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DATA AND METADATA REQUIREMENTS FOR COMPOSABLE MISSION SPACE ENVIRONMENTS

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ABSTRACT

Composability is the capability to select and assemble reusable simulation components in various combinations into simulation systems to meet user requirements. The Defense Modeling and Simulation Office's Composable Mission Space Environments program, seeks to develop concepts, technologies, and processes to enable the rapid, efficient, and flexible assembly of simulation systems from components. A workshop was held to examine the current state of composability, refine its definitions and intentions, identify capabilities and technologies needed to support practical composability, and propose research objectives and programmatic initiatives to move towards the goals of the Composable Mission Space Environments (CMSE) program. Approximately 35 experts from government, industry, and academia participated in four working groups (WGs). This paper reports the findings and recommendations of the Data and Metadata WG. The WG identified the crucial functions served by metadata descriptions of components in composable development, specified attributes of the components to be represented in the metadata, and sketched a high level concept of operations describing the roles and relationships of metadata stakeholders. This paper also reports the recommendations of all of the WGs for future actions in support of composability.

1 INTRODUCTION

This section briefly introduces the idea of composability and describes the structure of the paper. Most of the background material in this section is drawn from (Morse 2004).

1.1 Composability

Composability is the capability to select and assemble simulation components in various combinations into simulation systems to satisfy specific user requirements (Petty 2003). The components to be composed may be drawn from a library or repository of components. For example, such a library might include multiple network interfaces, different user interfaces, a range of classes of implemented entity models, a variety of implemented physical models at different levels of fidelity, and so on. Different sets of components from the repository may be composed into different simulation systems. The components may be reused in multiple simulation systems. Indeed, to a certain extent reuse depends on composability (Igarza 2001). The defining characteristic of composability is that the components can be composed in a variety of ways to produce different simulation systems, each suited to some distinct purpose, and the different possible compositions will be usefully valid. Composability is more than just the ability to assemble simulations from parts; it is the ability to combine and recombine, to configure and reconfigure, sets of components into different simulation systems to meet different needs. Composability could have many benefits for the practice of simulation and is an increasingly important issue in simulation system development.

From the point of view of components, composability exists in two forms, *syntactic* and *semantic*. Syntactic composability is the actual engineering implementation of composability. Syntactic composability is concerned with the compatibility of implementation details, such as parameter passing mechanisms, external data accesses, and timing mechanisms. It is the question of whether a set of components can be combined. Semantic composability, on the other hand, is concerned with whether the models that make up the composed simulation system can be composed and remain valid (Petty 2003a). Modeling issues such as domains of validity and consistent assumptions are central to semantic composability. It is the question of whether a composition of models is meaningful.

There are other views of composability. Given a set of components, structured descriptions or specifications of the components, sometimes called metadata or meta-models, can be used to guide the process of selecting components for a specific purpose and determining if a set of components can be effectively composed. Implementation of a library of components, and using those components to develop simulation systems, will likely occur in a collaborative team context and automated infrastructures to support collaboration composable development will be essential. Finally, for composability to succeed in practical applications, business issues such as the protection of intellectual property and the economics of developing reusable software must be worked out. Certainly, composability is a technical challenge, but technical solutions will not be enough (Davis 2003).

1.2 Scope and Structure of the Paper

This paper has four main sections after this introduction. The next introduces the Composable Mission Space Environments program and explains the goals and structure of the workshop reported in this paper. The subsequent sections report the thinking of the Data and Metadata WG on the meaning and application of data and metadata, followed by sections describing recommendations for developing a composability concept of operations and a metadata framework for supporting the concept of operations. The paper concludes with recommendations from all the WGs and a list of workshop participants.

2 COMPOSABLE MISSION SPACE ENVIRONMENTS

The Defense Modeling and Simulation Office initiated and organized the Composable Mission Space Environments (CMSE) program to pursue a comprehensive set of projects with the common theme of enhancing the composability of defense-related M&S. One of the activities of the CMSE program was a workshop on simulation composability that was charged with examining composability from a variety of perspectives.

