Proceedings of the 2000 Winter Simulation Conference
J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, eds.

COMPOSABLE SIMULATIONS

Stephen Kasputis

VisiTech
3107 North 18th Street,
Arlington, VA 22201, U.S.A.

Henry C. Ng

Naval Research Laboratory
4555 Overlook Ave., SW
Washington, DC 20375, U.S.A.

ABSTRACT

While there has been much attention paid to the applications of Modeling and Simulation (M&S) by the Department of Defense (DoD) lately, little has been done to address those broad technology areas that enable application-oriented simulations to be more easily constructed, run and analyzed. Model Composabilty is the ability to compose models/modules across a variety of application domains, levels of resolution and time scales. A composability framework for simulations offers a quantum leap in capability and provides the sought after ease of use. However, Composability is still a frontier subject in Modeling and Simulation, and current capability is limited. While model reuse is close to the Holy Grail of M&S, the goal is not within sight. We are discovering that unless models are designed to work together, they don't (at least not easily and cost effectively). Without a robust, theoretically grounded framework for design, we are consigned to repeat this problem for the foreseeable future. This position paper outlines the challenges and basic researches that are needed for composable simulation developments.

1 INTRODUCTION

As the budgets of the Department of Defense have fallen over the past dozen years, military leaders and managers have had to constantly look for methods to improve efficiency. One method that is often looked to is the judicious application of technology. One technology that is being increasingly relied upon is that of simulation. Simulation holds the potential to benefit all aspects of military functions. For example, it can be used to support the analyses that identify an emerging operational need. It can assist all activities associated with the definition, design, and production of systems to meet that need. It can increase military readiness by assisting the training of operators in the efficient employment of those systems, and increase military effectiveness through incorporation in tactical decision aids. To fully meet their potential, however, simulations need to become as common for the military operator as the spreadsheet or word processor is to the office worker.

There are many factors hindering the mainstreaming of simulations in the DoD community. These factors span the spectrum from cost, to ease of use and confidence in the value the simulation can provide. For each of these factors, there are a number of potential solutions. Rather than address each issue individually and hope that the solutions can be integrated into effective and efficient simulation systems, however, it is better to take a systems approach and develop a simulation infrastructure that simultaneously addresses as many of these issues as possible. The conceptual system from such an approach is that of a composable simulation framework.

In the next section we will present the concept of a composable simulation framework by describing the functionality desired. We will then present the benefits of such a framework, followed by the major issues in realizing it. We will then suggest some ways in which the known issues can be addressed and progress made toward achieving the conceptual system. The discussion in the following sections will be in the context of the simulation of military operations. The issues discussed are applicable to any simulation use domain, however and could just as well use terms such as "fluid flow problem space" instead of the military "mission space."

2 THE CONCEPTUAL SYSTEM

Currently, if a user identifies a need for a simulation, he must explain that need to a developer. The developer constructs the simulation. For complex simulations, this is often an iterative process with functionality added with each iteration. Once complete, the product must be delivered to the user along with instructions on use and maintenance. Finally, the user can employ the simulation.

As an alternative approach, it may be possible to establish a system with which simulations are created at runtime to meet the specific requirements of that run. The user specifies his needs to a system that in real time builds a simulation to produce exactly the information he needs from that specific run. If another run is needed to explore other aspects of the problem being considered, a new simulation is created to provide that information. These simulations are built from a library of software modules that can be flexibly combined to produce the required functionality. No longer is the life cycle of a simulation inception, elaboration, iterative construction, transition, and use. The new life cycle is simply inception and use. Simulation developers would no longer build large, inclusive, monolithic simulations. Instead, they would build small modules with well-defined functionality that are readily combined with other modules to produce the simulation functionality required. Simulation users need have no knowledge of specific module content, or how modules are selected, combined, or run.

A conceptual system for composable simulations (Page 1999, Page and Opper 1999) is shown in Figure 1 below. This conceptual system is provided as an example to understand the functionality required from a system of composable simulations.

