting tools are being developed to assist ESA in the definition of a ground systems reference architecture. The reference architecture supports the definition of standard services and common data models in order to improve interoperability between ground system elements. XASTRO also aims to improve the reuse of information through the full life cycle of the mission by promoting the use of formal system models, not simply as design artifacts, but also in the implementation and deployment of the ground system. As an ESA sponsored study, the focus of XASTRO is in the development of a reference architecture aimed at supporting ESA's own ground systems. However the approach taken is aligned with the Reference Architecture for Space Data Systems (RASDS) being developed by the CCSDS and potential exists for collaboration between the two groups.

The proposed XASTRO framework is to be based on the concepts of OMG's Model Driven Architecture (MDA) and RM-ODP. MDA provides XASTRO with a modelling framework based on the key open standards of UML, XML and MOF. RM-ODP provides the concepts and terminology that describe an open distributed processing system and which are important when trying to model ground system software.

The XASTRO study is still in its analysis phase and is in the process of evaluating existing technologies and standards and identify requirements on the framework and its supporting tools. Development of the framework and tools will take place during the remainder of 2004. The objectives of the XASTRO study are ambitious and it is likely that requirements on the framework will evolve, as the use and application of XASTRO becomes better understood.

To improve communication on the ideas of XASTRO and provide a mechanism for providing feedback, an XASTRO portal has been developed. The XASTRO portal can be accessed at http://portal.vega.de/xastro.

8. References

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