2.1 CMSE Program Summary

The idea of composable 'anything' is certainly not new; in fact, it's not even a new concept in M&S. Much has been written about composability, and we don't expect or want that to change. Some think composable M&S will never happen; some think we have achieved it; many believe we are practicing it to some extent now.

Distributed M&S, by its very nature, breaks down into some component structure. However, in practice today, there is little rigor applied to the way the breakdown (and complementary buildup) occurs. Any rigor applied is usually applied to a particular instantiation of a distributed M&S system. The lack of rigor is a major contributing factor in the recurrence of problems.

Experienced practitioners in M&S today, whether they are handling a single component, or trying to compose an M&S system, bump into the same type of problems over and over again. These problems range from fiscal, to time constraints, to technical issues. They involve the breakdown and buildup of the M&S system. They look into the pros and cons of small versus large. They have become systemic to the M&S environment. Experience will usually assist the practitioners on how to anticipate and handle the problems (we're learning!) but rarely is the experience codified and shared.

All three of the above issues led the Defense Modeling and Simulation Office to consider a different approach to composable M&S. Instead of treating each problem area separately, begin to look at composable M&S, with its problems, as a whole enterprise; from concept, to sunset, to policy and guidance, to cultural change. The program at DMSO was given two years to study the problem space, and suggest/attempt solutions.

During the first year, and given the breadth of the treatment needed, the most expedient way to get started was to gather some willing victims, from a large cross-section of the community, and give them time and space to be creative. So the Composable M&S workshops were tried. No outcome was expected; no influence applied.

2.2 CMSE Workshop Goals and Structure

In August 2003, a workshop was held to examine the current state of composability, refine its definitions and intentions, identify capabilities and technologies needed to support practical composability, and propose research objectives and programmatic initiatives to move towards the goals of the Composable Mission Space Environments program. Approximately 35 experts from government, industry, and academia participated. They were organized into four working groups, each with a distinct perspective on composability: Components, Collaborative Infrastructures, Data and Metadata, and Business Cases. Each group examined composability relative to its perspective, producing definitions, explanations of key concepts, specifications of enabling technologies and processes, and recommendations for future actions. All four groups provided recommendations for future actions in support of composability in general and the Composable Mission Space Environments program in particular.

3 DATA AND METADATA

The Data and Metadata group identified the crucial functions served by metadata descriptions of components in composable development, specified attributes of the components to be represented in the metadata, and sketched a high level concept of operations describing the roles and relationships of metadata stakeholders.

3.1 General Findings

Of the questions put to all the WGs, the Data and Metadata WG focused on two:

- What is composability?
- What are those fundamental attributes and properties necessary to describe a component, and what

are the mechanisms necessary to make those components usable for constructing composable systems?

3.1.1 Composability from the Data and Metadata Perspective

Data and metadata are the glue that will hold composability together. The composability process has two steps:

- Identification of components that meet fitness of purpose requirements
- Automatic unification/alignment of data models if possible

"Automatic" in this context refers to the user, not the engineer; tagging the data model will require effort by engineers in a manner somewhat analogous to the agile FOM concept, but probably more extensive. Automatic unification/alignment of data models happens at the physical interoperability level, i.e. for simulation components that have been determined to be meaningfully interoperable at the semantic level by some other mechanism. This leads to the questions, what metadata is required to support automatic unification/alignment and can we define metadata to support determination of semantic interoperability?