2.1 Identify User Requirements

To provide quick setup and be tailorable to the specific need of the user, a system should assist the user in defining his requirements and constraints. The effects of abstractions of one part of the battlespace on the fidelity of representations of a different part of the battlespace are complex and sometimes non-intuitive. It is unlikely that even sophisticated simulation users would be able to a priori identify all these effects and the resulting requirements for the simulation. Likewise, the user may not think of all the applicable constraints for his application. Once all the requirements and constraints are delineated, it is necessary to also prioritize them. If instances arise where all the requirements cannot simultaneously be met, the system that will create the simulation must know which requirements are most important. The first aspect of system functionality that must be present, therefore, is the ability to help the users identify, delineate, and prioritize all of their requirements and constraints.

2.2 Translation of User Requirements and Module Identification

User requirements will be stated in the form of operational requirements for the simulation. An example of this might be "the simulation will model the suppression of enemy air defenses at the engagement level." The definition of the simulation modules will include a functional description such as "models the effects of broadband jamming on air search radars." To identify which simulation modules provide the functionality required to meet the user-defined operational requirements, there needs to be a mapping or correlation of operational requirements to functional performance. The composable simulation system must, therefore, provide such translation functionality. Additionally, once the functional performance is identified, the system must also identify which of the fundamental modules in the system's library will provide that performance. This provides the candidate list of modules for construction of the desired simulation.

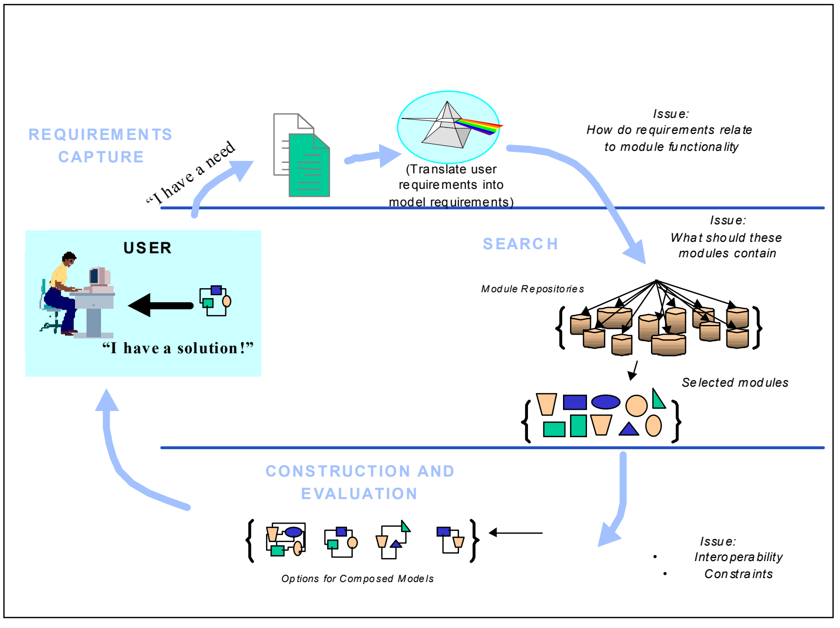

Figure 1: Concept for a Composable Simulation System.

2.3 Library of Simulation Modules

A library of simulation "building blocks" is required. This library needs to be extensive enough to address the desired level of detail for any and all aspects of the mission space and the needs of all application domains. Interactions between the building blocks or modules need to achieve more than simple compatibility; they must achieve levels of true interoperability. They, therefore, need to be defined according to critical descriptors that identify what they do, how they do it, how they can be employed, and how they can be combined with other modules. Modules may consist of fragments of algorithms, entire algorithms, models, or groups of models, depending on its level of resolution and intended use.

2.4 Development of Candidate Simulations

After identification of the modules that can provide the needed functionality has been accomplished, the system needs to determine how to best combine them into a simulation. It may be that more than one combination will be possible, and the system needs to identify all possible combinations or families of combinations.

