Proceedings of the 2011 Winter Simulation Conference
S. Jain, R.R. Creasey, J. Himmelspach, K.P. White, and M. Fu, eds.

TOWARDS A METHODOLOGICAL APPROACH TO IDENTIFY FUTURE M&S STANDARD NEEDS

Andreas Tolk

Old Dominion University
Engineering Management & Systems Engineering
241 Kaufman Hall
Norfolk, VA 23529, USA

Osman Balci

Virginia Tech
Department of Computer Science
3160B Torgersen Hall, MC 0106
Blacksburg, VA 24061, USA

Saikou Y. Diallo

Virginia Modeling Analysis & Simulation Center
Old Dominion University, 1030 University Blvd
Suffolk, VA 23435, USA

Paul A. Fishwick

University of Florida
Digital Arts and Sciences CISE Department
Gainesville, FL 32611, USA

Xiaolin Hu

Georgia State University
Computer Science Department
Atlanta, GA 30303, USA

Margaret Loper

Georgia Tech Research Institute
Information & Communications Laboratory
Atlanta, GA 30318, USA

Mikel D. Petty

University of Alabama in Huntsville
301 Sparkman Drive, Shelby Center 144
Huntsville, AL 35899, USA

Paul F. Reynolds Jr.

University of Virginia
151 Engineer's Way; P.O. Box 400740
Charlottesville, VA 22901, USA

Hessam Sarjoughian

Arizona State University
Center for Integrative Modeling and Simulation
Tempe, AZ 85271, USA

Bernard P. Zeigler

RTSync Corp.
11900 Parklawn Dr. Suite 130
Rockville, MD 20852, USA

ABSTRACT

Although Modeling and Simulation is successfully applied for several decades, the community only established a handful of M&S specific standards. Although the standards were applied enabling worldwide distributed simulation applications, in particular in the training application domain of military simulation systems, the general success of M&S standard efforts and their potential for general applicability has been debated repeatedly during several conferences and workshop. This collection of position statements discusses related questions, such as, "What makes M&S special that we need M&S standards," "Are M&S standards truly different from Software Engineering Standards," and "What metrics can be used to measure M&S standard success," and tries to contribute to establishing a methodological approach to identify

future M&S standard needs. These position statements have been contributed in preparation of a panel discussion and edited for the supporting proceedings.

1 INTRODUCTION

When approaching the question of developing a methodological approach to identify future M&S standards, a couple of questions arise immediately, such as:

- What makes M&S standards special (if they are indeed special)?
- What categories of M&S standards are necessary?
- What phases of the M&S life cycle are supported?
- What in M&S should be standardized, and what not?
- Can we plan for a successful standard (or do they just happen)?
- Are there metrics that can help?

Internationally recognized experts with experience in Modeling and Simulation (M&S) as well as in standardization activities were asked to contribute to a panel discussion on these and related topics. Part of these efforts is driven by experience, some was derived from funded research on this topic conducted in response to a task articulated by the US Congress: "What standardization activities are needed to better support the M&S industry?"

A general look at successful standards reveals that three requirements need to be fulfilled in order to enable a successful standard: the approach must be valuable, desirable, and reasonable. Figure 1 shows these three pillars for a successful standard.

Figure 1: Requirements for successful standards

- *Valuable* deals with the need for economic incentives. If the development of a standard does not contribute to making developments and applications faster, cheaper, or better, it will not be accepted. The return of investment for a significant number of stakeholders must be obvious. If, e.g., a company has a monopoly in a good solution protected as intellectual property, why should they share their knowledge by making the solution a potentially open standard? If, however, a group of industry partners build a consortium to establish a competition, they may use an open standards to increase their overall market value by bringing new partners in via this standard.
- *Desirable* describes the need to reach the critical mass. A very good solution for a problem that is not yet recognized by a significant part of the community of practice to be a real problem will not stick. Very often, the time for good ideas is simply not there yet. The graphical user interfaces of the early Apple computer and other features of its Local Integrated Software Architecture – better known as Apple Lisa – are examples for this syndrome: only several years after the solutions

were provided the need for these advanced concepts was recognized and often reinvented before standards helped to support easier integratability of components.