3.1.2 Fundamental Attributes and Properties of a Component

The fundamental attributes and properties of a component from a data/metadata perspective are fitness for purpose, i.e. a finite set of purposes. This may require multiple layers of metadata for different levels of detail and fitness for purpose will have multiple dimensions. Some metadata will be generic across all components, e.g.:

- Hardware/software support requirements
- Purpose/domain – some set of categories which identify the subsets of other metadata which apply to the component
- Acquisition, training, analysis, tactical decision support, vs. experimentation
- Live, virtual, constructive
- Versioning, status, authorship
- Information about the model as a software component—implementation details that impact its use for a given component (e.g., available as source/compiled code)
- Programming language used
- Communication protocol
- Interface standards supported, e.g. DIS, HLA, ALSP
- Security classification
- Development standards, e.g. SEI CMM, DoDAF
- Time management scheme
- Prior use documentation, including reviews and rationale, and exercises and applications

While other metadata will be applied as appropriate for the component, e.g.:

- Unit vs. entity
- ID the real-world asset/role the model represents (may be tangible/concrete or abstract object; e.g., F-15 or fear)
- Information about the model as a simulation component
- Spatial resolution; e.g., represent battalion as a point or area
- Aggregation; e.g., battalion represented as single unit or comprised of companies?
- Temporal resolution
- Category of real world asset; e.g., air-to-ground missile vs. specific missile

This metadata framework will require assessment processes/measures for determining a component's fitness for purpose, i.e. the degree to which it satisfies the requirements for a particular metadata value. The framework should also account for recording federation agreement-type information.

3.2 WG Unique Findings

In addition to the questions put to all the WGs, the data and metadata WG considered the following questions unique to the WG:

- Are components different for different domains, and if so, how should those differences be described?
- If components are not the basic building block for composability, what are and how should they be described?
- If all the necessary pieces were available that would allow construction of a composable system/product, would the marketplace use that capability?
- What are the roadblocks, hurdles, obstacles, and impediments to making composability a reality?

3.2.1 Components for Different Domains

Not only are components different for different domains (or communities of interest), but the metadata and data models to describe them are different. Communities of interest must decide what abstractions, and therefore metadata, are significant for differentiating different components A community of interest as a whole needs to decide on a framework of metadata, probably based on a framework accepted at a higher level (broader) community of interest, with domain specific metadata at the lowest levels. To do so will require leadership at all levels to drive the definition of the framework and coordinate communities of interest to consensus.

3.2.2 Basic Building Blocks of Composability

For the sake of honesty, we considered whether components might not be the basic building block for composability; and if not, what are and how should they be described? This question proved to be interesting because it presupposes a quantitatively measurable definition of component that is currently lacking. For now we must be content to work with qualitative definitions. We know that components must be black boxes with well-defined interfaces including metadata describing their capabilities. Composability should apply at multiple levels. This in turn led to the question, how much do we need to know about a component? If we know everything, there's no abstraction; it becomes merely data. Having a metadata framework would limit our universe to a finite, manageable set. This last realization led to an important recommendation described later.

3.3 The Composability Marketplace

Although the WG members were primarily scientists and engineers, we also examined the reality of the marketplace for composability. (For a more in depth analysis of the business case for composability, see the Business Case section of (Morse 2004).) Currently, there is no market incentive for migrating to component-based approaches. Program managers have a contract to deliver a product for a price. They seek to minimize risk, including dependency on outside sources; they want to maintain control of all aspects of the program. It's currently in the best interest of existing contractors' business models to maintain stovepipes. In fact, the Defense Acquisition University doesn't even teach M&S to program managers.

Migrating to component-based M&S will require a cultural change. The government will need to incentivize the market and address the intellectual property issues. There is a hopeful note in this pessimistic view; DoD Instruction 5000.1 and JCS 3170 require ACAT 1 and 2 programs to generate integrated architectures and to generate capability assessments, both based on joint capabilities. This may serve to incentivize componentization across services, but not necessarily across community boundaries, e.g. experimentation vs. analysis. In order for this to work across M&S, it must apply to small programs as well as large ones.

