

Multi-resolution Challenges for Command and Control M&S Services

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ABSTRACT: *The discussion on multi-resolution modeling gains a new quality in the era of M&S services. Every federation developer is very well aware of the request to align scope and resolution of the participating systems. However, there are more challenges to cope with, such as the orchestration to cope with time, the expected and observed behavior of components, and finally differences in purpose, capability, and use. While federation developers are highly skilled professionals, M&S Services are intended to be composed “on the fly” by users of the Global Information Grid (GIG). This requests that the data describing entities, associations, functionality, capability, constraints, and other relevant information must become part of the metadata so that agents or other composition programs can identify composable services. Particularly when services are used to support effect-based operations and planning, rigorous constraints- and assumption-propagation becomes mandatory.*

This paper summarizes the challenges, recommends solution, and shows the application in the net-centric environment. As the composition of services in the GIG will rely on proper metadata attached to the services, the paper will show potential and limits regarding the various potential solutions with special focus on effect-based operations.

1 Introduction

The era of service-oriented architectures (SOAs) raises the discussion on multi-resolution modeling (MRM) to a new quality. The main idea behind MRM is to combine high-fidelity models and their detailed analysis of particular problems with low-resolution models coping with the big picture in general. Without doubt, we will see high fidelity and high-resolution services to support detailed analysis as well as low-resolution trend models supporting high-level decision-making. Using only high-resolution models bears the danger of not being able to see the forest for the trees. Using only trend models bears the danger of overlooking important details. Even if all models were high-fidelity models, we still would have the challenge to aggregate the information into useable pieces of information for the high-level decision maker, and this process itself can be seen as a model [1].

The idea of SOAs is that functionality provided by services can be composed on the fly by bringing these different services together, based on the current requirements of the user to be supported in his opera-

tional context. This, however, requires that only services are composed that are composable, leading to the question: ***What M&S Services are composable?***

The work of Petty and Weisel [2, 3] contributed to a formal view on composability and resulted in the current widely accepted definition of composability: “*Composability is the capability to select and assemble simulation components in various combinations into simulation systems to satisfy specific user requirements. The defining characteristic of composability is the ability to combine and recombine components into different simulation systems for different purposes.*”

A recent RAND study resulted in a coherent overview of the state of composability for military simulation systems within the US Department of Defense [4]. One of the main findings in this report is that our systems are still not written in a way supporting composability. The current distributed simulation standards are necessary but not sufficient. They support the efficient exchange of bits and bytes, but they do not support the unambiguous exchange of information.

The research results of the Virginia Modeling Analysis and Simulation center (VMASC) led to the development of the “Levels of Conceptual Interoperability Model (LCIM),” which was presented in several papers and used as a reference in variant forums [5, 6]. LCIM copes with different layers of interoperation starting with technical aspects and going up to conceptual ideas being the basis for the purposeful abstraction of reality – which is the definition of a model – underlying an M&S service. Similar ideas are found in Page et al. [7] who introduced the idea of using three dimensions of composability, interoperability, and integratability in their paper.

The LCIM introduced seven layers to cope with the different aspects of interoperation. The different levels are characterized as follows:

- Stand-alone systems have *No Interoperability* (Level 0).
- On the level of *Technical Interoperability*, a communication protocol exists for exchanging data between participating systems (Level 1).
- The *Syntactic Interoperability* level introduces a common structure to exchange information, i.e., a common data format is applied (Level 2).
- If a common information exchange reference model is used, the level of *Semantic Interoperability* is reached. On this level, the meaning of the data is shared (Level 3).
- *Pragmatic Interoperability* is reached when the interoperating systems are aware of the methods and procedures that each are employing. In other words, the use of the data – or the context of its application – is understood by the participating systems (Level 4).
- As a system operates on data over time, the state of that system will change, and this includes the assumptions and constraints that affect its data interchange. If systems have attained *Dynamic Interoperability*, then they are able to comprehend the state changes that occur in the assumptions and constraints that each is making over time, and are able to take advantage of those changes (Level 5).
- Finally, if the conceptual models – i.e. the assumptions and constraints of the meaningful abstraction of reality – are aligned, the highest level of interoperability is reached: *Conceptual Interoperability*. This requires that conceptual models will be documented based on engineering methods enabling their inter-

pretation and evaluation by other engineers (Level 6).

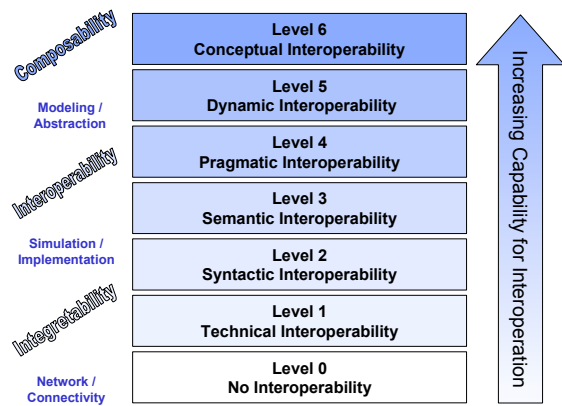


Figure 1 - LCIM and Composability, Interoperability, and Integratability

The first layer described – Level 1 – is technical interoperability, which comprises the physical connections necessary to enable information exchange. This level copes with hardware and firmware requirements and lower communication protocols, referred to as means of integration enabling *integratability* of components. This also includes problems of the underlying network including network connectivity.

