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Test-Beds Using the High-Level Architecture and Other Distributed-Simulation Frameworks

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Abstract

Distributed environments composed of Live, Virtual, and Constructive (LVC) simulations have been used extensively by the defense establishment for many years. They can be also used for analytical use and provide more hybrid, high-fidelity, and visualization capabilities than simpler software package-based simulations (e.g., Arena). This paper discusses our efforts to design an environment being developed to model space missions and LVC for warfighter scenarios. Several models representing different phases of missions and engineered systems could be used to abstract complex systems. These models can be built using different simulation paradigms. New tools such as VR-Forces can be utilized to support these environments. A very important feature is the utilization and support of the High Level Architecture (HLA) that provide capabilities to build Virtual Test Bed (VTB). This paper presents our on-going work.

Keywords
Space exploration, High Level Architecture, distributed-based simulation, warfighter

1. Introduction

Our completed Virtual Test Bed (VTB) development efforts for modeling space shuttle missions and operations at NASA Kennedy Space Center (KSC) are based on the High Level Architecture (HLA) and the Run-Time Infrastructure (RTI) [1, 2]. HLA is a distributed simulation architecture for interoperation and reuse of simulations. It facilitates interoperability among different types of models and simulation applications and promotes reuse of simulation software modules [3]. HLA is intended to provide a general purpose distributed simulation architecture suitable for any type of model and broad range of application including training, logistics planning, analysis, and simulation-based acquisition [4, 5]. HLA can support virtual, constructive, and live models and has inherent capabilities for both real-time and logical-time execution.

It is very important to state that HLA was developed in the mid 1990's. In 1995, Defense Advanced Research Projects Agency (DARPA) funded three industry teams to develop concepts for the definition of a high level architecture. The results of these efforts would eventually lead to the development of the DoD HLA 1.3 standards, and subsequently to the IEEE 1516 family of standards which continues to grow. Then commercial developers have been expressly involved in the active development of the IEEE HLA standards from the beginning (1998) [3, 6]. The Runtime Infrastructure (RTI), a software implementation of the HLA Interface Specification, defines the common interfaces for distributed simulation systems during the federation execution of the HLA simulation. It is the architectural foundation that promotes portability and interoperability. All shared information exchanged during a federation execution must be passed through the RTI.

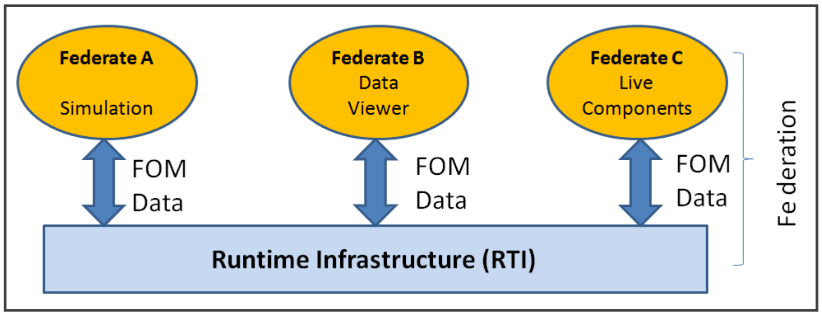

Figure 1: Conceptual diagram of a distributed simulation system using HLA/RTI

The above figure (Figure 1) shows a logical view of an HLA federation. Like the figure, multiple federates exchange data with each other during simulation execution. The simulation data exchange follows a Federation Object Model (FOM). The RTI provides a general set of services that support the simulations in carrying out these federate-to-federate interactions and federation management support functions. All interactions among federates go through the RTI.

The objective of our developments is to provide a collaborative computing environment that supports the creation, execution, and reuse of simulations that are capable of integrating multidisciplinary models representing the elements of complex systems (e.g., space exploration, military systems, corporate evacuation emergency training) [7]. Our new developments with the VTB are based on a layered approach. The enhanced VTB architecture design approach adopts the benefits of layered architectures and more flexible middleware solutions to achieve a desirable interoperability and scalability distributed simulation platform. This paper expands on lessons learned from our initial developments carried out in order to model complex systems.