2.5 Selection of Best Simulation Candidate

After the different combinations that could meet user requirements have been identified, selection of the one to run must be made. The system must identify weighted metrics based upon the previously identified operational requirements and constraints. The system must then develop estimates of simulation performance and compare these against the weighted metrics to determine the one most appropriate for meeting the user's needs.

2.6 System Evaluations

To meet the need for users' confidence, the system must have a series of evaluations. It must be able to provide the user with some sort of Figure of Merit for the simulation it provides. The user needs to know how the simulation provides the representations needed and in which areas and to what extent those representations might be lacking. For additional user confidence, there should also be similar Figures of Merit for the fundamental modules that comprise the simulation. If more than one composable system is constructed, there should also be a Figure of Merit for the overall system itself.

3 BENEFITS

A framework for composable simulations provides many benefits to both the user and developer communities. Such a system offers the potential for providing higher-quality simulations in less time for lower costs.

3.1 Higher-Quality Simulations

Simulations can be thought of simply as sources of information. As such, their value increases with both the extent and quality of information they can provide. The attributes of simulations that contribute to the extent and quality of information they can produce are comprehensiveness, consistency, and validity.

3.1.1 Comprehensiveness

Simulations must be comprehensive. That is, they must be able to address all aspects of the problem under investigation and represent all potentially important factors within the mission space. Simulations are rarely as comprehensive as the user would like, and often they are not as comprehensive as needed. This is usually as a result of constraints on time and funding or access to critical knowledge of the real world systems. Simulations are typically built for one user or user community. For a variety of reasons, little advantage is taken from existing similar simulation systems developed for other users. This lack of reuse results in many, mostly redundant, representations of some aspects of the mission space, while the representation of other important aspects is poor or entirely missing. A composable simulation framework would promote reuse of information, algorithms, and models. This would help avoid the redundancies currently seen, allowing application of resources to other aspects of the mission space. Over time, as the library of fundamental modules is built up and made accessible to all users, much more comprehensive representations of the mission space should be possible.

3.1.2 Consistency

The need or desire for variable or multi-resolution simulations has been extensively discussed in the literature (Davis 1998, Perakath, Delen, and Mayer 1998, Zigler 1999, Sales, Usher, and Page 1999, Davis 1993, Natrajan and Reynolds 1997). Implicit in such operations is the need for a consistent representation of reality throughout the spectrum of resolution required for military applications. That is, reality must not be changed by the selection of the detail of the representation. A composable simulation framework could support consistency in two possible ways. If module descriptors can be made complete enough, simulations will be constructed only from subsets of the modules that represent the battlespace in the same manner and ensure consistency. Even if descriptors cannot be made this complete, proper testing and configuration management of the library of modules, while labor intensive, can identify subsets of modules that are consistent with each other.

3.1.3 Validity

For simulations to be of any use, they must present some aspects of reality to some degree of fidelity or validity. It is well understood that no simulation can represent all aspects of reality. Knowing which aspects are represented well and which are not is critical. The limitations on a simulation's ability to represent reality need to be well understood by the users. Users need to understand these limitations to have confidence in the results of the simulation and ensure those results are only used in appropriate manners. Performing sufficient verification and validation (V&V) of models and simulations is a difficult task. Use of state-of-the-art techniques such as artificial intelligence, neural nets, or genetic algorithms and running these in distributed execution environments makes the task of V&V even harder. This difficult task is then compounded by the fact that the instances of required V&V are multiplied because of the lack of software product reuse and the resulting proliferation of redundant models. Establishment of a library of simulation modules could allow concentration of V&V resources. This will permit more thorough testing and documentation and result in higher user confidence.

3.2 Time Savings

The pace of military operations, as with the pace of technology development and commerce, continues to increase. The time available for decision cycles that simulations support are, therefore, decreasing. As a result, the time available for all aspects of simulation employment continues to decrease. It is important, therefore, that simulations can be made quickly available and that the results or information they produce can be quickly assimilated or used.