The following two levels in the LCIM – Level 2 and 3 – cope with implementation issues of interoperation, supporting *interoperability* of components: syntactic and semantic interoperability. This is the implementation of a model, the computer science side of the overall challenge. Looking at the discipline of modeling and simulation, the simulation side is coped with in this domain.

Finally, pragmatic, dynamic, and conceptual aspects on Level 4, 5, and 6 target the *composability*, the modeling side of M&S. Hoffmann calls these layers the “Model Based Information Processing System” specific issues [8]. They are unique to agile applications, such as M&S services.

Traditional computer science focuses on the theory of computation, often neglecting the data in the sight of algorithms. Algorithms alone, purely working on formal parameters, cannot capture a model. Furthermore, concentrating on information exchange between systems only is not sufficient to cope with their use within the system. Both views are needed. **Composability requires a holistic view.**

What does all of this have to do with MRM for M&S Services? MRM challenges will occur on different levels and in different layers. Some of them can be

taken care of by algorithms; others must be taken care of by developers. SOAs enable to compose services that designers and developers never meant to combine. Without guidance, the results are simply not usable.

An additional challenge emerges from the new doctrinal ideas of effect-based planning and effect-based operations (EBOs) as described by Smith [9], which are defined as “*coordinated sets of actions directed at shaping the behavior of friends, neutrals, and foes in peace, crisis, and war.*”

The application domain of military command and control is no longer limited to military, but must be seen in the context of policy and economy as well. In other words, the scope broadens significantly. Furthermore, EBOs introduce the idea of direct physical effects, related indirect psychological effects, and cascading indirect physical effects and related indirect psychological effects.

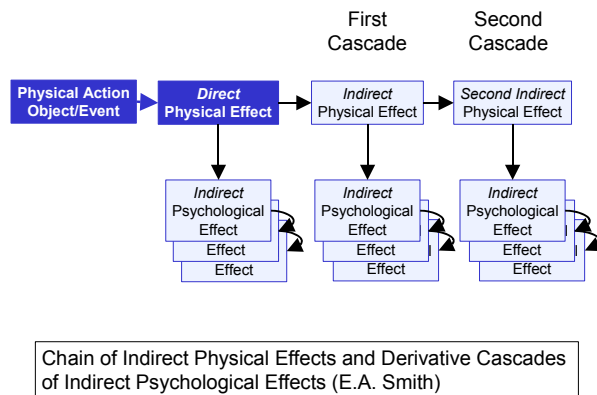


Figure 2: Effect-based Operations

Effect-based planning differs in some significant aspects. The “traditional” military planning process – often referred to as the OODA-loop describing the continuous process chain of observing, orienting, deciding, and acting – is driven from the observed status towards a desired outcome using the available capabilities. It is mainly interested in the desired direct first order physical effect. EBOs start with the desired outcome and analyze from there, asking the question: “How can I reach this objective?” EBO evaluates which of various means can be used to reach a goal, no matter if reach the effect directly, or by second- and third order effects. Of particular interest is the distinction between functionality – what is an entity designed for – and capability – what can an entity do in addition to its functionality. In the discussion on EBO requirements, we will show that these have significant conse-

quences for the scope and resolution to be implemented in M&S services.

This paper will enumerate some of the most demanding MRM challenges and will recommend some possible solutions. We will start with a set of definitions for property and associated concepts and will use these terms to define scope and resolution. Next, we will apply scope and resolution to different domains showing the MRM categories we have to cope with. Next, we will resume some major contributions to cope with these challenges and apply the results to recommend a framework for M&S services capable to support effect-based planning from the technical side. The main contribution of this paper, however, is to make the community aware of these challenges and show that several problems are interconnected and require a common approach instead of point solutions, as often seen in the past.

2 Multi-resolution Terms

The RAND Corporation has a leading role in the domain of MRM research. Many findings are already coped with in a report, which is several years old, but its findings are still valid and many recommendations are still open [10]. In this section, we will define the terms necessary to evaluate the application domains in the next section, focusing on scope and resolutions.

2.1 Definitions

As introduced in [10], we will use the idea of property values, properties, property concepts, and associated concepts to make the findings generally applicable. We will use property concepts as defined here in all application domains.

- *Properties* are the specifying characteristics of an entity. Properties are the tagged fields within XML or the attributes in relational databases.
- *Property values* are the allowed values for a specifying characteristic. Of particular interest are enumerations. Within XML, these are the allowed values within the documents. Within relational databases, these are enumeration values for attributes or other specifications, such as allowed data types, etc.
- *Property concepts* are a collection of specifying characteristics for an entity or concept in the domain of knowledge. These are collections of XML tag sets specifying a semantic entity in XML. In relational databases, these are tables (defined or specified by their attributes).