2. Architecture for LVC

The purpose of military training is to establish and improve the capabilities of military personnel in their mission area. The military training using simulation is officially classified as Live, Virtual and Constructive simulation by U.S. Department of Defense (DoD). Live, Virtual and Constructive (LVC) simulation is a system of systems which provides an environment where multiple systems interoperate with each other in real-time. System of systems, in this context, means a concept that includes all of operator, hardware and software. Diverse heterogeneous simulators and hardware systems participate in LVC environments. Although simulations systems can be standalone, they can be used as a distributed simulation system using a network that runs different simulations simultaneously. Each heterogeneous system is interoperated with others through networks even though each system is distributed and distant geographically. Each sub-system interacts with other systems as data producer and data consumer. Real-time means that the simulation time and the wall clock time advance within the same phase. Table 1 shows the characteristics of LVC simulations.

Table 1: Characteristics of LVC

Classification	Characteristics
Live	• Real people operating real systems • Field exercise • Human-in-the-loop • Multiple Integrated Laser Engagement System (MILES)
Virtual	• Real people operating simulated systems • Virtual environment • Human-in-the-loop • Virtual flight simulator
Constructive	• Simulated people operating simulated systems • Computed generated environment • War game

We are building an environment using a distributed hierarchical simulation platform based on HLA and cloud computing and LVC. This approach will be utilized to measure the flexibility of an approach for mission design, validation of strategies, and advancements in tackling complex problems where advanced engineered systems are used.

The development of fine granularity, large-scale distributed simulation applications require higher level of efficient utilization of simulation resources, load balancing and fault tolerance capabilities, and more simplified simulation deployment process. For the reasons, a cloud based simulation system can enhance the capability of the HLA. Cloud computing provides computing services remotely to users through the internet, thereby minimizing the burden related with managing computing resources and facilities [8]. The benefits that can be realized from cloud computing include but are not limited to on-demand simulation resources, shared and reuse of simulation resources, load balancing capacity improvement. Other advantages of cloud computing are cost reduction, resource sharing and time saved for new service deployment.

HLA provides very few security features when used as a distributed simulation framework. It cannot guarantee integrity and confidentiality of the data exchanged between different federates connected through the web. There are possibilities of intrusion as illegal users can access network through web enabled HLA/RTI and any federate may connect and get access to data exchanged between federates [9]. It is also possible for intruders to tamper with the data in transmission networks. To deal with security problems involved in web enabled HLA/RTI, cloud security features such as Hypertext Transfer Protocol Secure (HTTPS), Identity-based cryptography (IBC) and Public Key Infrastructure (PKI) can be adopted. The communication between federates and RTI needs security checks and also requests for data requires authentication. Users can be authenticated to prevent unauthorized users joining the federation and sensitive data can be encrypted to maintain the confidentiality.

The application of tablet computing in the cloud can provide flexibility of operation in spacecraft and military systems. Tablets can be used by astronauts as mobile devices for monitoring and visualization of space systems. The tablet can work as a display interface, while all computing and processing is done via the cloud. Data processed on the tablet can also be saved into cloud. Astronauts can query the system, input their observations and perform online data mining to spot trends through the use of tablets. With voice and gesture recognition, astronauts can connect with components to form "network ontology". Using the computing hierarchical/distributed infrastructure, astronauts can also study correlations and run simple simulation models of the current observed situations.

The addition of Web-Services [2, 10] to this distributed simulation and cloud computing scheme will allow for other types of user interfaces and applications. Service Oriented Architecture (SOA) technologies and Web-Services have proven to be useful to provide interoperability by creating a system designed to support machine-to-machine interaction over a network [10]. Figure 2 shows an example of VTB with HLA, cloud computing and Web-Services for Military application.

