Meta-Model Based Methodology of C4ISR System Architecture Development

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Abstract. Architecture framework which provides the methodology and descriptive technology of architecture with rules, guide and product description, ensures that there is a common standard in understanding, comparing and integrating architecture. Through analyzing and summarizing the latest progress in architecture from several aspects including framework, framework data model and architecture developing method, a new method of meta-model based C4ISR system architecture methodology was proposed which is a good manner to support data-centric architecture methodology. This method emphasized that data is the key point to develop architecture, ensuring the integration and interoperability between different architectures under disparate architectural methodologies. Based on the architecture meta-model, this method presented the foundational guidance for architecture modeling, description and data collection.

Keywords: Architecture framework, data model, metamodel, architecture developing

1. Introduction

The architecture of C4ISR is defined as the structure of components consisting of a system, their relationships, and the disciplines and guidelines governing their design and evolution over time. The quality of the architecture will decide whether the C4ISR system development is successful or not. Architecture framework provides the roles, guidance, and products for developing and presenting architecture, and provides a common criterion for architecture description development, presentation, and integration.

Along with the rapid development of information technologies and Architecture technologies, the trend of realizing multinational joint combat systems architecture require developing new methodology of architecture framework. Other nations in the world have strengthen the researches on architecture framework, in order to utilize new information systems technologies better and then provide further support to the understanding, interaction and integration of C4ISR system architecture data among multi-nation. Against the disadvantage in the current developing approaches of product centric architecture, this paper proposed architecture developing method of architecture, which is based on meta-model, through analyzing and summarizing the latest researches on architecture framework. The method emphases data centric, and support analysis and decision with utilizing and reusing architecture data much more effectively and flexibly.

Architecture framework data model has become the important resource and specification of architecture development, also a well-formed data model is the premise of exact architecture description and the foundation of standard modeling methods. In the past several years, many countries promulgated their new version of architecture framework, with the data model upgraded. Always the data model's evolution will influence the modeling methods of architecture development. So, for new architecture framework and data model, it needs novel architecture methodology to support analysis and decision-making. For new

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requirements, the product-centric architecture methodology can't yield high-quality architectures. When talking about data-centric architecture methodology, only a few researches on definition and conception are made, and the concrete operational processes have not been initiated.

The remainder of the paper is organized as follows: Section 2 overviews the leading architecture framework of C4ISR system and Section 3 elaborates the data model of each architecture framework, specially the International Defense Enterprise Architecture Specification which becomes the modeling foundation of architecture framework data model. According to the latest development of C4ISR architecture framework, Section 4 advances a new method to develop architecture, and summarize the features and advantages of this method. Finally, Section 5 concludes the paper and comment on future work.

2. Architecture Framework

2.1. DOD Architecture Framework

The U.S. published DODAF 2.0 official version in May, 2009[1] [2], which extended the kinds of viewpoints and the number of products. Its main changes are shown in figure 1. DODAF 2.0 deepened the transformation from "product-centric" to "data-centric" methodology, and developed the architecture design further. DODAF 2.0 highlights the idea of aim-orient, emphasizes collecting, design, organizing architecture data through data model based on the standard. Besides, it constructs architectural descriptions, to support the analysis and decision-making requirements of different decision-maker and architecture aim.
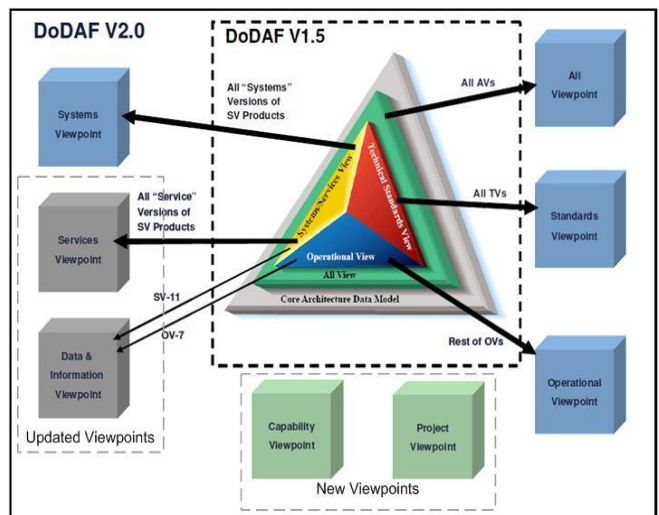

Figure 1.   DoDAF V1.5 Evolution to DoDAF V2.0

DODAF 2.0 is not limit to the previous versions, but absorbing the latest researches on architecture framework among different nations and organizations all around the world. It constructs architecture framework meta-model (DM2), standardizes architecture development more strictly, provides data model standards, and thus provides the utilizing and reusing of architecture data with more effective supports. The core idea of DODAF 2.0 is data centric; its focus is on architecture data, rather than a single product developing. The developing idea of data centric will benefit utilizing and reusing architecture more effectively and flexibly. This version emphasizes collecting, organizing and maintaining the architecture data, rather than the products developing in previous versions.