- *Associated concepts* are semantic entities in which data comprising more than one propertyed concept are given in a context.¹ These constructs are needed to provide the domain-specific context of the data. These are XML documents used to exchange information or views (or replication specifications) in the relational model.

It is worth mentioning that these ideas define a tree. The properties are the leaves (with property values being the allowed values for the tree); propertyed concepts are the first nodes to which the leaves (properties) are attached. All other inner nodes are associated concepts.

Furthermore, attributed relations are themselves propertyed concepts associated with the connected entities, whereby the relation can be unary, binary, or any other number. The following figure demonstrates the definitions, using squares for property values, diamonds for properties, ovals for propertyed concepts, and circles for associated concepts.

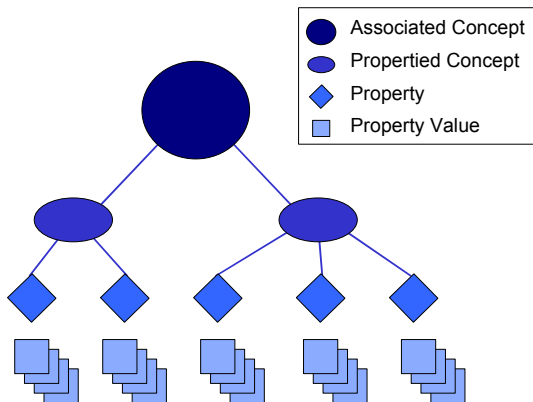


Figure 3: Concepts and Properties

2.2 Scope

The RAND MRM report [10] defines scope as the *extent of the system, input domain, and output range* treated. In other words, scope is the collection of concepts of the modeled world that are represented in the model and hence also in the system. Scope answers the questions: What is represented in the service?

While this seems trivial on the first glance, it becomes quite challenging when we are looking for a general description, as scope is not only applicable to concepts, but also to associations. Simply looking at the entities

¹ It is possible that an associative concept comprises not only propertyed and associated concepts, but properties as well (see section 3.1).

simulated is not sufficient. The degree of interaction and associations between the entities is as important as the entities themselves.

Furthermore, a model can cope with something relevant to the problem implicitly or explicitly. Although something may not be simulated as an entity, the influence may be taken into account by the model anyhow. In the military domain, air defense systems are a typical example: even without modeling these systems in detail their influence can be modeled by modifying the effect coefficients respectively, such as reduced efficiency of aircrafts attacking such a protected unit. Another typical example is the effect of camouflage on the ability of other systems to detect the concealed system.

Using our general definitions, the scope can be defined as *the extent of associated and propertyed concepts* implemented within an M&S service.

2.3 Resolution

Resolution is the *detail with which an entity* (or an association) *is modeled*. While two simulation systems may model the same concept, the number of properties or the granularity of property values used to describe the concepts may differ significantly. While two simulation systems can have the same scope, one system is highly detailed while the other system is highly aggregated. Furthermore, it should be pointed out that even when both systems model the same entities on the same level, there can still be a resolution problem, namely when the level of detail of the properties differs.

In the military domain, e.g., two systems may simulate tank units and their operations as a common scope. However, while the first simulation system models individual platforms, the second system models units by aggregating ten tanks into one single propertyed concept. Another example is when both systems model individual tanks, but while the first system uses highly detailed component sub-models, the second system just models the turret and the platform as components.

Using our model of concepts and associations, differences in the resolution is reflected by

- Different resolution in property values,
- Different resolution in properties, and/or
- Propertyed concepts of one system are associated concepts in the other system.

It should be pointed out that scope and resolution are tightly connected and often confused. If two simulation systems model tanks as entities, and system one models fuel and ammunition while system two

only models attrition, than this is a problem of scope, not resolution. In summary, we define that scope deals with the question “What is modeled?” and resolution with the question “In what detail is something modeled?”

However, the border between scope and resolution can be fluent sometimes, in particular when the aggregation levels differ: the aggregation itself already establishes a resolution challenge, and if the aggregation doesn’t aggregate all information available in the detailed model – or if it aggregates more information than available in the detailed model – we observe a scope issue in addition. Quite often, a resolution challenge on higher aggregation level becomes a scope issue on higher resolution level.

2.4 Types and Instances

One of the big contributions of the Command and Control Information Exchange Data Model was to introduce a specific model for object-types and object-items. By doing so, general observations and potential developments became accessible to the decision maker without having to instantiate them for this process. It became possible to find out if a tank in general has the capability to cross a river or not, without having to have a concrete tank standing at a river.

Unfortunately, the concept of having types and instances was only applied to objects on the battlefield: persons, organizations, facilities, features, and material. We are convinced that a broader application of types and instances is necessary. We need types of processes and capabilities and types of associations as well. We also need meta-types, which are types of types, enabling to deal with similarities of types, etc.

All these ideas can be realized by the propertied and associated concept idea proposed in this section.

3 Application Domains of Scope and Resolution

Scope – what is modeled – and resolution – in what detail is something modeled – are general concepts that are reflected in various application domains. In this section, we will have a look at the entities, their associations, their internal dynamics or behavior, their functionality and capabilities, and temporal and spatial concepts. The ideas presented here are given in more ontology-specific detail in [11, 12].