The nature of military operations has changed significantly in the last decade and continues to evolve. Military forces have been used for humanitarian aid missions, peacekeepers, and to assist in the war on drugs. As new roles for the military emerge, it is important that simulations adapt quickly to provide the needed support. Because the module library would span the range of use domains and levels of resolution, there is a high probability that most or all of the representations needed for a new operation type would already exist. Therefore, simulations that operate within a composable framework would have the potential to adapt quickly to emergent operations.

Facilitating the setup and initialization of simulations is critical to mainstreaming them. Many current simulations take considerable time and effort to set up and initialize. A composable framework could potentially reduce this overhead. If definition of the user's requirements and constraints is sufficiently complete and detailed, the construction of the simulation to support a specific exercise could include a complete initial state of both the system software and hardware. Even if generation of only part of the required initial state is ultimately possible, the time savings to the user could be significant.

The dimensionality of problems and exercises that simulations support continue to increase. The human capacity for handling dimensionality, however, is not increasing. It is, therefore, critical that the information presented to decision makers be the most critical related to the problem at hand. The implications of this for the simulation user is that matching the level at which the simulation produces data to the requirements of information of the decision maker is more critical than ever. Too detailed information results in information overload. Too little information results in high-risk decisions. One possible solution is additional processing of the information produced by the simulation before it is presented to the decision maker. This requires additional time to analyze the results from the simulation, identify what additional processing would be required, and execute that processing. If the simulation could be constructed to produce precisely the information desired, such post-processing would not be needed. Composable simulations as envisioned have the potential to be constructed to produce such precise information and thus reduce the post-simulation analysis time.

3.3 Lower Cost

Potential cost savings from the use of composable simulations come from several areas. The potential savings from extensive reuse of software and software designs has already been alluded to. As previously mentioned, these savings would allow for more expansive simulations with a higher degree of user confidence. A second factor toward potential cost savings could be lower maintenance costs. A major factor in maintenance costs is if the typical maintenance activities are simple to understand. The modular nature of composable simulations and the well-defined interfaces and descriptors of the modules should provide a degree of documentation that would make most maintenance tasks well understood.

4 DEVELOPMENT CHALLENGES

Current capability in composability is limited. While composable simulations offer great benefits in M&S, the goal is not within sight. We are discovering that unless models are designed to work together -- they don't (at least not easily and cost effectively). Without a robust, theoretically-grounded framework for design, we are consigned to repeat this problem for the foreseeable future.

We have neither horizontal (same granularity, different application) nor vertical (same domain, different granularities) design principles or technical audit trails. Significant research and development is required to produce the technologies needed to realize a system with the functionality of the conceptual system presented. One major reason is the model builders have no guiding principles for composable simulation design. Much theory needs to be developed.

4.1 Methodologies to Identify All Requirements and Constraints Applicable to Any Given Situation

It is important that the assembled simulation composed from the reusable modules precisely meets the end user's needs. The reusable modules should support both a span of domains and a range of granularity. Before selection and linking of the correct modules needed for any given application can be accomplished, the requirements and constraints for that application need to be understood. Composability will only work if the software objects and data can be linked to the user need in an effective and efficient manner. Currently, there is no methodology developed to guide the identification of those requirements and constraints. Without a formal methodology, it is also difficult to decompose the different requirements and constraints from many application domains and different levels of resolution into consistent, meaningful, and manageable measures that can be used to link requirements to software objects and data. The methodology will also assist in the identification of the extent of functionality the modules should contain to maximize their applicability. Basic research is needed to develop the formal methodology.

4.2 Theory to Support Identification of Descriptors of Modules

The pool of reusable modules is the most critical part for composable simulations. Objects in the reusable modules require multiple levels of abstraction in order to meet the needs for vertical and horizontal composability. But most fundamentally, there is a lack of robust theory upon which to base the identification and selection of the size and content of modules. What should the size and content be for composable modules? Should a module consist of pieces of algorithms, algorithms, models, or groups of models? Should the module content be on the basis of function, so that all sensors are grouped into a module, all weapons are grouped into a module, and so forth? Or should each sensor be a module by itself? Should the size and content of a module change, depending on the level of detail being addressed in the simulation? The engineering-level simulations might require that each piece of an algorithm have its own module, while the campaign-level simulations need modules that contain groups of models.