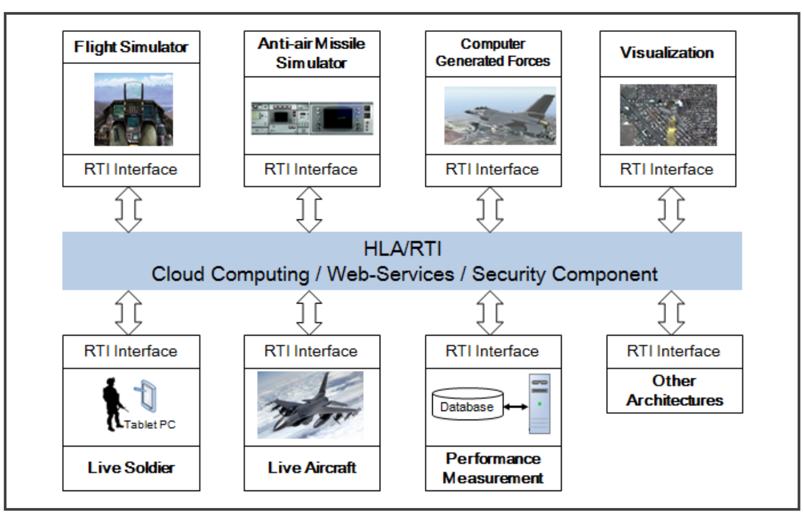

Figure 2: An example of VTB with HLA, cloud computing and Web-Services for Military application

3. An example of the NASA shuttle ground operation

As an example of the current developments in particular in visualization, we explain the NASA Shuttle Ground operations. We used Google SketchUp (http://www.sketchup.com/) in order to build the different 3D components. Google SketchUp is a free 3D design and modeling software released by Google. It was designed for users who feel difficulty using high-level 3D modeling software such as AutoCAD. The software provides easy-to-use Graphic User Interface (GUI) and enough feature richness, so users can design any architectural model from conceptual and detailed designs. Figure 3 shows the Vehicle Assembly Building (VAB) in the Kennedy Space Center (KSC).

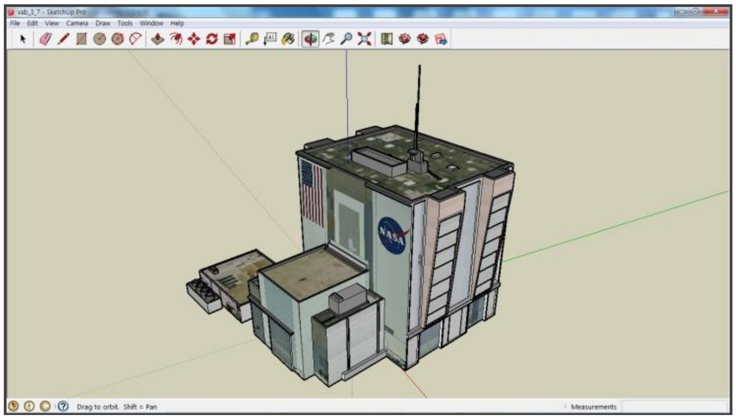

Figure 3: Vehicle Assembly Building (VAB) in Google SketchUp

SketchUp has many advantages as a 3D modeling software for this project. SketchUp supports most of the model formats supported by Computer Generated Forces (CGF) simulation platforms such as VR-Forces (http://www.mak.com/products/simulate/computer-generated-forces.html). These platforms have the resources to create synthetic environments with urban, battlefield, maritime, and airspace activity. VR-Forces supports several industry standards, objects, and formats such as 3DS, COLLADA, OBJ and OpenFlight. Since SketchUp has a rich web based 3D model repository named the 3D Warehouse, users can download high fidelity models from the repository. Users also obtain support from the community. After downloading Space Operation models from the repository, we imported the models to VR-Forces scenario through the Entity Editor which enables editing 3D models and parameters. We found that COLLADA format showed the best quality in the VR-Forces. Figure 4 shows the Space Shuttle model edited in the Entity Editor.

