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MULTI RESOLUTION MODELING

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ABSTRACT

Multi-resolution modeling (MRM) includes many different approaches. It is very well known by the Distributed Simulation community that the High Level Architecture (HLA) is an architecture designed to facilitate interoperability and software reuse. Therefore, the unit of MRM is usually the federate. Multi-resolution representation of entities consists in maintaining multiple and concurrent representations of entities. As such, several approaches may be used to manage the aggregation/disaggregation processes, according to the particular needs of the simulation exercised. However, we have found that there are many approaches presented in the literature. We have to weigh many considerations when comparing the different MRM approaches. This paper introduces the different approaches and provides an experiment using constructive simulation.

1 INTRODUCTION

One purpose of this study was to better understand MRM and the differences between the available approaches. MRM has a very interesting history and it is considered one of the key technologies for complex and large-scale simulations. RAND (http://www.rand.org/) stimulated the interest of the US Department of Defense's (DoD's) in 1990-1992 (Davis and Hillestad 1993). This initial work focused on connecting already existent models of different resolution. This proved quite difficult to accomplish well.

Aggregation and disaggregation were introduced in 1996 due to the issues in distributed interactive simulation (DIS) when several types of objects described at different levels of detail had to interact. These issues and seminal work in model abstraction from Fishwick (1988) and Fishwick and Lee (1996) brought attention to recognize the broad significance of the MRM problem. After those earlier accomplishments, different formal approaches and experiments were developed as explained in this paper.

The First Section of this report is divided in the following subsections. The first subsection describes the dimensions of resolution. The second subsection provides several definitions of MRM according to the most important papers found in the literature. Subsection 1.3 describes the taxonomy and design of

MRM. The next two subsections discuss the importance of MRM and the static and dynamic issues. Subsection 1.6 presents the consistency and cost effectiveness problems within MRM. Finally, formalisms in MRM are introduced in the last subsection.

1.1 Dimensions of resolution

Resolution is the detail with which a system (or attribute) is modeled. Resolution in modeling and simulation has many dimensions as Figure 1 depicts.

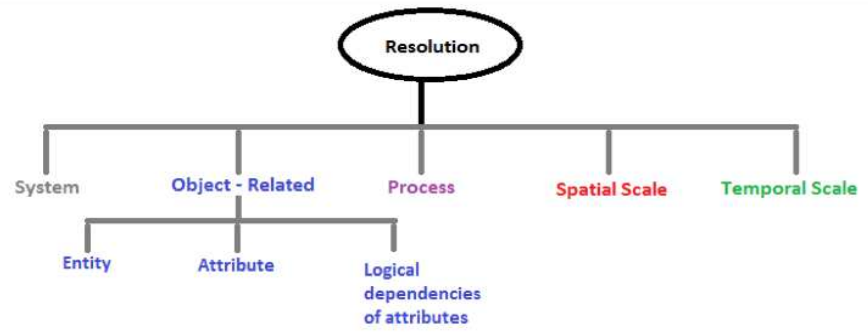

Figure 1: Dimensions of resolution.

1. **System:** Resolution can be from systems of systems modeling (i.e., lower resolution) to element modeling (i.e., higher resolution).
2. **Object-related:** It is possible to include higher resolution with the entities, the attributes, and the logical dependencies among attributes.
3. **Process:** More detailed description of the processes can result in finer-grained processes.
4. **Spatial Scale:** Fine-grained scales from kilometers to meters (e.g., maps and their scale) are possible.
5. **Temporal Scale:** Fine-grained scales in time from a simulation clock provided in days to one provided in seconds taking into consideration the respective temporal changes. For example, a model in system dynamics can use as a unit "weeks" in order to model the maintenance of a tank and another model in continuous time can use as a unit "seconds" in order to model the movement of a tank with the respective differential equations.

1.2 MRM Definition

Davis and Bigelow (1998) define multi-resolution modeling as follow:

1. Building a single model with different levels of resolution for a problem;
2. Building an integrated family of consistent models with different levels of resolution for a problem; or
3. Both

The different levels of resolutions could be associated to the level of abstraction desired to describe the situation. The level of abstraction or resolution in an MRM simulation approach can be related to the number of input/output parameters associated with a particular simulation model.

Davis and Tolk (2007) continue to explain that the traditional approach to MRM requires a "natural decomposition" of the system simulation models. The reason is that the MRM approach should be implemented in a hierarchical structure in order to support the definition of aggregate and disaggregate levels of models in a simulation.

