

Study on Aerospace Range M&S Technology Framework Based on CBD

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Abstract. In order to solve the problem of inefficiency and models' lack-of-reusability in traditional M&S (Modeling and Simulation) development of space range. This paper researched on three CBD (Component-based Design) technology and made an overview on their specifications and applications. After that, comprehensive comparisons and analysis were made among three technology. The paper then gave the demands of M&S applications in range test and proposed a technology implementation framework. Additionally, the paper prospect about the development of aerospace range M&S technology and concluded that generative M&S, represented by SMP2.0, would become a trend in aerospace range M&S in the future.

1. Introduction

The range is the experimental site for new weapons and equipment, it serves to help new military equipment become operational in battle. The space range involves various tasks, such as missile tests, aerospace tests, electronic tests and space tests. For the real system of these tests always have massive scale, along with their complexity in structure and high cost, M&S technology are widely used among aerospace range tests. Aerospace range tests M&S often involves various kinds of TT&C algorithms and lots of data exchange, which put high demands on the construction efficiency, interactive abilities as well as simulation effectiveness of system models. In traditional M&S, a combination of object-oriented and event-schedule method is often used in the model coding development, this way of model development has low efficiency, to be worse, due to its tightly-coupled structure inside the model, the reusability of the model is far from satisfactory. So, a reusable and efficient way of M&S becomes urgent need in aerospace range tests.

In recent years, Component-based design (CBD) has gained popularity in the field of M&S. The principle of CBD divides the simulation system into self-contained components. It offers standard interface specification to describe services provided, and separates business logic and simulation environment to eliminate the influences on business logic brought by middleware or integration. Model developers can rapidly build a model by assembling components, after the model gets parsed, simulation results can be acquired with the help of simulation engine.

Currently, there are three component-based technology that are widely accepted, namely DEVS (Discrete Event System specification), BOM (Base Object Model), and SMP2.0 (Simulation Model Portability) .

2. M&S Technology Based on DEVS

DEVS¹ was first introduced by Bernard P. Zeigler of Arizona University, America in 1976. It is a theoretical formalism and offers a method of modeling discrete event system in a hierarchical, modular way. The biggest advantage of DEVS is that it provides a strict mathematical description method. It specifies coupling relations among models and decomposes complex system into components, the hierarchical structure and the coupling of the system can be accurately described without any ambiguity.

In DEVS, models can be decomposed into smaller ones, indivisible model is called an atomic model. It describes the behavior of the component in a time transition level and is defined as a 7-tuple as follows.

$$AtomicDEVS = (X, Y, S, \delta_{int}, \delta_{ext}, \lambda, ta)$$

Where

X: input events set. Y: output events set. S: sequential states set. Ta: time advance function, calculating current time according to current state. δ_{int} : internal transition function, getting states that are transformed spontaneously, without driven by external events. δ_{ext} : external transition function, getting states that are driven by external events. λ : output function, establishing mapping from internal states to output set.

A couple model, which is coupled by multiple atomic models, tells how to use atomic models to form more complex models. DEVS specification is closed under coupling, simpler models can be coupled in a hierarchical way to represent a more sophisticated system, which is shown in Figure1.

