ARCHEO-E2E: A Reference Architecture for Earth Observation end-to-end Mission Performance Simulators

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ABSTRACT

End-to-end mission performance simulators for Earth Observation missions are a useful tool to assess the mission performance and support the consolidation of the technical requirements and conceptual design, as well as to allow end-users assessing the fulfilment of requirements by the mission. ESA is currently starting the development of these end-to-end simulators during the mission feasibility studies, so that if the mission is approved, the simulator will evolve into a support tool for the detailed design definition, preparation and validation of operations, data processing and higher-level mission products generation.

However, at this stage, the evolution of the design and the processing algorithms may require modifying or even replacing the components of the original simulator, what usually translates into a complex and costly reengineering process. ESA has promoted several activities in order to reduce this reengineering process, such as for example a simulation framework able to support the development of the simulator throughout the mission life cycle.

The ARCHEO-E2E activity, presented in this paper, is framed into this context, and it has the main objective of defining a Reference Architecture for Earth Observation end-to-end mission simulators. The rationale behind this Reference Architecture is promoting reuse in the development of mission performance simulators by:

- Categorising past, current and planned Earth Observation missions to identify the main elements affecting mission performance and impacting the simulator architecture.

- Identifying the architecture elements required to model the mission depending on the type of mission and instrument, and proposing a generic Reference Architecture that could be adapted for the different mission particularities.
- Describing the architecture elements, in particular those that can be generalized for the various mission categories.
- Evaluating the Reference Architecture by comparing the development of an end-to-end simulator using this new concept vs. ad-hoc simulator development.
- Defining a roadmap to reach an operational concept for the development of end-to-end simulators based on the presented Reference Architecture.

The ARCHEO-E2E activity is carried out under ESA contract by a consortium led by GMV (Spain) and including the following institutions: Aresys (Italy), Universidad de Valencia (Spain), Universidad Politècnica de Catalunya (Spain) and IPSL / Laboratoire de Météorologie Dynamique (France).

INTRODUCTION

The purpose of end-to-end mission performance simulators for Earth Observation Missions is to help in the assessment of different system implementation options, the development of retrieval algorithms at different data levels and the detailed design as well as the scientific preparation of the mission. In particular, end-to-end simulators (E2ES):

- Enable the generation of simulated Level-1 and Level-2 output data.
- Support the assessment of the end-to-end performance of the mission on the basis of Level-1 and Level-2 products simulated for selected test scenarios.
- Support the assessment of the impact of individual error sources on the output of an ideal system, both separately and simultaneously.
- Support the assessment of the performance of the retrieval algorithms and of their associated assumptions.

Usually, the first release of the simulator is developed as a prototype tool to support the initial performance assessment of the mission in Phase A. For the E2ES to evolve and support the detailed mission design during later phases, its architecture has to allow growth along two possible directions, as shown in Fig. 1.

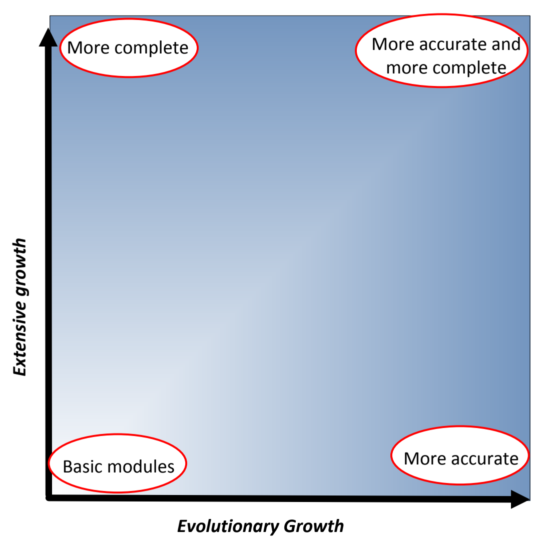

Fig. 1. Possible growth of the E2ES architecture

These two directions of potential growth are:

- Extensive growth, to include more effects and achieve a more complete simulation.
- Evolutionary growth, to achieve more accuracy in the simulator.

Therefore, the idea is to define a Reference Architecture that contains the basic modules for the E2ES, while providing the required flexibility to support both extensive and evolutionary growth. This, coupled to a simulator framework and a repository of models (or building blocks - BB), will allow defining and implementing the E2ES faster and with less effort. This concept is illustrated in Fig. 2.