1.3 Taxonomy and Design of MRM

Complexity usually needs more than one single model. Complexity may require the use of a set of models that collectively are able to define the entire structure (Yilmaz and Oren 2004). As stated by Yilmaz and Oren (2004) "a multi-model is a modular model that subsumes multiple submodels" (e.g., these submodels can be federates). These multiple models can represent the behavior of a complex process.

Following is a taxonomy of multi-model types that depends on the submodels' structure and activation mechanisms (Yilmaz and Oren 2004):

1. ***Two Cases of Completeness of Submodels***, One can know all the submodels at the beginning of the modeling stage. However, emergent conditions calls for additional submodels.
2. ***Two Cases of Active Submodels***, one needs to consider two cases: (1) Only one submodel is active at a given time or (2) two or more submodels are active at a given time.
3. ***Two Cases of Location of information.*** The information necessary for the activation of submodels can be (1) within the submodels or (2) it can be external to submodels.
4. ***Two Cases of Pattern-Directed Activation.*** The pattern-directed activation demands a meta-pattern to control (1) selection of known submodels and (2) request of new submodels "corresponding to an interruption of the simulation gaming using the guidance of the specific mechanisms built-in" (Yilmaz and Oren 2004).

In addition to the definition of multi-models, there are requirements that should be considered when designing Multi-Resolution Multi-Stage Multimodels (MRMSM) (Yilmaz et al. 2007):

1. The knowledge regarding its configuration and representation must be decoupled from the model.
2. The concurrent interactions at multiple levels of resolution must be combined consistently (Reynolds, Natrajan, and Srinivasan 1997).
3. The state of entities at different levels of resolution has to be consistent.
4. The behavior of the entities can be altered from within.
5. Independence of the constraints regarding when and under what conditions:
   a. the consistency of the elements of families of submodels in a multiresolution model be enforced and
   b. a shift in the stage of the problem be triggered.
6. Dynamic loading and linking of the entities into the run-time environment of the simulation.
7. Construction of the state can be continued from a specific state after an update operation.
8. The existence of a mechanism for changing the structure and behavior of the model dynamically.
9. Definitions of behavioral resolutions must be flexible to facilitate analysis that is independent of an implementation.
10. Mechanisms to decide when and under what conditions to replace existing models with a successor or alternative are important in order to perform the multi-resolution multi-stage multimodels.

1.4 Importance of MRM

MRM lets designers identify model and entity decompositions that make conceptual and analytical sense. The importance of MRM is based on the need for models to have multiple levels of resolution to understand the challenges while developing advanced simulation infrastructures.

MRM addresses and provides means to account for representations of the different perspectives of the world being represented. MRM allows analyst to obtain more understandable (i.e., explanatory power) results than either low level or high-level resolutions models could provide by themselves. On one hand, high resolutions results may be too complicated due to the level of details included but on the other hand, low-resolution results may lead to persuasive decision making due to the direct nature of the results.

1.5 Static/Dynamic MRM

1.5.1 The Static Approach

The static approaches represent extreme solution to MRM using the lowest resolution representation (i.e., Full Aggregation) and the highest resolution representation (i.e., Full Disaggregation). As stated by Reynolds, Natrajan, and Srinivasan (1997) "the static approaches mean that the resolution level at which entities are simulated is fixed when the simulation is constructed." Full Aggregation emphasizes that the entities involved will be simulated only at the lowest level of resolution. On the other hand, Full Disaggregation emphasizes the complete disaggregation of a low resolution entity into its corresponding/matching high resolution entities.

1.5.2 The Dynamic Approach

The dynamic approaches involves multiple spatial resolutions that happens dynamically and adaptively as the simulation runs while their "level of abstraction" maintains the same level. For example, Hu and Ntaimo (2006) showed that submodels can be initialized in a low resolution and then change to high resolution when becoming active. The approach they proposed is based on the Discrete Event System Specification (DEVS) formalism. They stated that "DEVS' variable structure modeling capability allows models at different resolutions to be dynamically added and/or removed during simulation." It is important to state that dynamically replacing a single submodel with multiple higher resolution submodels (or vice versa) requires a "right replacement policy" to ensure consistent transitions from a single submodel's state (i.e., just one single submodel with certain level of resolution) to the multiple submodels' states (i.e., with higher levels of details).