2.2. MOD Architecture Framework

MOD Architecture Framework 1.0 was published in 2005. MODAF consults DODAF 1.0, and combines with its own characteristics. It is seemed as an important means to realize network enabled ability. The framework adopts 6 views, i.e. Strategic Viewpoint, Operational Viewpoint, Systems Viewpoint, Technical Viewpoint, Acquisition Viewpoint and All Viewpoint, and 30 classes with 38 products. In 2010, the UK Ministry of Defense published MODAF 1.2 Improved Version [4], which adds Service-Oriented Viewpoint in the foundation of the previous 6 Viewpoints. MODAF 1.2 improves the meta-model and defines the

correlated meta-model of each product. It explains the details of meta-model as well, which make the describing grammar of architecture product more normative.

2.3. NATO Architecture Framework

To construct a weapon equipments architecture which is more suitable for the requirements of 21 century war, NATO actively follows and learns from the UK Ministry of Defense to precede architecture technology researches. The NATO Architecture Framework (NAF) 3.0 version was published in 2007, which extends the design and developing approach from C3 system to all areas, and deepens the architecture technology and theory researches. NAF 3.0 version definite 4 types of architectures, i.e. Overarching Architecture (OA), Reference Architecture (RA), Target Architecture (TA) and Baseline Architecture (BA), 7 kinds of architecture views and 48 sub views.

There are several new features and concepts in NAF 3.0, for example, several new view groups like Capability Viewpoint, Service-Oriented Viewpoint and Programme Viewpoint. In addition, all the architecture elements and sub-views are now underpinned by a common meta-model which becomes the core foundation of NAF 3.0. The meta-model that evolves from MODAF 1.0 is a key factor to architectural coherency and common understanding. The coherence of architecture descriptions and understanding is achieved by defining which architecture elements can be used in which NAF sub-views - architects create an object only once and reuse it from other sub-views.

3. Architecture Data Model

Architecture data model is important resource and standard to support architecture development. A good architecture data model is the premise to realize accurate architecture descriptions, the foundation of standard architecture modeling method, and the important grantee to effectively support the activities of analysis and decision-making.

3.1. International Defense Enterprise Architecture Specification (IDEAS)

The IDEAS is an Ontology-based modeling standard against architecture domains. It constructs top-level ontology of multinational architecture domain modeling to support the data interactive within multinational architectures, and then better accomplishes understanding and communicating of multinational joint operation system architecture data. The IDEAS is a formal, high order, 4D ontology with fine extensional mechanism. Its top-level ontology structure is shown in Figure 2. . It adopts physical existence as the standard of object (concept) identification, rather than identifying objects with the name of concepts. The fine model quality of the IDEAS makes it gradually become the standard in architecture modeling domain, which is used by multination.
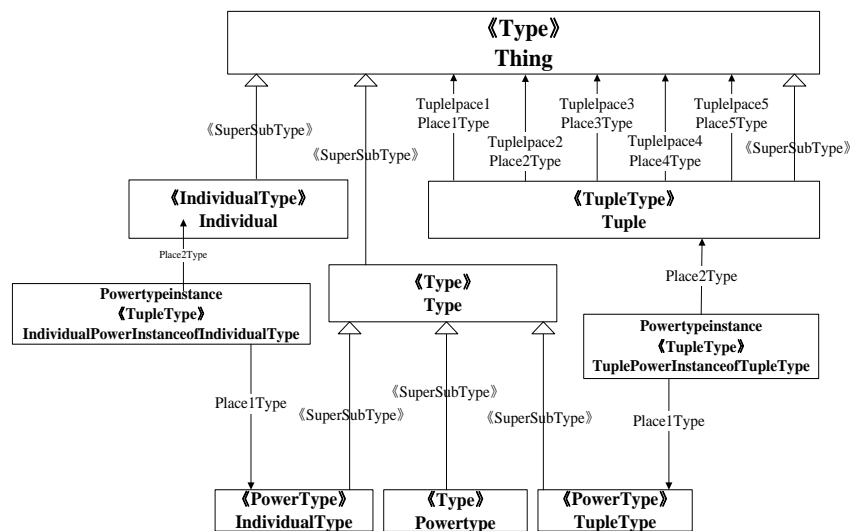