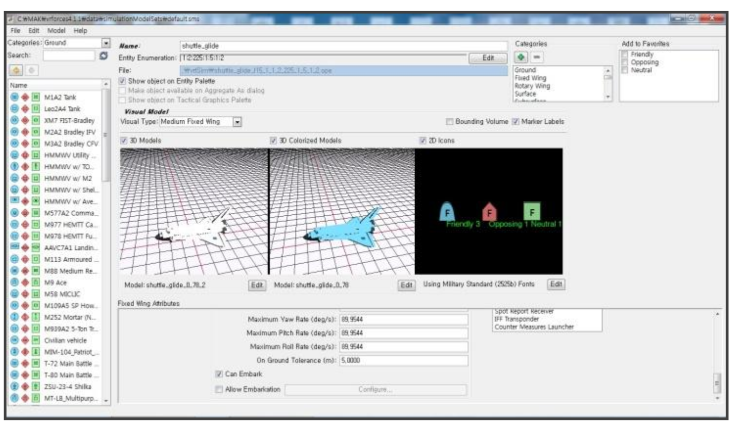

Figure 4: Space Shuttle model in the Entity Editor

VR-Forces is an all-encompassing mission generator complete with simulation of hundreds of models and terrains as well as scenario editing capabilities. VR-Forces has reactive simulation using artificial intelligence. The models used in the scenario may react to other properties of objects placed in the scenario as well. Scenarios are easy to build using two-dimensional or three-dimensional views for positioning each object into the terrain. Models may also be edited and configured to meet the needs of the scenario. Vehicle dynamics, sensor capabilities, and reactivity to the environment are all capabilities that are offered by the simulator. VR-Forces in the NASA space mission simulation was used to demonstrate the path of action for the space shuttle. The image of the Kennedy Space Center (KSC) on the Atlantic coast terrain was obtained and inserted into VR Forces as the platform of the mission. Models used in the mission were the space shuttle imported from Google SketchUp, the Vehicle Assembly Building (VAB), and other props including the runway, vehicles, and pedestrians. The mission was designed in three stages. Stage one showed the path of the space shuttle from the Orbiter Processing Facility (OPF) to the VAB (Figure 5).

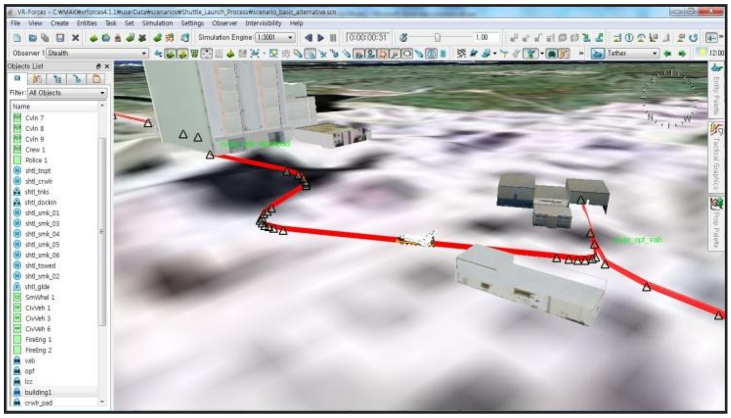

Figure 5: Space Shuttle moving from OPF to VAB

The shuttle then proceeds to the launch pad for lift off to the International Space Station (ISS) as shown in Figure 6.