Another important point is the lack of a theory to support decisions on addressing which relationships are necessary for each module to support the concept of composable simulations. What are the relationships that need to be addressed for each module within a simulation and for the simulation as a whole? The current approach addresses relationships within one mission space for one resolution. The main emphasis is on physical connectivity in the Battlespace, e.g., a radar on a ship can detect a missile. Other aspects such as the relationship between the model and user requirements, its interoperability at a semantic level with other models, or how it could be used in different simulation timing schemes are not addressed. Research is required to identify all the possible applicable relationships so a framework for the development of the composable modules can be defined. Figure 2 depicts the increased complexity of true composability over the level of complexity that is currently addressed in modeling or simulations. The dimensions depicted in Figure 2 are not intended to be exhaustive. For example, classification level and operating system are additional potential axes. It must also be noted that the different axes along which relationships between modules must be addressed are not necessarily uncorrelated. Therefore, defining the N-dimensional relationships needed is significantly more complicated than simply defining N-different relationships. The definition along one axis can affect the definition along another axis. Furthermore, the nature and strength of the relationships can change, depending on what the application is for a given simulation. A theory is needed that can guide development of a methodology for simultaneously determining the many relationships in a simulation.

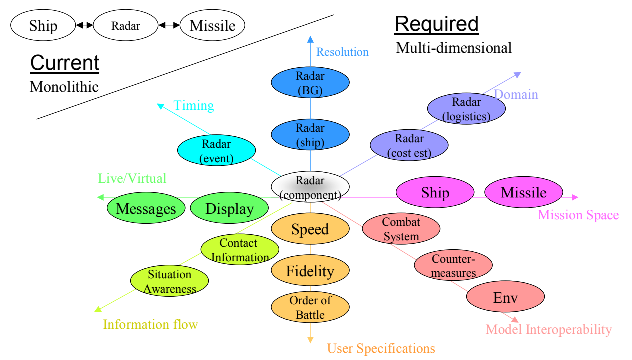

Figure 2: Complexity of Module Descriptors

To better understand the importance of the need of robust theories to support identification of descriptors of modules, consider an analogy using the periodic table. We are currently trying to identify the elements that should compose the table, as well as the information equivalent to atomic weight and number of valence electrons that need to be included as table entries. In addition to defining the periodic table, we need to identify the laws that govern chemical reactions and which compounds are possible. We also need to address measures of the value of the compounds as the building materials for skyscrapers or your house.

4.3 Theory to Relate Requirements and Constraints to Module Functionality

When composing a simulation from the reusable modules, it is important that the composed simulation will fully address the end user needs. It must be known what requirements each module should address within an application domain. The requirements that it addresses must not be transient in nature, but rather must be fundamental to the application domain. We need to be able to translate the user requirements and constraints into a set of module functionality so proper components of the simulation can be selected from the reusable modules. Currently, very limited theories have been developed that can be used to relate the user requirements and constraints to module functionality. Basic research in developing such theory is badly needed in order to accomplish this translation and correlation.

4.4 Methodologies for the Combination of Modules into Complete Simulations

How can the modules be selected and then combined in a way to meet specific requirements and groups of requirements? Little methodology exists for composing a simulation from fundamental modules to meet specific requirements. Methodologies need to be developed that address not just which modules meet which requirements, but which groups of modules meet which requirements. Evaluation of various combinations and permutations of modules against prioritized or weighted requirements must be addressed to determine which of those is optimum for the specific situation confronted by the user.

4.5 Theory to Support the Development of Figures of Merit for the Fundamental Modules, Constructed Simulations, and Overall Composition System

Some forms of the Figures of Merit need to be developed to give a more quantitative measure of how well a composed simulation meets the given set of requirements and constraints. These Figures of Merit must be based on standard metrics for measuring the quality of the various composable simulation options. Such standard metrics do not exist. In fact, development of appropriate Validation and Verification procedures for simulation construction and performance must be based on such standard metrics. Measures are also needed for the modules and the effectiveness of the system/methods of selecting and combining modules.