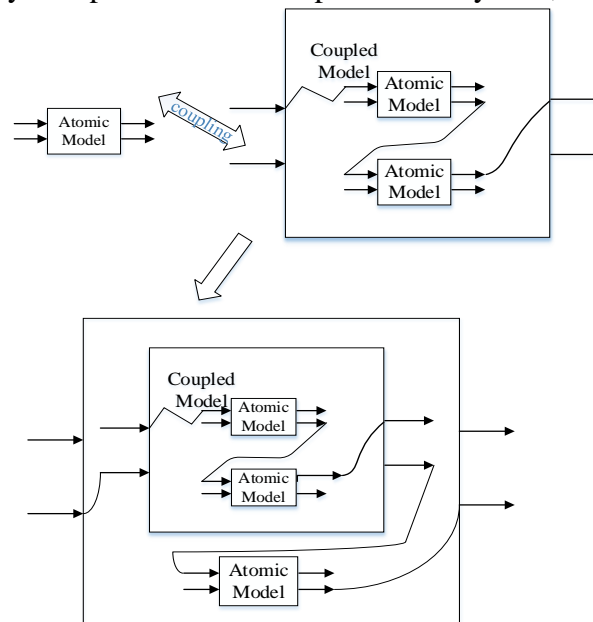


Fig. 1 Hierarchical Construction of a DEVS Model

3. M&S Technology Based on BOM

BOM⁶ was first proposed by the Simulation Interoperability Standards Organization (SISO) in 1997, it became a specification in 2006. Based on High Level Architecture (HLA), BOM is a component framework designed for enhancing the interoperability, reusability as well as composability of simulation models' components. Components can be built on this framework and corresponding component model libraries can be generated. Model developers can assembly components in model libraries to realize the quick construction of simulation model, which would accordingly increase the development efficiency of simulation system.

BOM is the modular expression for conceptual model, simulation object or federal object. As construction modules for the generation and extension of distributed simulation system, it uses four kinds of standard module structure to depict componentized simulation model⁷, namely Model Definition, Conceptual Model Definition, Model Mapping and Object Model Definition.

Description of BOM components is realized by Extensible Markup Language (XML) technology, component framework is automatically generated according to the information in XML. The encapsulation for BOM components contains two parts, including User Component Model and Component Interface. User component model is the software realization of components' function, which is independent from specific simulation platform and can achieve reusability among multiple simulation platforms. Component Interface is the interface between User Component Model and Extensible Simulation Running Framework (XSRFrame). As a universal simulation operation

framework, XSRframe is the middleware between BOM components and HLA, which serves to complete dynamic creation of federate, scheduling of components, distribution and storage of data, and maintain the simulation uniformity. Interface contains description information of components, and establishes mapping between components and federates. Restrictions are put on components in specified scope to guarantee uniformity of interface design, which help to satisfy all types of data transmission demands.

Before simulation begins, XSRFrame automatically loads BOM components to form federates, simulation services among federates are provided by Run-Time Infrastructure (RTI), Model developers can construct complex simulation system based on BOM and HLA. Figure2 shows simulation system based on BOM.

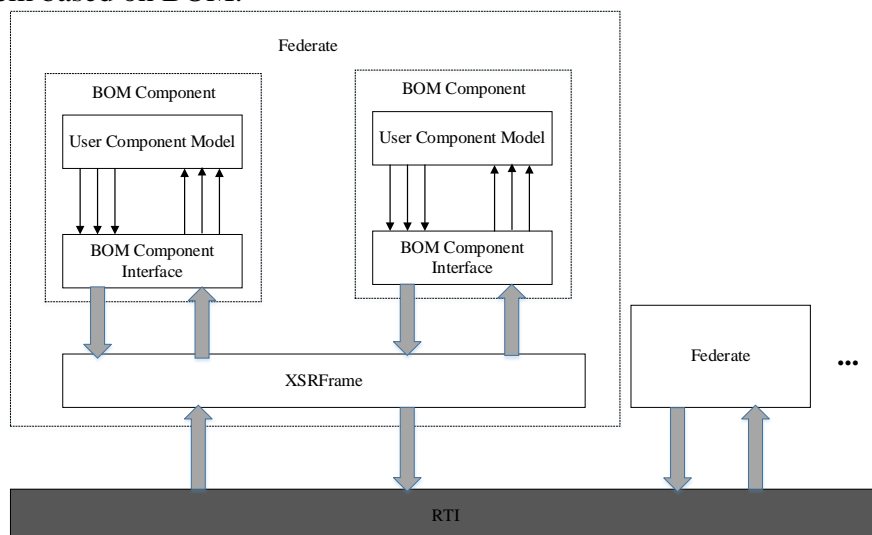


Fig. 2 Simulation System Based on BOM

4. M&S Technology Based on SMP2.0

SMP2.0 was introduced by European Space Agency in 2004, the specification adopted the concept of MDA introduced by Object Management Group (OMG), using Simulation Model Definition Language (SMDL), which was based on XML, to depict M&S design and component assembly information. It separated M&S design information from operating information, and provided basic model framework as well as simulation operating framework, including constitute of model system, interoperability among simulation models, access mechanism between simulation models and other component models, relevant simulation services, etc.