3.1 Entities

Entities are the central objects for the ideas coped with in this paper. They are the best-understood propertied concepts of the M&S service, the objects that are simulated. Entities can be weapon platforms down to components in high-resolution services, and entities can be tank companies or even divisions or corps in highly aggregated services.

Many of the papers dealing with scope and resolution, aggregation and disaggregation, and other related topics focus on entities, as they are often close to the intuitive understanding of the user, reflecting objects in the real world (as a purposeful abstraction). Furthermore, the theories of M&S are heavily influenced by systems theory, which evolves around the idea of describing systems as interacting objects that can be described by their states. Some theories reduce everything to state transitions of objects: if an object changes, its state changes; if an interaction occurs, the associated state changes; spatial and temporal aspects are reflected by states of the associated objects, etc.

We will follow a slightly different view in this paper. Entities are defined as the simulated entities representing objects in the real world. We will deal with their interactions, associations, internal dynamics, etc. in extra subsections.

Objects are propertied concepts or associated concepts. Only using propertied concepts would be a too narrow view. If an object is built of components that by themselves can be objects, we need associated concepts. While these components should be modeled as concepts, the characteristics of the higher object, which are not a component or part of a component, are properties of this higher object.

Another challenge results from the fact that properties are often interrelated, or that they comprise redundant information. In particular in aggregated models, information is often compressed on the level on which the model makes use of the information. The available ammunition in a battle tank influences, e.g., its overall weight, its vulnerability (in case these ammunitions get hit), its attrition rates, etc. Unfortunately, such associations are often only implicitly modeled and hardly documented. This motivates to model – or at least to document – all associations explicitly.

3.2 Associations

Whenever two or more concepts are related, they are connected via an association. They describe relations between entities. Associations can have characteristics by themselves, which means that they can be modeled

as propertied concepts, they have scope and resolution, etc.

Associations can be generally applicable to objects (non-specific), only applicable to a certain type of objects (class specific), or only applicable to an instance (instance specific).

Associations can describe possible or potential relations (how two or more objects can be related) as well as concrete relations (how two or more objects are related).

Entities and associations are necessary for the unambiguous description of a situation. Scope and resolution of how entities and associations are modeled in two M&S services must be aligned in order to compose them. If this is not the case, the resulting composition may show strange behavior due to variances within the composition.

Within the LCIM, the level of semantic interoperability copes with these issues. However, higher levels of interoperability rely on the proper foundation of a common aligned semantic understanding.

3.3 Functionality, Capability, and Processes

Functionality and capability of concepts can be seen as a special subclass of associations. They cope with actions and tasks that can be conducted by an object described by the concept. They describe WHAT can be done.

For composability of M&S services and their applicability for effect-based operations, we distinguish between the actions and tasks an object was designed for – its functionality – and actions and tasks an object may conduct, as it has the required characteristics and resources (both modeled as properties) – its capability.

Again, scope and resolution apply to ensure alignment between two M&S services: actions and task should require the same properties – or their aggregates. In addition, entities should be able to conduct the same actions and tasks, as otherwise the composition will show strange behavior.

An example supporting the requirements formulated in this section are the artillery units that are used as police units within peace keeping operations. While they have been designed for something completely different – namely to conduct the artillery combat in high-density conflicts – their structure and resources allow them to support very infantry-specific tasks as well.

Within this paper, we propose to see processes connected with state change in participating entities or the embedding environment. If a process doesn't change

the entities of interest or their environment, it is not perceivable using the methods proposed here. Nonetheless, we do not want to rigorously exclude the possibility that there may be the need to cope with processes as concepts of their own. Examples are concepts such as seasons, natural events – in particular disasters –, etc.

Closely related to functionality and capability is the domain of behavior. While this section coped with what and entity can do, the next section will deal with how an entity reactions when something is done do it.

3.4 Behavior or Internal Dynamics

While actions and tasks can be modeled as associations between the action and the targeted object, the behavior and internal dynamics describe what happens to the objects when the association is instantiated.

This domain is significantly different from others as the temporal component becomes important. The other domains dealt with so far have properties capturing temporal and spatial prerequisites, such as proximity for an engagement of two entities. However, they all can be reduced to snapshots of situations, in most cases with Markov attributes (which are without memory, which means that it is not important HOW a property got a value assigned but only THAT it has a given value). Here, we explicitly have to deal with the dynamic behavior of state changes of participating entities. Cause-effect relationships (modeled via associations) are as important as the behavior over time, with which we will cope in the next section.

Within the LCIM, the levels of pragmatic and dynamic interoperability have been introduced to cope with the issues.

This section is critical for effect-based operations. As stated in [13], one of the requirements for simulation systems – and respectively M&S services – to be applicable for support of operations is that all aspects of relevance are modeled at least implicitly. In the context of effect-based planning this means that effect chains as shown in Figure 2 must be modeled as well. Such effect chains can start at various points, but to ensure that they can be aligned in M&S services, they should all be modeled as an association with the state change of objects.