- *Reasonable* introduces academic rigor. The solution proposed for standardization must be academically sound, aligned with current research, and must be technically mature. Many standardization organizations are therefore requiring that the feasibility demonstration in form of a prototype based on the recommended standard be a part of the standardization effort.

If one of these pillars is missing, the success of the standardization effort is doubtful. In his essay on the "Law of Standards," John Sowa (2004) observes the following: *"What has consistently failed are the 'proactive' attempts to design new systems from scratch that are declared to be standard before anyone has had a chance to implement them, test them, use them, and live with them."* Instead, such attempts did often lead to the development of much easier de facto standards. Sowa (2004) gives several examples that could be observed in the information technology world, ranging from operation systems to programming languages. While many arguments can be made if these close relations really exist, they all show that the workforce not only needs to understand the problem, they will also go – similar to following Occam's Razor idea – for the easiest and simplest solution to solve this problem.

This panel discussion to be conducted during the Winter Simulation Conference 2011 shall help to present constraints and research results in support of establishing a research agenda in support of a methodological approach to identify future M&S standard needs. Some of the authors of these contributions and position papers participated in a series of workshops conducted on behalf of the US Congress and facilitated by the US Modeling and Simulation Coordination Office (MSCO), as described by Collins et al. (2010). However, we are still in the research phase to better understand the challenge of M&S standardization. Others draw from several years of experience in this and related domains. The following sections present related ideas and propose solutions.

- Tolk focuses on the question "What makes M&S special?" and identifies two factors: the different roles of simulation that need to be supported, and the different interoperation layers that can be addressed by standards.
- Fishwick deals with cultural issues. He concludes that before addressing the technical maturity of solution, a change of culture may be needed that is more directed at value of the ideas of sharing within a common and broader M&S community.
- While the intuitive understanding in the community is that a standard is a commonly agreed solution to an existing problem, Diallo introduces the idea of identifying problem situations that are exposing a new set of challenges.
- Balci draws the attention of the community to the challenges in standardization of M&S life cycle processes that needs to be addressed in future activities.
- Using their experiences with DEVS, Sarjoughian, Zeigler, and Hu show the need for simulation, modeling, and domain-specific standards.
- Based on experiences in a current study, Petty documents efforts in defining metrics for successful standards.
- Loper reports from one of the larger preparation efforts to identify standards supporting the coupling of life systems with virtual simulators and constructive simulations.
- Reynolds focuses on some limits of standards that are rooted in the computational nature of simulation systems as well as supporting standards.

2 WHAT MAKES M&S SPECIAL? (TOLK)

When shifting the general view to the more specific challenges of M&S, the different application domains depicted in Figure 2 and the role of M&S may define what can and should be standardized. Reynolds (2008) distinguishes two major roles for M&S: Using simulation to solve problems by providing knowledge, and using simulation to gain insight by supporting understanding.

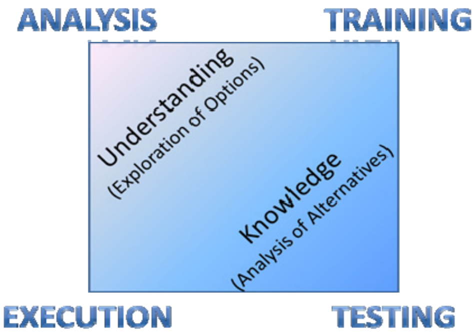

Figure 2: Application domains and M&S roles

If the simulation system represents established and validated knowledge in the form of executable theories, it allows for a systematic evaluation of alternatives. The simulation system becomes a knowledge base that represents known facts about the truth. The objects, processes, and relations behave accurate enough to represent the real system. This role represents the classical view on M&S: an accurate simulation of a real system that behaves in accordance with the underlying requirements and observations. In particular physics-based models fall into this category.