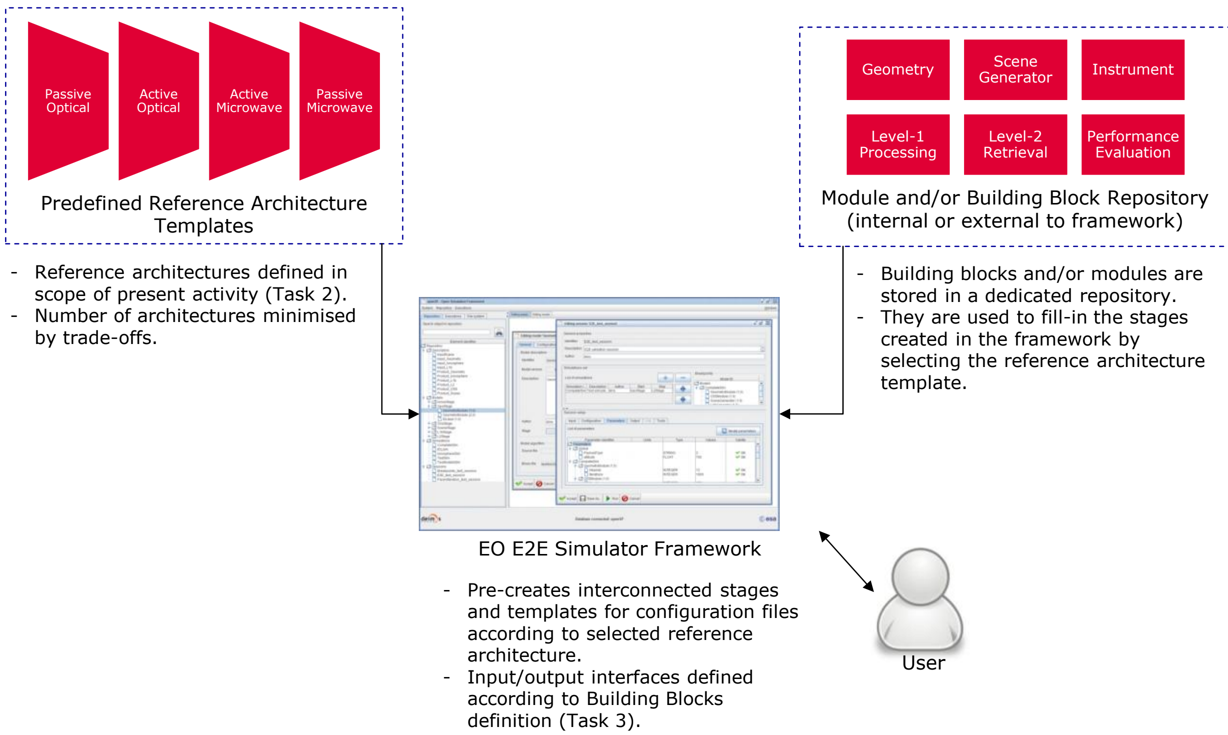

Fig. 2. Proposed solution for the implementation of the Reference Architecture concept

The initial steps in the definition of the Reference Architecture have involved categorizing past, current and planned Earth Observation missions to identify the main elements affecting mission performance and having an impact over the simulator architecture. Then, the architecture elements required to model the mission depending on the type of mission and instrument have been identified, to finally propose a generic Reference Architecture that could be adapted for most EO missions.

MISSION AND INSTRUMENT SURVEY AND CATEGORISATION

A detailed review of past, current and planned Earth Observation missions and instruments has been performed to analyse the different options and their implications on the definition of the reference architecture, such as the possibility of using common blocks or defining independent processing chains.

With respect to mission categorisation, a number of criteria have been investigated, such as: number of satellites in the mission, number of instruments on-board the spacecraft, scientific objective of the mission (see Fig. 3), links with other missions, orbit characteristics, observation geometry/scanning method, etc. It shall be noted that these criteria are interconnected. For instance, a mission consisting of a single instrument mounted in a single platform will usually have a single scientific target.