Figure 2.   IDEAS Foundation Top-Level

IDEAS provide the construction of architecture framework data model with mathematical stricture and accurate foundation of architecture descriptions; the use of generalization patterns, which reduce the overhead of modeling and proceeding; enhance the ability of exchange and reuse among different architecture framework methodology, such as MODAF, DODAF, and NAF etc. Its high level structure of generalized patterns is shown in Figure 3.
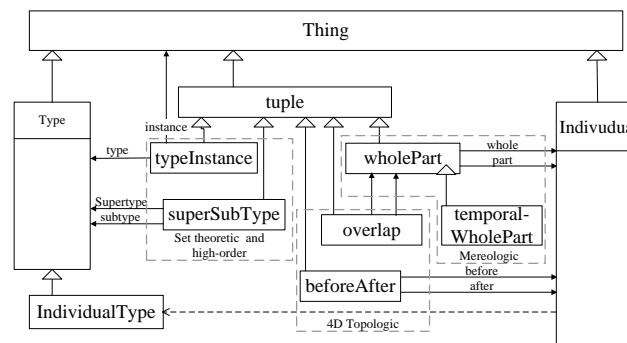

Figure 3.   IDEAS Upper Ontology

The IDEAS ontology is strictly extensional—individuals are defined according their spatio-temporal extent, and classes are identified by their members. The IDEAS Upper Ontology presents common patterns, such as before-after, overlaps, whole-part, etc. and subject areas. The Upper Ontology also founds the important architectural concepts and views within architecture frameworks of many countries [6].

3.2. DODAF 2.0 Meta-Model (DM2)

Under the supervision of data centric architecture developing idea, DODAF 2.0 developed meta-model of DODAF (DM2) which replaces the previous core architecture data model (CADM) in early versions. DM2 build the foundation of semantic consistency both different architectures and intra-architectures. Due to this way, DM2 can realize accurate architecture description better, standard architecture modeling method, and support exchange and reuse of architecture information.

DM2 is a data model based on IDEAS ontology standard, and provides a method that using a more understandable way to collect, organize and store data in order to export information that is essential to analysis and decision-making. DM2 includes Concept Data Model (CDM), Logical Data Model (LDM) and Physical Exchange Standard (PES) [9]. Based on DM2, DODAF 2.0 proposed the realization scheme of architecture consistency, i.e. the data in architecture description is defined by the concepts, relationships and properties in DM2; the architecture data is able to exchange according to PES standard.

The Conceptual Data Model (CDM) defines the high-level data structures from which Architecture Descriptions are created in non-technical forms, and thus the managers and executers in different level can understand the meaning of architecture descriptions. The CDM provides the data foundation for modeling the Logical Data Model (LDM). The LDM adds technical information to the CDM, such as attributes, clarification of relationships, etc. Essentially, the LDM provides the reification and formalization to the concepts and relationships of the CDM. The Physical Exchange Specification (PES) consists of the LDM with general data types specified and implementation attributes added, and then generated as an XSD, which is the foundation of exchange specification within different architecture tools and frameworks.

3.3. MODAF 1.2 Meta-Model(M3)

M3 is developed based on MODAF 1.2 version by UK Ministry of Defense, and delimit the basic structures of architecture information. Its aim is make the MODAF tools model-based driven [3]. M3 provides the description of the same information among different views with consistency foundation. It identifies all the architecture elemental concepts and the relationship among them. Model-driven means that the MODAF supported tools and dataset developments is based on M3, and it provides the foundation of data consistency, strict semantic standard and the foundation to realize data exchange among different architectures developed by diverse MODAF tools.

M3 provides the foundation of model consistency, realizes the integration of both view description level and data level. M3 provides a kind of effective data exchanging format, which is based on XML standard of OMG. For the maximum reuse of XML interface, M3 delimits the abstract grammar of UML profile, through extending the meta-model in UML 2.0. M3 specifies a UML stereotype for each element it defined, but does not provide a concrete grammar (visual description to class template) with it. It is because that UML cannot be used as the optimal modeling approach for MODAF products, and abstract grammar is enough for M3 to generate exchange specification which is based on XMI.

4. Meta-model based architecture development method

Data-centric methodology has become the mainstream idea of current architecture development and design. However, the data-centric architecture methodology research is just stay on the concept and precedes — some simple work. There is little research fruits in the detailed realizing methods. Against the latest progress of architecture framework, this paper proposed a new architecture developing method which is meta-model based, and delimits this method as follow: standard based architecture meta-model adopts meta-model supported standard modeling design method to collect, organize and store architecture data and then export the information which is essential to analysis and decision-making; it provides fine reuse and exchange standards of architecture data, and shows data in flexible architecture describing methods; it realizes comparability and integration of architecture for further developed systems. This method ensures the clear and consistent description of architecture data; and it can support architecture decision analysis much better.