Not so the new application domain of human social cultural and behavioral (HSCB) modeling (Tolk et al. 2010). Several alternative hypotheses coexist without clear evidence of superiority. Instead of a clear and unambiguous representation of one common truth, the simulation systems represent interpretations in the light of the supporting theory. Instead of evaluating alternatives all following one common view, simulations represent clearly different options and provide the basis for exploratory analysis of consequences of these options. A better known example can be the different weather models that are used to make forecasts when hurricanes approach: each simulation system produces a projected paths, and the common understanding of all forecasts – the map that shows the projected paths – allows to explore options and consequences.

While standards for physics-based models and other examples that support an accepted common theory on how to deal with related problems make perfect sense, standards for models routed in interpretivism may exclude valuable options. When simulation systems are used to test equipment, the provided environment must behave exactly as expected by the test developers. Validated and verified systems are essential in this context. When conducting analyses or experimentation on the other hand, we are actually interested in evaluating new options and behavior that may not even have a reference systems in the real world. Simulations are used to gain insight in the expected behavior of complex systems. Validation and verification are in many cases not even realistic options and need to be replaced with plausibility evaluations. However, this observation should not be an excuse not to conduct validation and verification where it is possible. If, e.g., new doctrine is evaluated in the military domain, the weapon models used should be validated and verified; if a new treatment procedure in medical simulation is modeled, the effect models of treatment phases must represent reality, etc. Training and support of real operations during their execution normally utilize both roles of simulation in support of fulfilling their tasks. Of additional interest is that the role of M&S in the lifecycle can change.

This leads to the second point that shall be made in this section. While many members of the M&S community of practice see M&S as a special field of software engineering, M&S is not just another domain to use software. As stated by Hester and Tolk (2010): *"While modeling is the process of abstracting, theorizing, and capturing the resulting concepts and relations in a conceptual model, simulation is the process of specifying, implementing, and executing this model. Modeling resides on the abstraction level, whereas simulation resides on the implementation level. Simulation systems are model-based implementations. Whether or not it is possible to merge two simulation systems in collaborative support of user re-*

quirements not only depends on the integratability of the underlying networks and the interoperability of the simulation implementations, but also on the composability of the underlying models." Software engineering focuses on integratability and interoperability, but modeling requires the alignment for composability. As a model is a purposeful abstraction and simplification of a perception of reality created in support of conducting a special task, like answering a research question or supporting a training event, standardization seems to be very difficult: if we standardize a model – or parts thereof – we also standardize a solution, and that may be counterproductive to the creative process of modeling.

It is recommended to think in layers representing these ideas, such as the three categories originally recommended by Page, Briggs, and Tufarolo (2004) and further specified by Tolk (2009):

- *Integratability* contends with the physical/technical realms of connections between systems, which include hardware and firmware, protocols, networks, etc. Hardware standards are already successfully applied in this category.
- *Interoperability* contends with the software and implementation details of interoperations; this includes exchange of data elements via interfaces, the use of middleware, mapping to common information exchange models, etc. Software engineering standards can help here. Also, current M&S standards, such as IEEE1278 and IEEE1516, focus on this category.
- *Composability* contends with the alignment of issues on the modeling level. The underlying models are purposeful abstractions of reality used for the conceptualization being implemented by the resulting systems. As stated before: these models are the reality for the simulation. Tolk et al. (2011) observe that the conceptualization of the referent system replaces the real world referent. Best practices and guidelines can help here, but are not specified with the necessary rigor of engineering methods yet.

In summary, successful interoperation of solutions requires integratability of infrastructures, interoperability of systems, and composability of models. Successful standards for interoperable solutions must address all three categories. While the M&S community understands the problems in the categories of integratability and interoperability, many of them shared in the broader environment of network and software engineering – which also ensures mature solutions and economic incentives, the conceptual level of composability is still not addressed sufficiently and unique to M&S (King 2009).