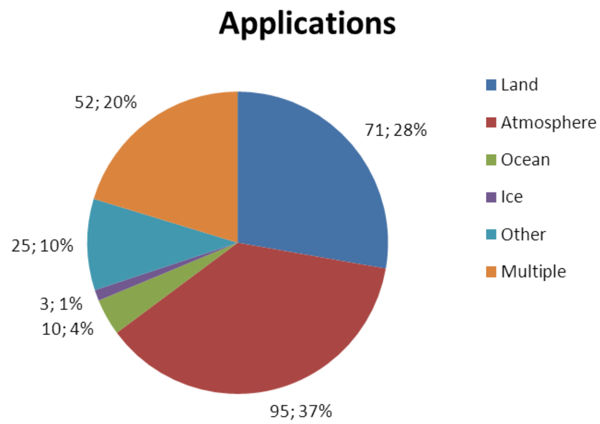

Fig. 3. Example of statistical analysis of the surveyed missions: area of applications.

Taking into account the above mentioned criteria, different mission classifications have been defined and analysed (see fig.4) , and the impact over the E2ES architecture has been evaluated. The conclusion is that, while the mission characteristics affect the E2ES architecture at a very high level, the instrument type has a big impact at lower level, i.e. at building blocks level

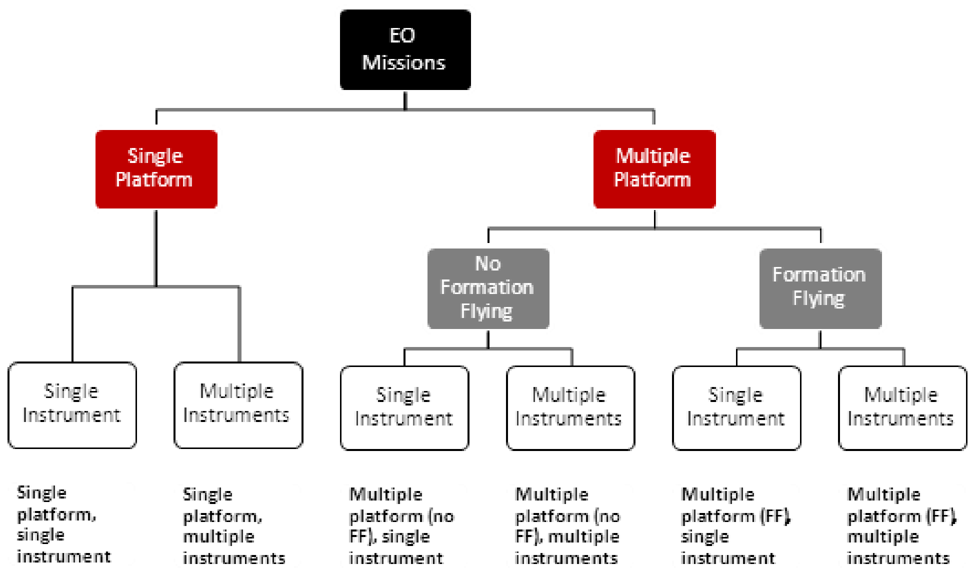

Fig. 4. Categorization of Earth Observation Missions by number of satellites and number of instruments in the mission

After analysing the different instruments, and based on the experience of the team, the instrument classification selected is the one shown in Fig. 5, in which the classification criteria is the region of the spectrum being used and the passive/active condition. This classification is, therefore, the one that has driven the development of the Reference Architecture.

The four main categories that have been defined are active microwave, passive optical, passive microwave and active optical. These cover most of the missions past, present and future, with the first two instrument types being the most common ones at least among European missions. An additional category, “others”, includes instruments that fall outside any of these categories, such as magnetometers and gravimeters.

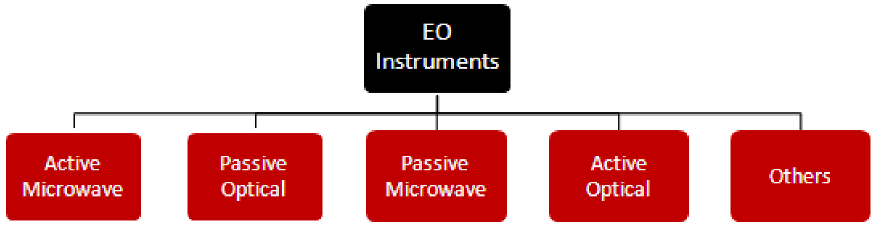

Fig. 5. Categorisation of Earth Observation Instruments

Each of these instrument categories has been analysed and commonalities or "generic" elements have been identified. While there may be different options for the modelling of the different instruments, the priority has been to follow those solutions that exploit commonalities with other types of instruments.