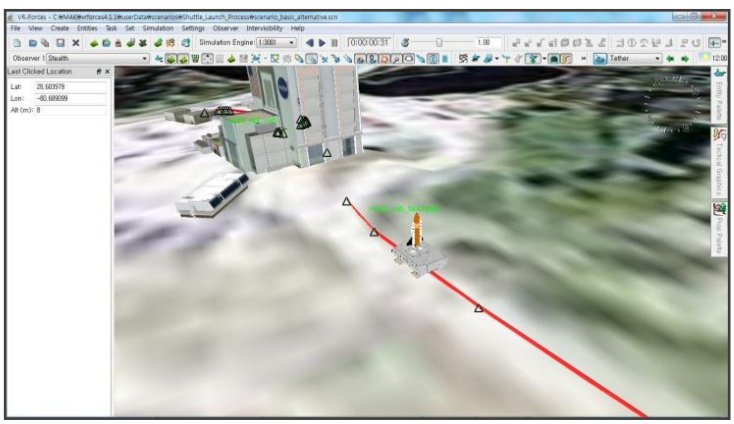

Figure 6: Space Shuttle on the Crawler (from VAB to the Launch Pad)

The control logic of the entire mission is modeled using a discrete-event simulator (www.anylogic.com). The Orbiter is processed in the Orbiter Processing Facility (OPF). When the hardware problems are resolved, system or component repairs/ replacements are completed and Orbiter modifications are achieved, the vehicle is prepared for roll over to Vehicle Assembly Building (VAB) for vehicle operations. Then the vehicle is transferred from VAB to the Launch Pad (LP). Next step is to launch the Shuttle in to the Space to reach International Space Station (ISS). The final step is the entry and landing of the Shuttle at a particular location (e.g., KSC or Vanderberg, California). The flowchart is as shown in the Figure 7.

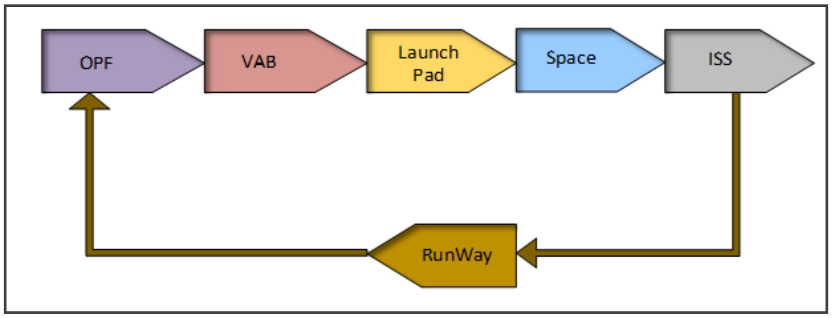

Figure 7: Flowchart of Space Shuttle operation

This model in AnyLogic is a probabilistic simulation model of the operational life cycle of the Space Shuttle through ground facilities at Kennedy Space Center (KSC). Flight operations such as ascent, mission duration and landing are also modeled. This discrete event simulation model is built by consulting NASA experts and using the processing times/features of the NASA Shuttle as a baseline. Figure 8 shows the discrete event simulation model.