5 THE WAY AHEAD

It is obvious that realization of the conceptual composable simulation system is a long way off. The potential benefits of such a system to the advancement of simulations, however, cannot be ignored. The question is not one of if research in the area should be pursued, but how best to proceed and how should research in this area be prioritized against other areas in the realm of modeling and simulation. Here are our recommendations. These are based upon factors such as the state of the technology base to support further research, the potential for near-term as well as long-term benefit, and the value of the resulting capability, irrespective of its inclusion in the conceptual system.

Work could begin immediately in two of the areas discussed above. The first is the study of methodologies to identify all requirements and constraints applicable to any given situation. Proper identification of requirements is critical to any development project, so advances would be widely applicable. The other area is development of a theory to support identification of descriptors of modules. This work should eventually lead to the establishment of a standard for the coding of "self-describing" modules. This work would also have general applicability to simulation interoperability. As described in Aronson and Wade (2000), composition can be made much easier through standardized component descriptions. Complementary to this work would be identification of the infrastructure requirements for composable simulation systems. For example, DoD's High Level Architecture does not allow for methods to be included in the definition of objects. This may be too limiting for composable simulations.

One obvious recommended guideline for the pursuit of the research is to start with quantities in which we have the most confidence in our current simulation capability. Specifically, modeling of the physics of the battlespace is better understood than modeling aspects such as command and control or human behavior. Therefore, initial work in the two recommended areas above should deal with physical descriptions. Lessons learned in structures and processes can then be applied to the modeling of other aspects as they mature. It is also wise to limit the initial effort to one or a few domain areas or classes of applications. Models of the same entity or phenomenon may need to be significantly different for different applications. This difference may be larger than can be accommodated through simple parameter changes and may require changes in the model itself. This is a complicating factor that should be avoided in early efforts.

Another obvious guideline would be to continuously support the development of theory with experimentation. This practice of essentially build-a-little, test-a-little would substantiate the identification of solutions as well as support the identification of the next set of issues to address. There is, however, a relative absence of simulation environments to support such testing by making composable simulation designs straightforward. A pressing need exists for new computational tools and improved environments to assist the evolution of the needed theory.

There is tremendous amount of research (Aronson 1998, Davis 1999, Harkrider and Lunceford 1999, Pratt and Ragusa 1999) being performed by much of the science and technology (S&T) community, both within and outside of the Department of Defense, in advancing the foundations of simulation science. Modeling is a mixture of art and science and benefits greatly from the shared experiences of diverse individuals. What is lacking in composable simulation systems is the mechanism that allows the sharing and exchanging of the knowledge and techniques gained by individuals so we can learn from each other to advance the state –of the art. Besides the strong support by DMSO, one of the major reasons that the distributed simulation technology has made great strides in recent years is the yearly Spring and Fall Simulation Interoperability Workshops (formerly known as Distributed Interactive Simulation (DIS) Workshop) which provides a forum for interested parties to exchange information, techniques, and lessons learned. More importantly, the information is consolidated and readily available for any individual from the High Level Architecture (HLA) data repository. It would be extremely valuable if there were a similar setup and data repository specifically designed for the composable simulation practitioners to use as a place to share and discuss issues as raised in this paper

6 SUMMARY

The presented conceptual composable simulation system offers an integrated system approach to many of the requirements for mainstreaming simulations. There are, however, many issues to be addressed before the concept of composable simulations can become a reality. The scope of this paper did not allow for the discussion of the current state of technology, but that technology is sufficiently advanced to allow for pursuit of some of the issues as recommended. Even if the conceptual system is never realized, investigation into most of these issues required for that system would benefit the general interoperability and usability of simulations. The potential benefits of not only the conceptual system, but also the ancillary product from its pursuit, dictate that the research in the associated issues begins as soon as possible. The discussion of how best to pursue this research should begin now.