Understanding the different roles of simulation and the layered nature of M&S will support addressing standardization issues in a methodological structure, reflecting roles and targeted interoperation category, with particular emphasis on composability, as this is the interoperation layer special to M&S.

3 CULTURAL ISSUES REGARDING STANDARDIZATION (FISHWICK)

The process of standardization within M&S is fundamentally a cultural one. A culture is a social product defined as a set of norms established and nourished by a set of individuals. These individuals come together in groups with a perceived need to better communicate with one another either using a common language or set of formal procedures. There are different forms that standardization may assume, and each form is based on how the M&S field is organized. For example, we might standardize a dynamic system model in terms of either its syntax or semantics. For syntax, the cultural goal is one of a common *look and feel* to the model definition; a mathematical model will employ the same number of variables and overall functional form. A visual model will use commonly defined graphical icons and perhaps a graph grammar to ensure its coherence among individual examples.

In either situation, the concept of model is one rooted in language (Fishwick 1995, Fishwick 2007). For semantics, we would attempt to ensure that models of a specific form behave in the same way regardless of computational platform. Given that syntax and semantics are both critical sub-components of language theory, if we are to standardize, we should be considering both simultaneously. Slightly more flexible, and pragmatic, definitions of standards could be organized around specific types of application software. If everyone were to use GPSS to craft models and perform simulations, this could be the basis for a way to standardize within M&S. For popular software, this type of thinking is fairly commonplacescientists using MATLAB (2011) represent a cultural collective organized around a consumer product that performs well in the marketplace.

Andrew Tanenbaum is credited with the oft-heard phrase "*The good thing about standards is that there are so many to choose from.*" This quote gives rise to questions of the plurality of standards, and leads to the questions of where standards may lead within M&S if we are to look at related fields, such as computer programming languages, or indeed, natural languages such as Chinese and English. For both natural and artificial languages, it is generally assumed that these languages follow a growth-decay curve not unlike those found in biological natural selection. There are efforts to standardize within specific cultures, and some languages eventually emerge on an endangered species list, while other languages seem to grow without abatement.

Some cultures are influenced from the top and others from the bottom. In politics, we might consider a top-down approach to be authoritarian or dictatorial; however, our standards organizations usually have some element of top-down structure if only to manage and organize rather than to direct. If we consider the early emphasis on the Distributed Interactive Simulation (DIS, IEEE1278) standard (Neyland 1997), and the evolutionary branch of the High Level Architecture (HLA, IEEE1516) (Kuhl, Weatherly, and Dahmann 1999; Fujimoto 2000), these standards were strongly encouraged, and funded, by the Department of Defense (DoD). These standards yielded a rich set of protocols for distributed simulations, and with DoD backing, the standards were widely employed in industry. All branches of the federal government have played key roles in top-down standards formation. The only downside is when the funding runs out. If there is no continued top-down "push" for an M&S standard, it may wither. In 1980s, the DoD mandated the use of a computer programming language, Ada, which became an ANSI standard. Despite this backing, Ada is not a language that enjoys mass popularity today. Even though Ada is not directly related to the M&S field, there are lessons that might be considered, one of which being that the top-down approach is not always successful in the long run. On the positive side, a top-down approach can be successful if a self-sustaining community results over the long haul, well beyond the startup phase. A bottom-approach approach to standards development is more chaotic, but more natural: someone, or some group, creates a modeling approach and others find themselves attracted to it. Petri nets (Peterson 1981) are one of many examples of this phenomenon. Communities of scholars found themselves drawn to the Petri net modeling approach or perhaps to the corresponding visual diagrams. This resulted in a cultural movement that began in the early 1960s and continues to grow.

4 MOVING FROM REACTIVE TO PROACTIVE STANDARDS AND STANDARDS MANAGEMENT IN MODELING AND SIMULATION (DIALLO)

There is an intuitive understanding that a standard is a commonly agreed solution to an existing problem. This understanding assumes the existence of a well defined problem for which there is a solution. However, it is important to note that in most cases this is not true as we are not dealing with problems but with problem situations.