3.5 Time

All the ideas mentioned so far can be reflected by propertied concepts and associations. However, simulations are defined as the execution of a model over time, and modeling this aspect has been neglected in

this paper so far. How time is coped with, and how the concept of time is reflected in various sub-systems, must be made explicit.

There are different models for time and different methods to align or synchronize time in distributed systems. It goes beyond the scope of this paper to evaluate these approaches explicitly. The interested reader is in particular directed towards the proceedings of the annual Parallel and Distributed Simulation (PADS) conferences as well as to the HLA specific evaluation in [14].

Some of the minimal pieces of information concerning temporal constraints of an M&S service are:

- Real-time capabilities (can the service support real-time)
- Real-time limitations (is the service limited to real-time)
- Internal time or external time used
- Synchronization points can be set from outside
- Trigger synchronization points in other services

This list is everything but complete. It just list the absolute minimum of information needed to synchronize the orchestrated execution of compositions of services. The internal dynamics described before require much more detail.

3.6 Space

Finally, the spatial component has to be taken into account. There are various spatial concepts that can be modeled using, for example

- Different coordinate systems (x,y,z-coordinates, polar coordinates),
- Different grid models (regular polygons, such as hexagons or chessboard-like structures),
- Different earth-models (flat world, earth as a perfect ball, etc.),
- Different projection systems, and many more.

The spatial reference model (SRM) of SEDRIS [15] gives a good overview of the most common approaches and how they can be mapped to each other. This is the minimal information necessary to ensure the composition of M&S services based on their represented or expected spatial model.

The results of section 3 can be summarized as follows: we have to capture in a rigorous and common way for all M&S services what entities are modeled, what associations they have, how they behave (internal dynamics, effects), what they can do (capability) and for what

they have been designed (functionality), and their temporal and spatial concepts. These concepts reflect the well-known categories WHO is doing WHAT, WHERE, WHEN, and – if we take the effects as state changes in the property concepts into account – WHY. All this information must be captured in metadata accessible to supporting software.

4 Contributions to a Recommended Solution

As this paper copes with M&S Services, the obvious observation is that everything recommended must be captured in metadata describing the services. As already pointed out in [5], the current metadata repositories envisioned in the Net-centric Data Strategy are not sufficient to support M&S services.

In this section, we will cope with the requirements and recommended solutions that have to be captured in metadata. How this can be done is not the subject of the current paper and will be evaluated in another context.

4.1 Atomic Information Elements

The elementary components used here are properties building property concepts. If the resolution is differs, property concepts of one service may be associated concepts of another.

It is also possible that two concepts only partly overlap. In this case, there are common elements that are mapped complemented with model-specific extensions that do not overlap.

We would like to pose the question to what degree it makes sense to postulate concepts for general information exchange. Concepts, property and associated, reflect entities of interest within the application domain resulting from the purposeful abstraction process of modeling. However, what belongs together in one application doesn't necessarily belong together in another application. Both ways to structure the information are legitimate. Both are results of academically sound and valid abstraction processes.

If we agree to base the structure of the information passed on a common information exchange model, we force applications following another abstraction into this scheme. But how do we evaluate which schema is appropriate? Which abstraction is applicable to the information exchange? Whose purpose is more important that it should drive the abstraction used for information exchange?

Our proposal is to use atomic information elements for information exchange, which means to use properties in the highest resolution. We propose to avoid concepts, no matter if they are propertyed or associated. Every concept is a limitation to their use. Only the minimal pieces of information, the highest resolution of information elements (or properties) are stable with regard to potential information exchange; and even these elements may become subject to increasing partition and may be split up due to a new model with higher resolution.

Even when evaluating only one model we may be forced to break up properties into higher resolution elements to avoid inconsistencies rooted in redundant information. For example, a simulation may use kill probabilities for the attrition and movement coefficients for the ability to use certain bridges. Both data elements are connected with the armor. If we increase the armor making it thicker to increase the survivability of the tank, we also increase its weight and by doing so decrease its ability to use certain bridges. The property kill-probability and the property movement coefficient must be based on the same atomic information elements group describing the armor. Instead of exchanging the probability and the coefficient, we should exchange the underlying information, in particular when federating with high-resolution services.

The result is an “unstructured attribute soup,” in which all the information is available, but we do not hard-code how the elements are connected with each other. The structure is in the metadata, not in a standard for information exchange elements. The next subsection will cope with this in more detail.

However, before we go into detail of the metadata to capture the structure of information to be exchanged, we need to introduce one recommended concept for content representation: We need to distinguish between types and instances. While we cannot and should not standardize how type information must be structured, we must make sure that information presenting instances must be grouped together. While we must enable that the information that tank A has ammunition of type BA and BB may be regrouped in other applications, we must make sure that the instance A1 of such a tank with BA1 and BB1 amount of ammunition and instance A2 with BA2 and BB2 ammunition don't get confused.