1.6 Problems with MRM (Consistency and Cost Effectiveness)

Consistency and cost effectiveness are complex problems in MRM. Jie et al. (2012) explain that data translations between different models at different levels of resolution should maintain consistency. Davis and Tolk (2007) expressed that when implementing MRM methods the concept of composability is very closely aligned with MRM. They discussed how MRM inconsistency issues and challenges could be addressed by adopting a model composability approach to MRM.

The authors claimed that composability of simulation models need to address interoperability between simulation models in a systematic fashion. Jie et al. (2012) expressed that mapping functions can be defined in MRM implementation efforts to develop information transformation schemes for models in different levels of resolutions during aggregation and disaggregation methods. Lastly, Hong and Kim (2013) argue that using the multi-resolution event (MRE) interface approach (explained in the next Section) for MRM entity definition alone and independently specifying a multi-resolution event interface (MREI) can also aid with MRM information inconsistency issues.

MRM cost-effectiveness can be associated to the amount of computational parameters needed to hold MRM consistency. More specifically, Jie et al. (2012) expressed that MRM cost-effectiveness is related to the number of actions required to maintain a desired level of consistency between simulated entities at different levels of resolution. The number of attributes in a particular task during MRM entity interactions can be defined as a measure of the actions.

1.7 Formalisms

In MRM applications, formalism can facilitate the representation of the resolution - related information with complete semantics (Baohong 2007). According to Board (1997), MRM formalisms are necessary to define and control modeling concepts and methodologies for representation and entity abstraction. The literature presents several types of formalisms that have been proposed to the simulation design community in today's multi resolution applications. To date, however, the MRM community still lacks a concrete model specification method.

Many formalism implementations have been based on the formal specification DEVS (Discrete Event System Specification - http://en.wikipedia.org/wiki/DEVS). Some of the formalisms (based on DEVS) that have been developed for the MRM community are: the Dynamic Structure DEVS (DSDEVS) and the Multi-resolution modeling space (MRMS) (Hong et al. 2013).

An example of MRM formalism is the Multi- Resolution Modeling Space (MRMS). MRMS supports MRM in two forms:

a. **Resolution Conversion.** This is important when the model structures are dynamically changing.
b. **Resolution Matching of Interfaces.** This is essential in particular between events in different levels of resolutions.

2 APPROACHES

Multi-resolution modeling is the capability of executing a complete model (and its different submodels) or a sophisticated set of federates at different levels of resolution corresponding to the environment being modeled. We have found a diversity of approaches to MRM (from 1998 to 2013). We have found nine approaches well recognized in the MRM community. These approaches are described in Table 1.

Table 1: Comparison of the different MRM approaches.

MRM Approach	Interaction	Consistency	COTS Standard	Scalability
Hierarch modeling (IHVR)	Interactions are based on hierarchical structures defined by the modeler.	Consistency can be achieved through the hierarchical process and sub process structures.	The hierarchical structure of high/low resolution variables can be implemented with HLA, DIS and TENA standards.	The issues that could arise are those of the distributed network.
Regulation as Middleware	Interactions are designed by the user.	Mapping functions must be implemented by the user.	This approach is customized. COTS and Standards are not supported.	Does not support scalability due to extensive programming required to implement it.
Regulator as Federate	Interactions are based on the modeler's design. The Regulator regulates the interactions.	Mapping functions are coded by the user in the federate. The consistency is modular and efficient.	COTS can be used. Standards such as HLA are possible due to the advantage of using a Federate.	This approach supports scalability by adding complexity to the Regulator.
Resolution Converter	Interactions follow inter-operability, which facilitate Multi- interactions.	Consistency is based on interaction rules of inter-operability	Applicable to HLA standards. Can be used with COTS.	There is no limitation on scalability, but very large scale