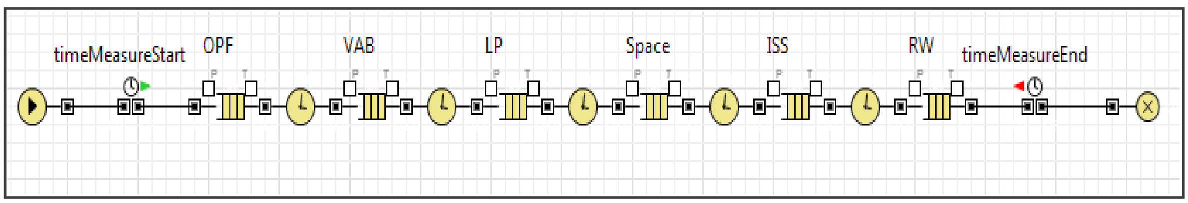

Figure 8: Discrete event simulation model of shuttle operations using AnyLogic

With the utilization of the RTI and the different federates, it is possible to drive VR-Forces from the AnyLogic Model and then, a sophisticated visualization, animation, simulation is performed. This is a simulation that not only respects the statistical characteristics and constraints of the processes but also the terrain, the spatial constraints (e.g., geometric dimensions of the building), climate/weather issues, gravity effects, material effects, and human behavior (we can assign behavior based on artificial intelligence/agent based modeling). In addition, the visualization and the distribution of it cannot be matched by any discrete-event simulator in the market. For example, one user in Florida can see the launch view from the east side of NASA KSC and another user in California of the simulation can see the same lunch at the same time from the north side of NASA KSC.

4. An Example of the Defense Industry

The same environment can be used in the Defense Industry. The purpose of military training is that to establish and improve the capabilities of military personnel in their special area. Traditionally, the military execute the field training exercises (FTX) but, they are extremely costly activities. The defense industry uses advanced modeling and simulations (M&S) to provide realistic training. In virtual simulations, real people operate simulated systems allowing trainee to acquire a professional skill such as flying an airplane. Although simulations systems can be standalone, they can be used as a distributed simulation system using a network that runs different simulations simultaneously. In constructive simulations, simulated entities interact with simulated systems. Besides, virtual and constructive simulations can be used with live simulations which refer to a simulation involving real people operating real system.

Military Simulation systems known as Computer Generated Forces (CGF) or semi-automated forces (SAF) play an important role in modern warfare by supporting military activities like training, experimentation, acquisition, and analysis. As an example of military system, a scenario of the movie “Black Hawk Down” was created using a CGF tool (VR-Forces). VR-Forces is a commercial of the shelf (COTS) simulation system developed by VT MÄ K as an option to government solutions. VR-Forces is mostly used for military training at the tactical level because it provides high level of details about battlefield. The scenario demonstrated diverse military situations and difficulty of military operations in a dense city. Figure 9 shows a sample military operation scenario developed by VR-Forces.

Figure 9: A sample military operation scenario developed by VR-Forces in our University. The "movie" recreates the scenes of the operations of a US Special Forces Team in Somalia with a high level of realism (following the script of the movie "Black Haw Down").

5. Lessons Learned: Several RTI platforms are available and you have to select an appropriate one

One of the lessons learned during this initial effort was the selection of the RTI. The performance of the RTI is crucial to the optimization of the federation. For this reason, the evaluation and choice of an RTI was considered during the design phase. The implementation language of the RTI can have an impact on performance. For example, Java implementations may require more system resources while the cross-platform nature of Java enables it to run without modification on any Java-enabled platform. Other independent variables that affect performance include: number of federates, distribution of federates, Data Distribution Management, network transport mode, objects per federate, attributes per object, interactions per federate, parameters per interaction, attribute buffer size, interaction buffer size, and data bundling. The effects of these independent variables on measures of comparison such as latency and throughput should be evaluated before a choice of an open source or commercial RTI is made [11].

Commonly used commercial HLA-compliant RTI implementations are the MÄK Real-time RTI, Pitch portable RTI (pRTI) and RTI Next Generation. For this experiment we utilized the MÄK Real-time RTI. Designed for superior performance, MÄK RTI implements the HLA specifications in C++. The MÄK RTI supports a wide variety of network topologies and architectures. It has been verified by the Defense Modeling and Simulation Office (DMSO) to be compliant with the HLA Interface Specification and the IEEE 1516. In a HLA RTI performance evaluation, the MÄK RTI showed lower round-trip time compared to two open-source RTI implementations (CERTI and Portico), although the MÄK RTI has a limitation of transmitted data size for the best effort setting [11]. The RTI is compatible with Windows (7/Vista/XP) and Red Hat Enterprise Linux.