This topic is related to the type discussion reflected in possible groupings of properties into concepts. One possibility is to use the metadata describing the concepts of the information source (capturing the structure the data comes from). Alternatively, the information

target may be of more interest, in particular when we deal with multiple sources (parallel or completing) for one source. Finally, a federated scheme taking into account multiple sources and multiple targets may be necessary as a general solution.

4.2 Metadata for Alternative Propertyed and Associated Concepts

This section describes some solution constraints to deal with the requirement of alternative views. By now, the necessity should be clear: whenever two model-based applications exchange information, their information requirements are based on model specific abstractions. The information exchange requirement must satisfy both purposeful abstractions.

Unambiguous information exchange requires capturing the structure of content as a first step. As the structure of the information exchange must satisfy all possible purposeful abstractions potentially participating, we need a configurable approach.

Our proposal is to capture applicable concepts in metadata associated with the atomic information elements, which means the properties. By doing so, an information element is not embedded in an information exchange model but has references to all applicable concepts, be they in a data source, a data target, or a federated schema. This requires an open, two-layered approach, exemplified by Figure 4:

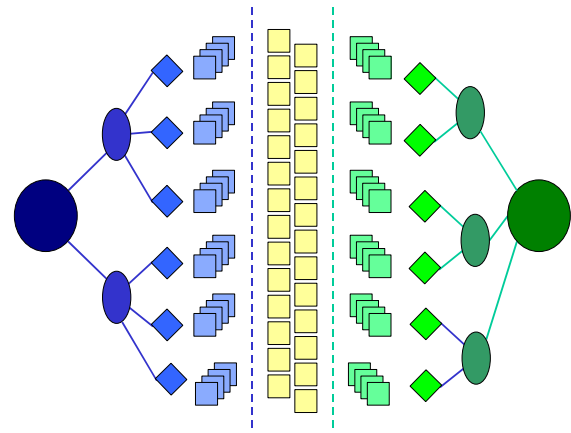


Figure 4: Two alternative concept groups utilizing the same set of atomic information elements

- The information exchange layer comprises the atomic information elements. This is a common layer.
- The information structure layer is used to organize the information elements to reflect the concepts of the participating systems. They

are unique for each system or – in case an agreement is already in place – to a federated scheme reflecting the agreements of a community of interest, etc.

It should be pointed out that we have not yet a prototype in place, but several doctoral theses at VMASC are evaluating the applicability of this proposal.

There are multiple ways to cope with alternative concepts utilizing atomic information elements. On the one hand side, we can model every concept individually and capture them in an extra layer. On the other hand, side, we may be able to utilize the idea of meta-types of types to conceptualize the alternative cases. We are not aware of any ready-to-go solutions. This is definitely an area of ongoing research, although many ideas from the area of data engineering, such as ISO 11179, seem to have lots of potential [16].

4.3 Qualitative and Quantitative Associations

There is a significant difference between qualitative and quantitative associations. Qualitative associations feature properties with non-numerical property values; quantitative associations have at least one property with numerical property values.

Generally, quantitative associations have qualitative features: if a given number is provided by a quantitative association, it equals a specified quality. However, it is not possible the other way round.

Again, this can be reflected in different resolutions. If the information is detailed enough, qualitative associations can be broken down to quantitative associations. We observe the same as generally observed for properties describing entities in section 3.1 of this paper.

The idea needs proof. So far, we assume that we generally can capture such constraints. It remains to be shown how this can be done in general, and even more importantly: how this can be done in practice.

4.4 Potential and Actual Capabilities

It is also important to distinguish between potential and actual capabilities. In most cases, it requires resources to instantiate a potential capability, which means to make it an actual, available capability.

If the resolution is high enough and all associations are modeled, this can be made explicit. However, many models will not support an explicit model, so the information exchange must capture this.

In addition, it is essential to capture what an entity – in particular when it is to be used as a facility for effect-based operations – is currently able to support. It is operationally of no use that a unit in a current operation is generally capable to do many more things, but not able to support the desired function immediately. Nonetheless, in effect-based planning the potential make be a very valuable piece of information, as – time permitting – a potential capability can be changed into an actual capability by assigning the necessary resources or fulfilling other necessary constraints.

We are not aware of simulation systems offering this detail, but it seems to be possible with the right resolution and the necessary associations.

4.5 Purpose, Capabilities, and Use

Finally, it is of interest to distinguish between the capabilities (what a concept can do), the purpose (what a concept was made for), and the use (what a concept is used as). In the context of this paper, the capability should embed purpose and use. However, many models and resulting simulations focus on the purpose and drop other possibilities in the course of the purposeful abstraction.

Why is this important? In particular for effect-based operations, details insignificant to traditional military operations become important. If insurgents fire at combatants from the cover of a building, mortar or artillery fire can be an adequate military answer, but what if this building is a mosque?

In order to make use of such capabilities in the process of effect-based planning, the respective level of resolution is needed. Again, these details have often been cut in the process of the modeling process as unnecessary detail in the light of the original purpose of the model and are now hard to re-instantiate. Nonetheless, it is necessary in order to support the new purpose of M&S service support in Command and Control, in particular for effect-based operations.