3.3.1 Roadblocks, Hurdles, Obstacles, and Impediments

Having considered the challenges of the marketplace, the WG performed a broader survey of challenges to success. While the list appears discouraging at first glance, it proved to be effective guidance for the WG in developing the subsequent recommendations:

- Lack of data and metadata framework
- Lack of conops/use case; how would people use a composability capability if they had it?
- Representation of level of fidelity
- Lack of definitions
- V&V of composed models - – is there a validating/certifying authority and process for components; how do you get community buy in; how do users have confidence that the components do what they claim to do; this also leads to the need for configuration management of components and associated metadata
- Capturing uncertainty/precision/accuracy of a model's mathematics and algorithms as they impact results
- Lack of a systems engineering process for composability
- Lack of funding
- How does the user translate between a conceptual model and component requirements? Should there be a conceptual model language? Can the translation from the conceptual model language to component requirements be automatic or does the user have to be led through the translation, either manually or with tool support?

3.4 Next Steps for Data and Metadata

Based on our findings, the WG recommended two major future actions with respect to data and metadata:

- Develop a composability concept of operations (conops) with use cases to clarify composability definition and elucidate requirements
- Develop a metadata framework; this will require participation from modeling subject matter experts from communities of interest

In support of these recommendations, we sketched an action plan for achieving these goals once the composability conops produces detailed requirements. At a minimum, the follow steps will be required:

1. Develop a "Common Conceptual Modeling Language" that describes what the components do and how well they do it
2. Define the metadata attributes/metrics (for a finite list of fitness of purpose) as an initial description point, but extensible and modifiable (by the community at large), leading to a metadata framework
3. Develop quantitative values for metadata fitness where possible

4. Define a process to determine qualitative values when quantitative values are not practical
5. Develop search/query tools that use the metadata framework to identify semantically composable components

Figure 1 illustrates the responsibilities, and relationships and information shared between the stakeholders in the composability concept of operations.

4 COMPOSABILITY CONOPS

The first major action recommended by the WG is to develop a composability conops with use cases. As a starting point, the WG raised the following questions as guidance for developing the use cases:

- How does the user quantitatively state the requirements for the desired simulation?
- How do we structure metadata to select components to meet the requirements?
- How do simulation builders search metadata based on fitness for purpose, especially when the model/component builder describes the model in terms of data representation and mathematics/algorithms; by whom/how are the mappings performed?
- Should Architecture Framework OVs include metadata?
- Do components have to be designed for a specific purpose to be used for it?

Table 1 shows an example of an extremely simplified method for evaluating the applicability of a single component. This example does not assume the existence of a conceptual modeling language that could automatically map a conceptual model to metadata tags that represent the user's requirements. The user specifies the metadata tags, highlighted in orange, that identify the requirements. The values of the metadata highlighted in yellow are pulled directly from a registry. The user specifies both the weighting (importance) and mapping function for the metadata values. These two values taken together indicate the importance of the component having that characteristic. The mapping function indicates the acceptable values and the weighting indicates how important it is that this particular element has an acceptable value. In this example the user has indicated that the component must be HLA compliant and provide entity level modeling, but is more flexible about programming language and temporal resolution.