For the realization of MDA, SMP2.0 separates Platform-Independent Model (PIM) from Platform-Specific Model (PSM). PIM, which is independent from simulation platform technology, contains model specification, assembling information and scheduling information. By using mapping and code-generation technology, conversion from PIM to PSM can be realized. With this method, even if the platform technology are constantly updated, once proper mapping rules are set, PIM can be converted to new PSM, therefore enabling interoperability of models.

In addition, SMP2.0 separates design components from operating components. Design components depict construction of models (including interface and feature information), while operating components depict assembling and integrating information. Communication among components is realized by interfaces, and there are two types of interfaces. The first type is the interface between model and simulation environment, while another type is the interface between models. To guarantee the universal scheduling after developing a model, SMP2.0 also introduces four types of services that support the simulation environment, namely Logger, Scheduler, Time Keeper and Event Manager. Figure 3 shows the architecture of SMP.

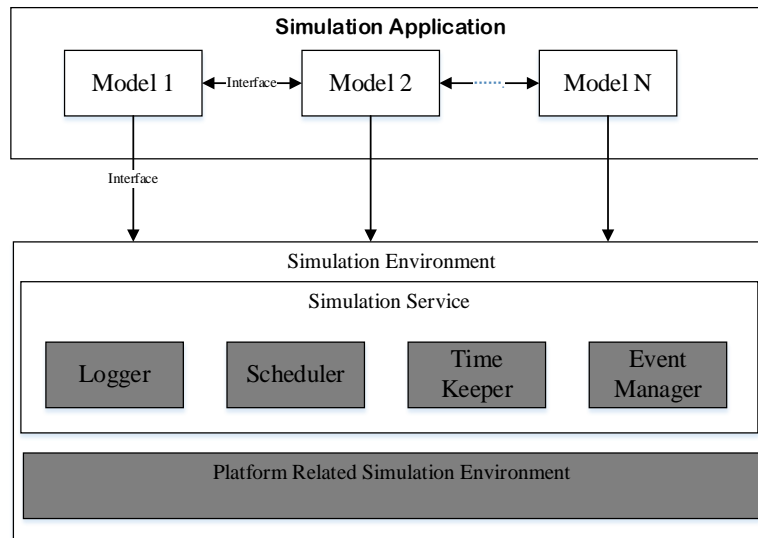


Fig. 3 SMP Architecture

5. Comparisons and Analysis

Above makes an overview on three kinds of M&S technology based on CBD, considering specification itself and its M&S effects, each of three has advantages and disadvantages. Table 1 makes a comparison among three specifications.

Table 1 Comparison among Three M&S Technology Based on CBD

Number	Items	DEVS	BOM	SMP2.0
1	Model Design Based on MDA	Not support	Not support	Support(by defining SMDL to describe PIM model)
2	Model Behavior Description Ability	Not support	Not support	Use UML to describe the model, provide multiple views and support natural description for models in different domains, strong description ability for models' behavior
3	Model Instance Description Ability	Strict mathematical description method, can depict multiple models system in a lossless way. Strong in model description	M&S architecture based on HLA, focus on interoperability, reusability design of components, poor in model description.	UML lack of support for simulation elements in model, poor in model description ability.
4	Interoperability among Different Platforms	Lack of formal semantics, poor in interoperability among different platforms	Based on HLA, in a publish/subscribe way	By establishing mapping to realize interoperation among platforms
5	Interface Description	Support(described by the specification of atomic models and coupled models)	Support(the data structure of interface is defined in conceptual model, realization of interface function is based on federate class of RTI)	Support(interfaces of model components are specified by SCM, which is short for Simulation Component Model)
6	Code Generation Ability	Support auto-generation of component framework, the framework code is generated according to component description file	Support auto-generation of component framework, the framework code is generated according to component description file	Support conversion from PIM to PSM, to some extent, realize the code-generation of executive model
7	Component Assembling Information	XML	XML	SMDL
8	Simulation Engine	Provide design framework for simulation engine	Provide design framework for simulation engine	Provide design framework for simulation engine