REFERENCE ARCHITECTURE FOR E2E SIMULATORS

The Reference Architecture should cope with the categories of missions and instruments identified, but at the same time take into account the characteristics of a framework supporting future simulator developments (based on the proposed Reference Architecture). In particular the OpenSF framework has been considered as the reference framework, although this fact hasn't conditioned the definition of the Reference Architecture.

These two conditions - the application of the reference architecture to all types of missions/instruments and the use of a simulation framework - support the decision of defining certain elements at high level that would be present in all simulators, independently of the category of the mission and the type of instrument. In the reference architecture concept these high-level elements are called modules, and they could be identified as the simulator Stages (or even more, simulator Modules) of the framework.

Regarding the definition of the high-level reference architecture, one of the premises has been to keep it as simple as possible, defining very few variations with respect to the nominal solution, if possible. This allows having more coherence between the different simulators that will be implemented based on the architecture, being their reuse for other missions favoured, even if they are quite different.

Thus, the approach has been to define very few high-level architectures, depending on the type of mission (multi-instrument, multi-platform…). Then, the type of instrument has impact on the second layer, when analysing the building blocks and internal architecture of the different high-level modules.

The main premises of the Reference Architecture, illustrated in Fig. 6 are:

- The Reference Architecture defines a series of six high-level modules and the interfaces among them that are common to all type of missions and instruments.
- Although the reference architecture is generic, it is flexible to be adapted for the different mission particularities.
- Depending on the type of instrument to be simulated each of the six high-level modules will have an internal architecture broken down in building blocks. This internal architecture is, for most cases, generic across instrument types.
- Different implementations of the same building blocks account for mission parameters, evolution of algorithms throughout the different mission phases, etc.
- Some of the high-level modules and lower-level building blocks will be generic across missions and instruments.

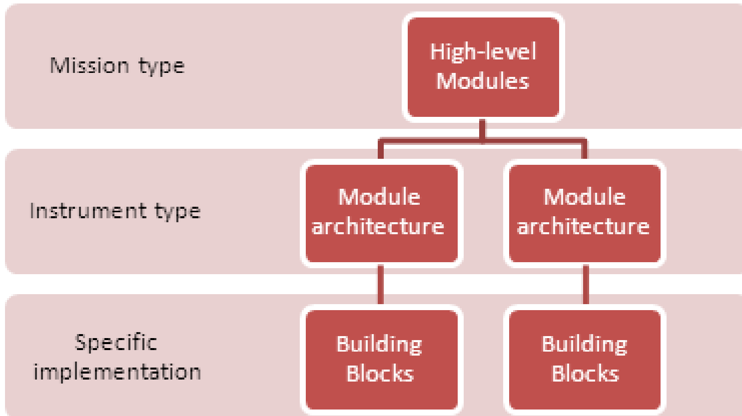

Fig. 6. The Reference Architecture Concept

Including the high-level modules and the lower-level building blocks, the E2ES can be decomposed in three main elements:

- Modules (or Building Blocks): software objects that implement the chosen models.
- Data: input/output information for the models; exchanged among then different Modules.
- Configuration: defined by the user depending on the simulation to be run. Divided in:
    - Configuration parameters, used to configure the Modules in order to process the data under the desired conditions (i.e. instrument characteristics, data sampling, etc.).
    - Activation flags, used to enable/disable the execution of a subset of models or to select the algorithm to be adopted when the E2ES is run. These activation flags could also be used to select a particular implementation of the building block if it is shared by different types of instruments.

High-Level Elements of the Reference Architecture

The identification of the high-level elements of the Reference Architecture has been done from the categorization of missions and analysis of commonalities, and takes into account the project team's experience in the design and implementation of E2ES. Each of these high-level modules, six in total, implements a certain functionality of the E2ES, and has defined interfaces and configuration parameters. Table 1 summarises the purpose of each module and its main interfaces.