		architectures.		of distributed simulation
Selective Viewing (SV)	SV requires mechanisms to resolve the effects of dependencies.	Mapping functions are required in order to translate attributes from one representation to another one.	SV individually entity behavior can potentially be a part of a multi-part distributed model.	SV entity behavior as part of a whole is consistent than the behaviors of the entity executed individually.
Aggregation/ disaggregation (A/D)	In most variants of A/D, multiple models do not execute jointly due to the system transitions among models.	Mapping inconsistencies between levels are a potential problem.	Network traffic is a potential problem because each entity could be a sender/ receiver of messages	Chain disaggregation occurs during the interactions of disaggregate-entities with aggregate-entities
MRE	Dependent interactions are resolve by using specific policies	MRE always maintains the simulation entity's attributes at all levels of resolution.	Multi model entity interactions at different levels may facilitate message interchange during joint execution of multiple models.	Multi models may grow in complexity as determined by designers.
Hybrid (disaggregation/ MRE)	The Hybrid Interaction Resolver handles the concurrent interactions in different resolution levels.	MRE method always maintains attributes of an entity in all levels of resolution.	Network traffic is a potential problem because each entity could be a sender/ receiver of messages.	Small-scale multi-models feature disaggregation.
Agent-Based	Interactions are explicit in the design of the classes of the agents.	The flexibility of the agent approach is based on the object oriented approach utilized.	The distributed architectures are good fit for the agent-based approach. COTS can be used.	Due to the object-oriented nature, it has a very high level of scalability.

3 EXPERIMENT

We decided to create an MRM environment based on the one from Raue and Gallois (2011) with several enhancements. The example from Raue and Gallois (2011) is the most sophisticated found in the literature using an aggregation-disaggregation scheme. We decided to enhance that example using different tools and creating a sophisticated/complex scenario. Disaggregation occurs when a unit enters within the terrain area designated as a disaggregation area. But to the contrary, aggregation occurs when the center of mass of the disaggregated unit, goes out from the disaggregation area.

3.1 Scenario

Figure 2 demonstrates an instant in time during the execution of a scenario for aggregation-disaggregation. The upper half of the figure represents an executing unit level model where the units move and engage in combat. The lower half represents an executing entity level model. In that model, the entities move and engage in combat. The simulation involves four battalion sized forces composed of a company and a platoon mechanized infantry and some armor units. From the beginning, none of these units exist in the entity level model. The unit level scenario occurs in a large terrain area of the entity level model.

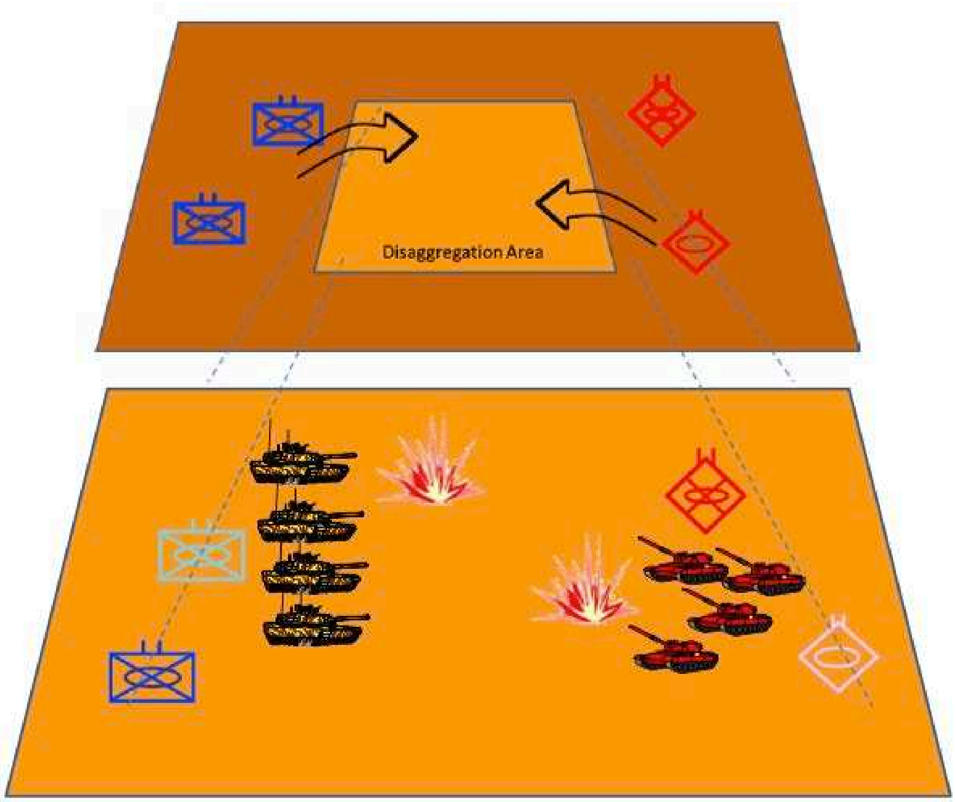

Figure 2: Experiment of a multi-resolution combat model (Raue and Gallois 2011).