4.6 Effects

We already covered various aspects of effect-based operations and planning. However, one aspect has not been covered yet, and that is the way effect-based plans are developed. The traditional military decision cycle has been described in the introduction to this paper, the OODA-loop. The way a problem is analyzed is very much comparable with the forward chaining of rule, connection “if...then...” rules with each other. This sort of system is also known as **data-**

driven rule-based system. The alternative is a **goal-driven** rule-based system that uses backward chaining.² These systems start with the desired outcome and look for chains ending in the observed status.

The traditional OODA-loop is data-driven. It drives from the observed status towards the desired status using the purpose of entities and their resources to task them to reach the goal.

Effect-based planning is different in two aspects. First, it takes into account the first and second order effects, so that the evaluated effect tree grows. Second, it is more interested in effects, not data-driven approaches. As such, effect-based planning is more goal-driven than data-driven. Reaching the goal by minimizing the undesirable effects and maximizing the desirable effects is the objective. It is not significant if reaching the goal is conducted by a purpose-driven approach, or if capabilities and second-order effects are used. To enable this sort of planning, goal-driven and constraint approaches are necessary.

Current simulation systems are not always usable for such an approach, as many higher-order effects as well as non-purpose capabilities have been eliminated in the modeling process. While they were sufficient for OODA-loop oriented decision support, they are insufficient for effect-based, goal-driven and constraint planning processes. M&S services in support of Joint Command and Control must consider this and therefore be designed (and described by the metadata) to support this planning idea.

5 Learning from Neighbored Research

The ideas recommended in this paper are not new. They have been developed in various neighbored research domains. What is new is the approach to use a coherent view combining all these aspects in order to become a framework for consistent interoperation. The sections are neither complete nor exclusive. Driven by the constraints of this paper we can only scratch the surface, but the reader may find a topic for personal intensive study.

5.1 Systems Theory and Systems of Systems Engineering

Systems theory is *“the transdisciplinary study of the abstract organization of phenomena, independent of their substance, type, or spatial or temporal scale of existence. It investigates both, the principles common*

to all complex entities, and the – usually mathematical – models, which can be used to describe them.” Another term used is cybernetics.

System theory is not reductionism, but emphasizes that systems generally are open, interact with their environment, and evolve over time, which means that qualitatively new properties may emerge.

The traditional system theory was expended in order to cope with systems of systems. When systems are federated into another system, a broader set of engineering skills is needed in order to cope with the new set of requirements. While system theory could focus on the purpose and intended use, the use of system functionality within the systems of systems can become easily much broader. Systems with similar functionality must be identified, compared, and evaluated and selected based on the best support of a current operational need.

M&S services must behave in the same way: they interact with the operational environment and should be open enough to adapt to different situations, or at least to recognize if the constraints of a situation don't match its assumption and make the user aware that its use is not adequate.

5.2 Taxonomies and Ontologies

Taxonomies and ontologies are rooted in the idea that the vocabularies of a common domain should be completely enumerated, well defined and controlled by a common registration authority, so-called controlled vocabularies as defined in dictionaries and glossaries [17].

A Taxonomy can be best defined as a tree structure of classifications for a given set of objects. At the top of this structure is a single classification—the root node—that applies to all objects. Nodes below this root are more specific classifications that apply to subsets of the total set of classified objects. The main purpose is the classification of terms.

An Ontology is an attempt to formulate an exhaustive and rigorous conceptual schema within a given domain. Although this is typically a hierarchical data structure containing all the relevant entities, it is not necessarily a tree. Furthermore, in addition to the entities the ontology contains relationships and rules (such as theorems and regulations) within that domain. Therefore, a taxonomy is a subset of an ontology. In practice it is agreed that an ontology should contain at a minimum not only a hierarchy of concepts organized by the subsumption relation, but other 'semantic relations' that specify how one concept is related to

² See http://en.wikipedia.org/wiki/Expert_system

another. The main purpose is the definition of entities and their relationships.

We showed in [11, 12] how the Command and Control Information Exchange Data Model (C2IEDM) plays in the context of ontologies. We showed among other things that objects and entities of the battlefield are well modeled and allow for extensibility, but that activities and actions – in this paper referred to as processes and capabilities – are not modeled as needed for a pure ontological approach. The fact that the C2IEDM distinguishes between object types and object items but not between task types and task items points to the challenge.

We are sure that ontologies are the best way to cope with the challenge to manage the different possible conceptualizations that utilize the same atomic information element. This assumption, however, has not yet been proven.

5.3 Situation Theory

One of the shortcomings of ontologies is that they are able to describe state changes, but overall are more static in nature. Situation theory may help to overcome this by associating situations with each other. Situations are individuals having properties and standing in relations [18].

A theory of situations allows us to study and compare various types of situations, or facts, events, and scenes. One of the central themes of situation theory is that a theory of meaning and reference should be set within a general theory of information, one moreover that is rich enough to do justice to perception, communication and thought. Situation theory gives a rigorous mathematical account of the principles of information that underwrite the theory. It is closely related to ontologies, which are used to describe situations.