Table 1. Details of the high-level modules of the Reference Architecture

Module	Purpose	Configuration	Inputs	Outputs
Geometry	Simulates SC orbit and attitude and observation geometry of each instrument	Orbit & AOCS configuration	N/A	Geometry data
Scene Generator	Simulates scene to be observed and environmental effects needed for generation of stimuli to enter instrument model.	Scene configuration	Geometry data	Stimuli
Instrument	Simulates sensor behavior, having different outputs depending on type of instrument.	Instrument configuration	Stimuli	Raw data
Level-1 Processing	Generates Level-1 products.	Processing configuration	Raw data	Level-1 products
Level-2 Retrieval	Performs retrieval of geophysical parameters objective of the mission/instrument.	Retrieval configuration	Level-1 products	Retrieval products

Module	Purpose	Configuration	Inputs	Outputs
Performance Evaluation	Performs analysis of simulator outputs to evaluate mission performances. It could be run at different points of the simulation chain.	Orbit & AOCS configuration Scene configuration	Stimuli Raw data Level-1 products Retrieval products	Performance reports

Although the data flows between these high-level modules and even their order of execution could vary depending on the type of mission and instrument at which they are applied to, Fig. 7 shows the typical generic data flow that is considered as the main Reference Architecture.

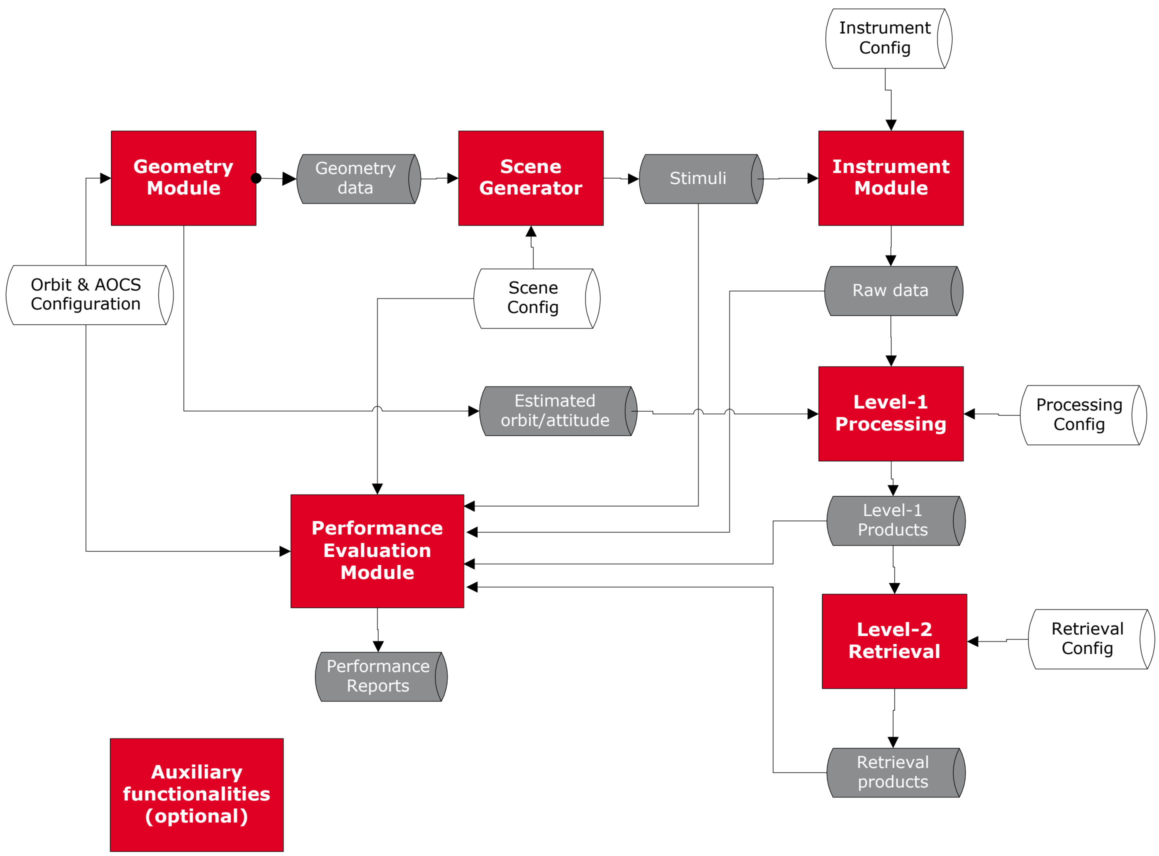

Fig. 7. Generic data flow at the highest level of the Reference Architecture

The concept of the Reference Architecture, as proposed, is flexible enough to accommodate particularities of certain mission. The following are the main three variations of the Reference Architecture that have been identified:

- Nominal Reference Architecture, valid for the following categories:
    - Single instrument missions, independently on the number of spacecraft and formation flying conditions.
    - Multiple instrument missions, if each instrument is simulated in a different E2ES.
- Multiple instruments, identical biophysical parameter to be analysed. The modules of Scene Generation and Retrieval are identical for both instruments.
- Multiple instruments, different biophysical parameter to be analysed. Only the Geometry Module is shared between the two instruments.

Building Blocks

Following the Reference Architecture concept presented, each of the different high-level modules has been broken down in a series of building blocks. The granularity of the building blocks has been determined after the identification of the elements to be modelled and a thorough analysis of commonalities. Once the preferred option (or options) for the definition and implementation of a building block has been identified, the building block itself has been defined.

To ensure the adequate level of detail in the definition of the building blocks, a custom template has been developed (see Fig. 8.). This level of detail is important to allow composability (i.e. reuse) of the architectural elements, both at syntactic (engineering) level and at semantic (modelling) level.

Building Block Description		
General Information		
Building Block Name:	*Write the Building Block name here*	
Instrument Type: (*tick all that apply with ☑*)		
☐ Generic	☐ Active Microwave	☐ Passive Optical
☐ Passive Microwave	☐ Active Optical	
Module: (*tick applicable module with ☑*)		
☐ Geometry Module	☐ Scene Generator Module	☐ Instrument Module
☐ Level-1 Processing Module	☐ Level-2 Retrieval Module	☐ Performance Evaluation Module
Higher-level Building Blocks:		
If applicable, list the higher-level building blocks up to the Module-level.		
Functional Description:		
Include a short functional description of the building block.		

Fig. 8. Partial template for the definition of Building Blocks

Considerations on the Simulation Framework

The definition of the reference architecture and of the generic building blocks is not affected by the selection of the simulation framework, as no requirement has been imposed in the interfaces of the architecture and input/output of the building blocks. However there are a number of aspects related to the simulation framework that have implications on the way the Reference Architecture can be interpreted and on the definition of the scope of the building blocks. These aspects refer to issues such as the interconnection of the modules, the level of reusability, the flexibility in the implementation, the timing of the execution, the disk access, etc. This impact has been evaluated and the features of the simulation framework that affect the interpretation of the reference architecture and the building blocks have been identified.

The solution recommended for a simulation framework supporting the Reference Architecture concept is somewhere between a strictly sequential execution of monolithic modules and the use of building blocks as library elements that can be easily interconnected to build a high-level module.

CONCLUSIONS AND NEXT STEPS

An extensive review of Earth Observation missions and their instruments has allowed deriving a Reference Architecture for end-to-end mission performance simulators. The use of this Reference Architecture for the development of new simulators has the potential of reducing the reengineering process associated to the evolution of the simulator throughout the different mission phases. Moreover, the identification of common elements for different types of instruments also enables reuse of the architectural elements across several mission simulators.

The Reference Architecture has been defined and the building blocks identified and described by means of a standard template. The next step will be to evaluate the Reference Architecture to gain an understanding of the advantages of the Reference Architecture approach with respect to the current approach. This evaluation will be done in three different areas:

- Analyse the process of designing and developing an E2E simulator for a specific EO mission by applying the Reference Architecture.
- Evaluate the proposed Reference Architecture concept compared to ad-hoc E2E simulators development.
- Assess the capabilities of existing simulation frameworks and repositories to support the Reference Architecture and propose, if applicable, improvements to both of them.

The final task to be performed in the ARCHEO-E2E activity will be the definition of a roadmap to reach an operational Reference Architecture, including the identification of priorities in implementing generic building blocks and improvements to the existing simulation framework and model repository.

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