The specific zone of the terrain area represented in the unit level model has been defined as a "disaggregation area". Units entering the disaggregation area are disaggregated. The disaggregation process includes instantiating the individual entities that make up the disaggregating unit in the entity level model. The unit level model then loses control of the unit and the entity level model takes over control of that unit's entities. After the disaggregation operation, the simulation process resumes,. The status of the entities is up to date at all times in both environments through the HLA connection.

Using COTS simulation products, Battle Command and VR-Forces from VT MÄK Technologies (http://www.mak.com/products.html) and SIMbox from Simigon (http://www.simigon.com/) to implement an engagement measurement routing, a proof of notional scenario was prepared. The simulations were connected through HLA/RTI. A terrain database was created from VT MÄK Technologies geographical data, which ensured terrain coherence among the environments. In addition, an engagement measurement mechanism was aggregated to the scenario.

3.2 MRM Experimental Implementation

3.2.1 Terrain Coherency

The experimental example must display geographical data coherency at all times. All geospatial data and map feature data for this proof of concept example was coordinated through a terrain generation tool by VT MÄK Technologies to ensured that entity positions and terrain elevation were adequate at all times during the simulation, which can be observed in Figure 3. Further, terrain coherency guarantees that time, position and scenario data interactions are properly achieved through data exchange mechanisms between the simulation environments as simulation HLA-based entity status and updates are performed.

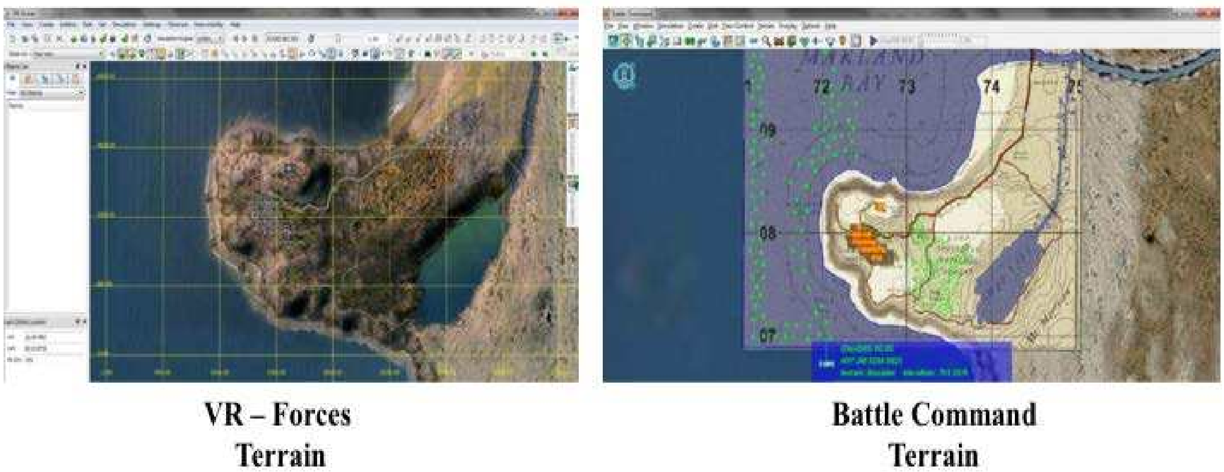

Figure 3: Terrain coherency of COTS simulation tools.

3.2.2 Battle Command

The experimental example used Battle Command for executing the unit level model in the scenario description shown in Figure 2. In that model, the units move and engage in combat through an HLA/RTI based distributed simulation network connection. Figure 4 depicts one blue force battalion and one red force battalion entering the disaggregation area. Through HLA based interactions and updates VR-Forces can detect when aggregate entities in Battle Command are entering the disaggregated area. The aggregated units in Battle Command can be specified with the desired level of munitions for the aggregate compositions. All of this data can be transmitted to VR-Forces for the recognition of entities.

Figure 4: Battle Command disaggregation area.