The idea to interpret Common Operational Pictures (COPs) as situation and to apply situation theory to describe the likelihood of change from one situation into another is published in [19]. This example shows the potential application of these theories working together, supported by M&S services connecting the views and being the common framework.

6 Summary

This paper does not support the user in finding out what model or implementation fits his purpose best. It should always be remembered that *models are purposeful abstractions of reality*. Each abstraction has its value, or models would be equal. We federate models because each model has something unique to

contribute to the federation. If we force models to use a common information exchange model, we force the model to use the underlying conceptualization, which may not be aligned with the view of the particular model. M&S Services are based on models. In order to support their composability, their conceptualization must be captured and taken into account when composing services. The structures proposed in this paper support this process.

It should be pointed out that this paper doesn't condemn standardized information exchange proposals. Actually, they are necessary to come up with unambiguous information exchange definitions in lieu of a better lingua franca to communicate the meaning of data between services and systems. However, the reader must be aware of the limitations.

The proposal summarized in this paper is to standardize the atomic information elements. In addition, we need metadata structure to capture the different conceptualizations, the composition of properties into propertyed concepts and associated concepts. For all these concepts, it is essential to distinguish between type information and instantiations, no matter if we are talking about objects, entities, associations, or processes.

Neighbored research domains can help to solve the challenges during the search for a better framework for interoperation. System of Systems Engineering, Ontologies, and Situation Theory are promising candidates.

Many of our assumptions are not yet proven and require additional research. We invite everyone who finds this paper interesting to contribute to the discussions. What we need to come up with at the end of this work is a metadata-based framework ensuring the composability of M&S services for Joint Command and Control support.

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7 References

- [1] Bigelow, J.H., and Davis, P.K. 2002. Implications of Multi-Resolution Modeling (MRM) and Exploratory Analysis for Validation. *Proceedings Foundations 2002 V&V Workshop*

- [2] Petty, M.D., and Weisel, E.W. 2003. A Composability Lexicon. *Proceedings Spring Simulation Interoperability Workshop*, IEEE CS Press
- [3] Weisel, E.W., and Petty, M.D. 2003. A Formal Basis for a Theory of Semantic Composability. *Proceedings Spring Simulation Interoperability Workshop*, IEEE CS Press
- [4] Davis, P.K. and R.H. Anderson. 2003. Improving the Composability of Department of Defense Models and Simulations. *RAND Graduate School of Policy Studies*
- [5] Tolk, A., and Muguira, J.A. 2003. The Levels of Conceptual Interoperability Model (LCIM). *Proceedings Fall Simulation Interoperability Workshop*, IEEE CS Press
- [6] Turnitsa, C. 2005. Extending the Levels of Conceptual Interoperability Model. *Proceedings Summer Computer Simulation Conference*, IEEE CS Press
- [7] Page, E.H., R. Briggs, and J.A. Tufarolo. 2004. Toward a Family of Maturity Models for the Simulation Interconnection Problem. *Proceedings Spring Simulation Interoperability Workshop*, IEEE CS Press
- [8] Hoffmann, M. 2004. Challenges of Model Interoperation in Military Simulations. *SIMULATION*, Vol. 80, pp. 659-667
- [9] Smith, E.A. 2002. Effect Based Operations: Applying Network Centric Warfare in Peace, Crisis, and War. *CCRP Press*
- [10] Davis, P.K., and Biglow, J.H. 1998. Experiments in Multiresolution Modeling (MRM). *RAND Graduate School of Policy Studies*
- [11] Turnitsa, C., and A. Tolk. 2005. Evaluation of the C2IEDM as an Interoperability-Enabling Ontology. *Proceedings European Simulation Interoperability Workshop*, ACM Press
- [12] Turnitsa, C., and A. Tolk. 2005. Ontology of the C2IEDM – Further studies to enable Semantic Interoperability. *Proceedings Fall Simulation Interoperability Workshop*, IEEE CS Press
- [13] Tolk, A. 1999. Requirements for Simulation Systems when being used as Decision Support Systems. *Proceedings Fall Simulation Interoperability Workshop*, IEEE CS Press
- [14] Fujimoto, R. 1998. Time Management in the High Level Architecture. *SIMULATION*, Vol. 71, pp. 388-400
- [15] ISO/IEC FDIS 18026:2006(E). Information Technology – Spatial Reference Model (SRM). Via <http://www.sedris.org/#18026>
- [16] ISO/IEC 11179. 2005. Information Technology: Metadata Registries (MDR), via <http://metadata-standards.org/11179/>
- [17] Tolk, A. and C. Blais. 2005. Taxonomies, Ontologies, and Battle Management Languages - Recommendations for the Coalition BML Study Group. *Spring Simulation Interoperability Workshop*, IEEE CS Press
- [18] Cooper, R., K. Mukai, and J. Perry. 1991. Situation Theory and its Application. *Lecture Notes*, CSLI Press
- [19] McMichael, D., G. Jarraf, S. Williams, and M. Kennet. 2004. Modeling, Simulation and Estimation of Situation Histories. *7th International Conference on Information Fusion*, F.O.I. Swedish Defense Research Agency, IEEE Press

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