In general, DEVS adopts strict mathematical description method, and gives rigid definitions to

components and interfaces. The hierarchical, modular simulation concept and its complete description power to the model are the biggest advantages compared with other specifications. BOM, which is based on HLA, realizes quick construction of components and increases the modeling efficiency. However, due to complexity of HLA itself, the cost of realization is normally high, so there are great limitations when applying HLA. SMP2.0 adopts the generative modeling method of MDA and software technology of CBD, it separates design information from operating information of the simulation model, and M&S efficiency is greatly increased thanks to model conversion and code generation technology applied.

6. Demands and Technology Implementation Framework of Aerospace Range M&S

In aerospace range test, there are many aerospace TT&C algorithms involved. In traditional way of object-oriented M&S, model developer should not only master related specified knowledge but also be skilled at coding. The simulation model developed in this way, however, can only support single test with low modeling efficiency and poor model reusability. Once the algorithm adopted needs modified, model developer should recode and integrate the new code with the old, which would bring large amounts of work. Therefore, aerospace range test is in urgent need of an interface-friendly simulation tool which can support components generation, components management and quick construction of models,

Though the simulation model developed in every single test varies from each other, when conducting simulation in the same domain, there are many modules with similar or even identical functions in different models. According to this feature, component developers can adopt a set of component-based model specification, with which they can divide different simulation elements in simulation system into self-contained components, and utilize Component Generation Module to complete the visual encapsulation as well as generation of components. After that, model developers can use the simulation platform to import required components, by dragging, connecting visualized components, and complete model construction in a 'building-block' approach. After the configuration of model parameters, the model will be parsed by the simulation tool, the scheduling pattern is sent to engine to conduct simulation. Tables, graphs and simulation assessment report are automatically generated by Simulation Result Display Module to show Simulation results in a visualized way. Figure 4 shows the technology implementation framework.



Fig. 4 Technology Implementation Framework

To sum up, generative M&S, represented by SMP2.0, can well satisfy the demands of aerospace range M&S: Use SMP2.0 as specification to develop algorithm components, combined with visualization technology, unification of component interface and visual encapsulation can be guaranteed. Model developers can utilize SMDL to describe components as well as their assembling

information, and refer to its simulation operation framework to design simulation engine. After construction of model, auto-generation of execution model can be realized by model conversion and code generation technology. Consequently, scheduled and calculated by simulation engine, simulation results can be acquired to realize the unified M&S of test system. By this way, simulation professional staff can not only save plenty of time in arduous and trivial work of components development, but modify simulation model in a flexible, effective way. Reusability as well as quick construction of M&S can be both realized.

In fact, SMP2.0 related technology is now in continuous development: To compensate for deficiency in behavior modeling of SMP2.0, researchers realized mapping and model conversion from DEVS to SMP2.0¹⁰, which proved the possibility that other formalisms can be mapped to SMP2.0, and laid foundation for realizing complex system M&S in various formalisms. Generative technology of simulation model and engine technology are also under researched. In conclusion, component-based, generative modeling method is really promising, and it must become a trend in space range M&S in the future.

7. Conclusion

According to the situation of poor reusability and efficiency in current aerospace range M&S, this paper researched on three component-based technology and made an overview on their specifications and applications. After that, comprehensive comparisons and analysis were made among three technologies. The paper then gave the demands of M&S applications in range test and proposed a technology implementation framework. Additionally, the paper prospect about the development of space range M&S technology and concluded that generative M&S, represented by SMP2.0, would become a trend in space range M&S in the future.

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