REFERENCES

Aronson, Jesse. 1998. Model-based simulation composability. *Proceedings of Simulation Interoperability Workshop*, 98F-SIW-055.

Aronson, Jesse and David Wade. 2000. Benefits and pitfalls of composable simulation. *Proceedings of 2000 Spring Simulation Interoperability Workshop*.

Davis, Demetrius. 1999. Component selection techniques to support composable simulation. *Proceedings of 1999 Spring Simulation Interoperability Workshop,* 99S-SIW-043.

Davis, Paul. 1998. Experiments of Multiresolution Models, Rand Corp. Report 1998. `<http://www.rand.org/publications/MR/MR1004/MR1004>.`

Davis, Paul K. 1993. Families of models that cross levels of resolution: Issues for design, calibration and management. *Proceedings of the 1993 Winter Simulation Conference.*

Harkrider, Susan and Dell Lunceford. 1999 Modeling and simulation composability. *Proceedings of the 1999 I/ITSEC Conference.*

Natrajan, Anand, Paul F. Reynolds, Jr., and Sudhir Srinivasan, 1997. MRE: A flexible approach to multi-resolution modeling, *IEEE Journal.*

Page, Ernest. 1999. Observations on the complexity of composable simulation. *Proceedings of the 1999 Winter Simulation Conference.*

Page, Ernest and Jeffery Opper. 1999. Theory and rractice in user-composable simulation systems, DARPA Advanced Simulation Technology Thrust (ASTT).

Perakath, Madhav Erraguntla, Dursun Delen, and Richard Mayer. 1998. Simulation modeling at a multiple levels of abstraction. *Proceedings of 1998 Winter Simulation Conference.*

Pratt, David and Charles Ragusa. 1999. Composability as an architecture driver. *Proceedings of the 1999 I/ITSEC Conference.*

Sale, Nickie, Tony Usher, and Ian Page. 1999. Multiple representations in synthetic environments. *Proceedings of the 8th Computer Generated Forces and Behaviors Conference.*

Zeigler, Bernard. 1999. Support for hierarchical modular component-based model construction in DEVS/HLA. *Proceedings of 1999 Spring Simulation Interoperability Workshop*, 99S-SIW-066.

AUTHOR BIOGRAPHIES

STEPHEN KASPUTIS is the Vice President of Visi-Tech, Ltd. He has 15 years experience in the establishment and management of research and development programs. Dr. Kasputis was the lead systems engineer for the development of synthetic forces for the DARPA STOW program and the system architect for an upgrade to the

Navy's Battle Force Tactical Trainer. His previous positions include Technical Director of the Undersea Warfare Directorate of Techmatics, Inc., Director, Science and Technology, Signal Corporation, Technical Director of the Navy's Fixed Distributed System, Deputy Program Manager of the Navy's second generation signal processor, and the Advanced Technology Officer for Undersea Surveillance Systems.. His email and web addresses are <kasputis@visitech.com> and <www. visitech.com>.

HENRY C. NG is the Head of the Visualization and Computing Systems Section of the Advanced Information Technology branch in Naval Research Laboratory and is in charge of advanced simulation and virtual environment technology development. He has been actively involved in simulation and modeling for over twenty years. Prior to joining NRL in 1996, he was the Head of the Simulation and Modeling branch of the Warfare Analysis Department of Naval Surface Warfare Center Dahlgren Division (NSWCDD) in White Oak, Maryland, where he specialized in computer simulation and modeling, broad studies of Naval warfare, and the tradeoffs among systems and forces. He was instrumental in the design and development of the Surface Warfare Analysis Laboratory at NSWCDD and was the principal architect of a large-scale sea, space, and land battle force level simulation model known as MARS (Multi-warfare Assessment and Research System). In addition, Henry was a member of the Technical Support Team to support DMSO in developing High Level Architecture during 1994 –1996. His email and web addresses are <ng@ait.nrl.navy.mil> and <www. ait.nrl.navy.mil>.