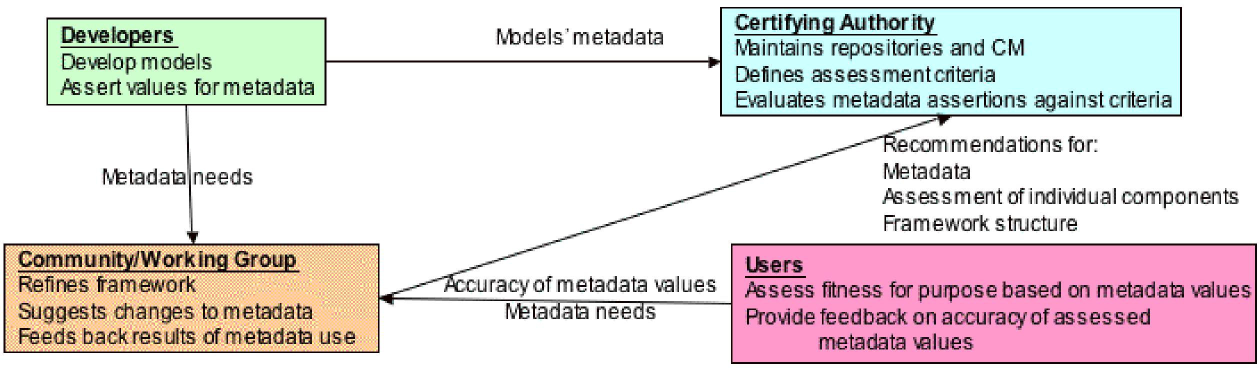

Figure 1: Composability Stakeholder Roles, Responsibilities, and Relationships

Table 1: Sample Evaluation Spreadsheet

Requirement	Value for Component	Mapped Value	Weighting	Score	Notes on Mapping Function
Protocol	HLA	1	10	10	HLA = 1, DIS = 0, ALSP=0
Aggregation	entity	1	15	15	entity = 1, unit = 0
Support cost	150,000	0.1	5	0.5	0-10K = 1, 11K-50K=.5, 50K-100K=.2, >100K=.1
Temporal resolution	10 min	0.5	10	5	<1 min=1, 1-59 min=.5, >1 hr=.1
LVC	constructive	1	20	20	live=0, virtual=.5, constructive=1
Programming language	C++	0.5	10	5	FORTRAN=0, C++=.5, Java=1
Security classification	unclass	0	30	0	unclass=0, secret=.5, TS=1
		MUST = 100	100		
			TOTAL	55.5	

Note that this very simplified approach only works for a single component and doesn't address assessment of sets of components that meet the user's requirements. It also shows only the most simplistic measure of merit or distance from optimal satisfaction of the requirements. With any process, the user may need to iterate on requirements' weighting if the resulting set of components is known not to satisfy the conceptual model.

5 METADATA FRAMEWORK

The metadata framework needs to support both the statement of simulation requirements and descriptions of the models to meet those requirements. The group originally considered a true hierarchy for the metadata framework. However, it was pointed out that JSIMS had tried this approach and failed while only considering the entities modeled in JSIMS. Upon further consideration, the framework may be capped by generic metadata of the type identified above, and comprised of "bags" of metadata where the labels on the bags may be separated along multiple dimensions, e.g. domain. Some metadata may fall into multiple bags. Within some bags there may be small hierarchical relationships where the hierarchy allows the user to search/ specify down to the level necessary for the intended simulation, leaving the levels below as "don't care." A small example of the type that may be serve as a use case for developing the actual metadata will help to clarify these concepts.

Two users are searching for weather components that model temperature. The first is building an entity level ground combat simulation that will include the use of chem-bio weapons. The user wants to model the effects of temperature on fatigue of dismounted infantry wearing protective gear. For this simulation, knowing the temperature to within a few degrees is sufficient. The second user is simulating the efficiency of sonar and wants to know the water temperature. Setting aside for the moment the fact that they are looking for temperatures for different media, it's clear that the second user needs significantly more information about the way in which temperature is modeled in candidate components. If the water temperature is modeled as measured from a satellite, it will indicate the temperature at the surface. If it's modeled as measured at a ship intake, it will be the temperature several feet below the surface. Furthermore, our sonar simulation user is probably an expert in the physics of sonar and knows that different algorithms yield different types of errors under different circumstances. Knowing the type and accuracy of the algorithm is crucial to this user. Similar use cases can be drawn for calculating geo-spatial location.