6. Lessons Learned: Advance visualization is important

Another important lesson learned was related to visualization. Visualization is an important feature of modern simulation modeling environments. As our research of different visualization paradigms continues, we find that two types of visualizations are required [1]. First, a visualization of data and/or the specialized functions is an essential part of Commercial Off-The-Shelf (COTS) tools. In order to integrate the visualization into the VTB, a federate has to be created. This federate will interact with both the RTI and the visualization's external interface. A second type of visualization will have a simulation engine which includes a set of integrated animation facilities to display the state of the system being simulated, which may allow user-model interaction.

Our research has found that there are many visualization schemes available. In addition, another system with distributed capabilities and one of the most popular and complete simulation and visualization COTS available is SIMbox from SIMGON (http://www.simigon.com/overview.html), a Modeling, Simulation & Training solutions provider. It is a platform which provides the ability to create, modify, manage and deploy any simulation-based content. SIMbox is a system architecture which allows users to create simulation-based training. Building a new system, such as a new engine, control systems are possible at a finer level of detail. Because SIMbox training environment are based on real-time 3D visualization, trainee can feel high fidelity visual effects in the virtual environment. Figure 10 shows the SIMbox training environment.

Figure 10: SIMbox training environment for an F16 fighter. This environment can be integrated with an actual cockpit (with joysticks, etc.) to provide more realism.

Another COTS visualization architecture is a software system developed by Presagis (http://www.presagis.com/). Presagis has a visualization product named Vega Prime which is a toolkit for the real-time 3D development and deployment of simulation applications. It allows rapid design and prototyping of real-time 3D application, and it shows high performance. Figure 11 shows a sample 3D visualization effect by Vega Prime.

Figure 11: A sample 3D visualization effect by Vega Prime

7. Lessons Learned: High-performance computing platforms can be used to speed up and support multiple-resolution modes

Our current work with warfighter scenarios and LVC has required the addition of "accelerators" in order to improve the real-time capabilities and data integrity. We have used high-performance computing platforms such as the Synchronous Parallel Environment for Emulation and Discrete Event Simulation (SPEEDES) [12, 13] with success. Our developments are benchmarking WarpIV (the next generation of SPEEDES - http://www.warpiv.com/) in order to be integrated to our VTB. Performance-based training requires the generation of sophisticated environments (e.g., realistic) and required the solution to higher-order levels of numerous mathematical equations. The mathematical developers are used to build these models using tools such as MATLAB/SimuLink. However, the accelerators can use the code in C++ and with highly parallel/distributed capabilities (even in heterogeneous computing environments) speed up the solutions allowing integration with Live entities.

8. Conclusions

Distributed simulation is very important to tame complexity. It is essential to emphasize the hybrid nature of distributed simulation models where discrete-event and continuous models are required due to the nature of the engineered systems [4, 5]. There are many sources of expertise required to build and model these engineered systems. Then, there is a need for different type of models to have the analysis capability to encompass their sub-systems, processes, and life cycles.

This approach of Hierarchical/Distribution simulation modeling can be used for planning at different levels (i.e., strategic, operational, and tactical). It is very important to appreciate the level of integration to be achieved with other information systems and the real-time issues involved in particular for advanced concepts. Scripted visualization and simulation visualization are very different concepts. Simulation visualization is the one requested by the analysts while scripted visualization is just a replica of a movie.

We use COTS simulation tools to establish new VTB architecture for LVC. Using COTS simulation tool is very common in defense industry. The simulation provides high fidelity environments which replicate diverse operational situations that trainees could encounter. By repeating training in the environment, trainees can be familiar with the situations and this lead to effective training and cost reduction. Also high level of visualization provides realistic training environment in which trainee can acquire skill and created experience. We emphasize the importance of high fidelity visualization implemented with COTS simulation tools. Additional research area to upgrade VTB such as cloud computing, tablet computing and security scheme for VTB were explained.

This paper outlined some of our preliminary work that will evolve toward a more sophisticated and responsive simulation environment. We will report our progress in future papers.

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