3.2.3 VR-Forces

Further, the experimental example utilized the constructive simulation platform VR-Forces for the entity level simulation. The VR-Forces simulation platform was connected to the Battle Command scenarios through the HLA/RTI based distributed simulation network connection as well. The VR-Forces simulation engine has the capability of modeling AI base automated entity behaviors. This AI behavior supports the MRM modeling approach as command control operational scenarios can be established with multiple representations of entities that can be driven by particular events or processes. In our experimental approach we described the aggregation and disaggregation MRM method and the proof of concept experimental implementation was demonstrated. Figure 5 shows a 2D view of the disaggregation in VR-Forces as well as 3D view of the entities entering the disaggregation area.

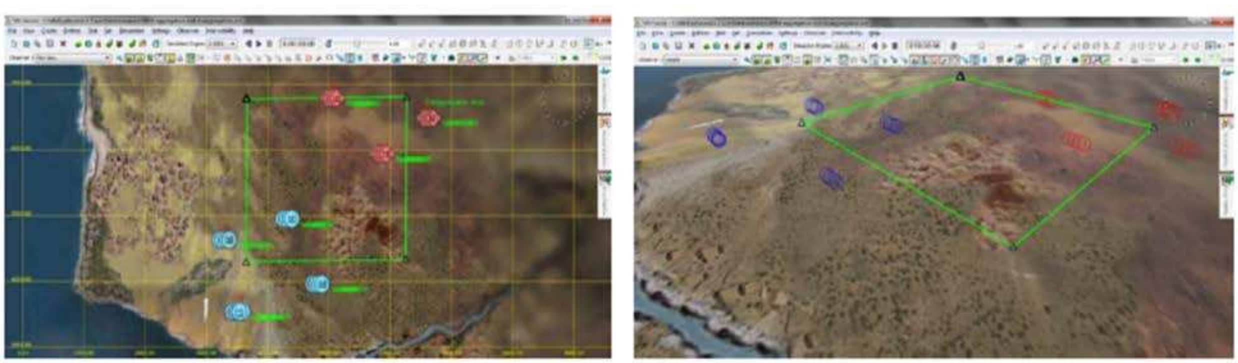

Figure 5: VR-Forces 2D and 3D Disaggregation Area.

3.2.4 Engagement Measurement

The addition of an engagement measurement and additional forces was performed from a different viewpoint. Simulation engine listens to explosion events. These events should be published when an entity has been destroyed and the user wants the engine to calculate the damage the explosion caused at a designated location such as the one of disaggregation. Example of the code added in SIMbox:

```
void EntityStatus::entityHitCB(const SimApi::EventParams* param){
int entityId;
param->getParam("EntityID")->getValue(entityId);
int currentDamageValue;
param->getParam("Damage")->getValue(currentDamageValue);
bool isDestroyed;
param->getParam("IsDestroyed")->getValue(isDestoryed);//listener
};
```

3.3 Summary and Recommendations and Further Work

3.3.1 Summary

The research conducted an extensive survey of the different reports and papers written by leading experts on MRM. MRM is an approach and architecture for modeling combat scenarios when both low resolution unit level modeling for large size scenarios and high resolution entity level modeling for detailed scenario coexist. These schemes provides flexibility and better modeling of complex problems.

In addition, we investigated the different approaches utilized to implement MRM. We also developed a set of experiments to utilize the COTS simulations in with a particular MRM approach (as built in the recent literature).

3.3.2 Recommendations and Further Work

Development and application of multi-resolution modeling spur very complex works. The work includes significant highly skilled effort and time, and creation of experiment settings. The work also requires well organized systematic approaches theoretically and practically. Because MRM is closely related to simulation architecture and application, further works are required to enhance the flexibility and accuracy of combat models.

4 CONCLUSIONS

MRM, the joint execution of multiple models, is a significant challenge facing the simulation community. We have learned by researching the literature and building an experiment that effective MRM leads to the design of multi-models that satisfy their users' requirements. Our experiment confirms the assumption that simulation systems built with modern simulation COTS products and sharing/communicating using existing and upcoming interoperability standards (e.g., HLA) can be used to implement MRM in an efficient and more sophisticated manner. The utilization of COTS such as VR Forces (http://www.mak.com/products/simulate/vr-forces.html), MASA Sword (http://www.masagroup.net/products/masa-sword/), Pressagis (http://www.presagis.com/), and Simigon (http://www.simigon.com/) opens up a whole new set of modeling and simulation opportunities to address the different needs of a training audience at different levels using MRM. The disaggregation is becoming much more feasible with improvements to simulation tools that are well designed and share common standards such as HLA.

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