Figure 2 shows a sketch of a notional metadata framework that captures the use case above. It only illustrates two dimensions, one of which is the application domain. The second dimension is unknown at this point. As the community as a whole identifies requirements, the framework could evolve to have multiple dimensions. Notice that the temperature metadata element straddles weather and combat, but its children, algorithm and measurement method, only fall in weather modeling. The combat modeler must be able to specify that their values are "don't care" during component searching. Subject matter experts (SMEs) from each of the communities of interest will need to define the metadata components, their allowable values, and any hierarchical relationships between them.

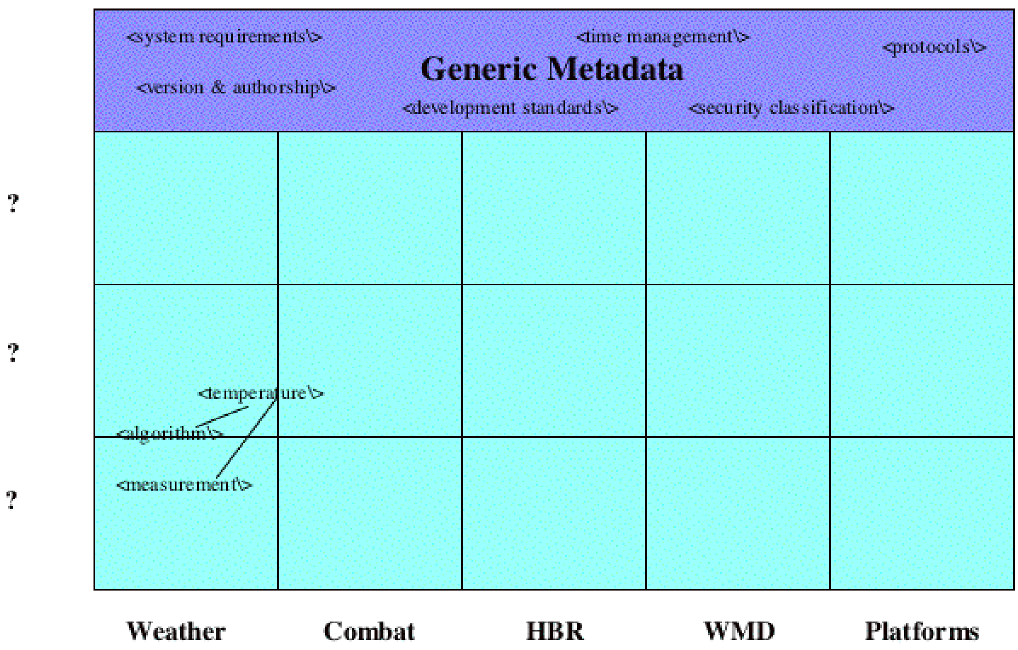

Figure 2: Notional Metadata Framework

5.1 Composability Metadata Framework Definition Process

The following is a very rough sketch of a process for defining the metadata framework.

1. Define conops (see above)
2. Engage all communities of interest in defining dimensions of framework
3. Individual communities of interest derive metadata, including fitness for purpose, required to support conops
4. Refine framework structure as necessary based on results of metadata derivation
5. Iterate between framework and metadata to ensure that framework contains all identified metadata in a logical place
6. Individual communities of interest define allowable values for metadata and hierarchical relationships
7. Individual communities of interest provide input to certification authority for testing developers' metadata value assertions

6 SUMMARY AND RECOMMENDATIONS

Composability has great potential to enhance and facilitate the development of defense-related models and simulations. However, before that potential can realize a number of challenges must be overcome, not all of which are technical. Composability has a technical basis set in an explicit, operational, business context, but technical solutions need to be socialized in order to be successful. The opportunity exists to facilitate propitious business case conditions. The workshop made the following recommendations based on the recognition of this opportunity:

- DMSO adopt 'Business Case' as an agenda item
- Establish 'Canonical' Composition Process Models
- Evolve 'Formal Use-Case'
- Pursue payoff deriving from *conceptual modeling* of simulation architectures and simulation representational schema
- Pursue Lessons-Learned process

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