The meta-model based architecture design method is an effective way to realize data-centric architecture methodology. Through the method of building meta-model, it utilizes plentiful semantic information of architecture data model to standardize and guide architecture development. Its concept model is shown in Figure 4. The main processes are as follows: firstly, based on meta-model the architects choose the appropriate modeling methods, with their modeling primitives and patterns mapping to the elements in the meta-model, to collect the requiring data that needed to support architecture analysis and decision-making. Secondly, according to the meta-model, the architects determine the right manner to organize and store the architecture data which is collected in the first step — usually as a file format of XSD. Then, in the light of the diverse requirements and styles of managers at different levels, the architects decide the compatible fashion to exhibit the architecture data, and generate the architecture description for analysis activities.
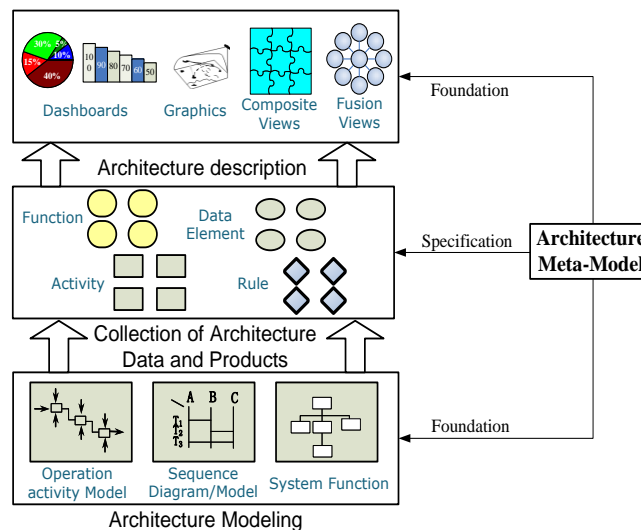

Figure 4.   The conceptual model of meta-model based architecture development

In the developing of data-centric architecture, meta-model is the foundation of organizing and managing the architecture data. It is the foundation of both supporting various architecture modeling methods and flexibly architecture description supported decision as well. The relationships among architecture meta-model, architecture framework and modeling methods are shown in Figure 5. The meta-model is constructed according to architecture framework, the design patterns and primitives of modeling methods is mapped to

the correlated elements in the meta-model, and the various view products in the framework is supported by corresponding modeling methods. The main characteristics and advantages are shown as below:

- It provides the foundation of architecture data semantic consistency, which is beneficial to the data consistency in whole architecture developing process, and is the foundation of developing accurate and shareable architecture descriptions.
- It is able to support various modeling methods to develop models, which improves the effectiveness of architecture modeling executing, and supports utilizing the most familiar modeling method to construct architectures by modeling stuffs of different preferences.
- Flexible architecture description mechanism enhances the understandability of architecture within different organizations, and promotes the ability of analysis and decision-making, which is beneficial to the comparability and integration of architecture.
- It can support reuse and exchange of architecture data better, to realize architecture sharing among different frameworks and tools, and effectively simplify the data collecting process in architecture modeling.
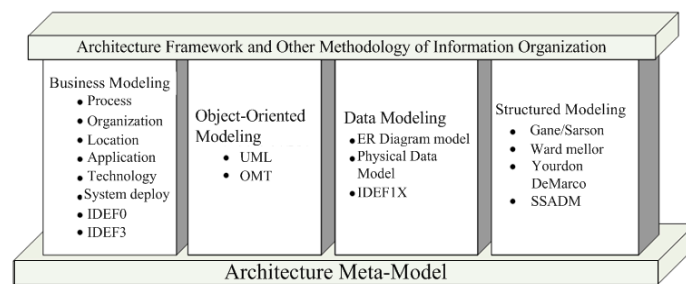

Figure 5.   The relationship of architecture framework, architecture meta-model and modeling methods

It is beneficial to the evolution of architecture description; and according to the architecture objective and the changes of decision-makers, it is able to dynamically adjust the architecture description, in order to satisfy the demands of analysis and decision-making.

5. Conclusion

Along with the more and more widely use of architecture in information system constructing, many nations are strengthening the research of architecture, aware of that the core foundation of architecture is data, and thus developed its own meta-model of frameworks to standardize the mathematical foundation of architecture and specify the grammar and semantic of data. Based on the latest research progresses in C4ISR system architecture framework, this paper proposed a new architectural developing method based on meta-model that will be a good manner for implementing the data-centric architecture methodology, and analyzed the relationships among architecture, metamodel and modeling method, and provided important grantee to realize data centric architecture developing and promote the understanding, exchange and integration. With the data standard of the meta-model, in despite of which modeling method is chosen for developing architecture models it will always obtain the common understanding with the premise that the modeling patterns and primitives of the modeling method are needed to map to the elements in the meta-model strictly.

Ongoing work includes the modeling method of architecture framework, the concrete meta-model based architecture development process, and the Self-adaptive evolution of architecture products along with the data model's upgrade.

6. Acknowledgment

7. References

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