Problem situations are problems for which there is no agreement on the nature of the problem or whether there is even a problem (Vennix 1996). The process of determining where a standard is needed necessarily involves at a minimum the transition from a problem situation to a problem. In general, the context in which a standard exist is depicted in Figure 3. While the problem situation is the top layer in this figure, it does not indicate an order or sequence. The process depicted can be top-down, bottom-up or inside out. The only requirement is consistency across the layers. For the sake of discussion, let us start with the problem situation:

- *From problem situation to problem:* The transition from situation to problem is a social and cultural activity driven by individuals and organizations as described by Fishwick. It is important to note that stakeholders have to agree whether there is a problem and if so what is the nature of the problem or the problem space. It is essential to ensure a sufficient level of consensus at this level in order to bound the problem space such that it reflects the agreed upon worldview. As a simple example many stakeholders can look at a situation where multiple systems have to interoperate.

After several discussions they might agree that there are two problems, namely how to initialize the systems consistently and how to make them interoperable during run time.

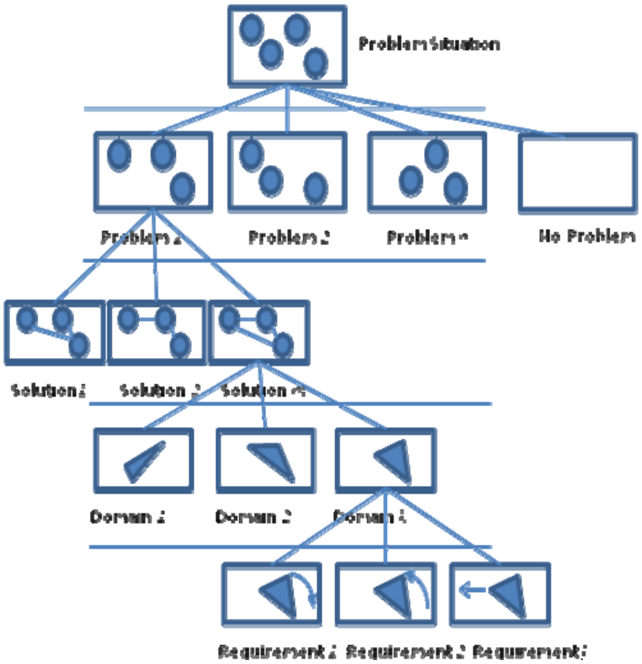

Figure 3: Standards in The Context of Problem Situations

- *From problem to solution:* Once a problem is well defined and bounded, there might be a large number of solutions to select from. If the problem is common enough and/or commonly encountered, it is very likely that solutions already exist and the standardization process reduces to selecting one of them. However, it is possible that even if there is an agreement on the problem, the conclusion is not to standardize a solution or simply not to bother solving the problem for one reason or another (resources, maturity of existing solutions, etc.). In keeping with the example, the group might decide that interoperability during run time is worth solving but in light of the resources available initialization will be solved ad hoc or at a later date.
- *From solution to domain:* A domain is a generalization of a community of interest (military, medical, transportation, Command and Control, etc.). A standard solution often applies to a domain and usually this domain is directly mappable to the problem space associated with a problem situation. A solution can apply to one or more domains and in general one has to be careful to understand the domain of applicability of a standard before contemplating its reuse in another domain. Staying with our example, the solution that is standardized for run time interoperability might be designed to support the interoperability of simulations in the military domain and more specifically the interoperability of combat simulations.
- *From domain to requirements:* In this case, each domain has a set of requirements that defines whether a solution is applicable or not. The standard might be applicable given one set of requirements and completely inadequate given another. Each application of a standard should be evaluated on a case by case basis and in most cases, more than one standard is needed to fulfill all the requirements of a domain. To finish with the example, interoperability of combat simulations in the military domain must support several requirements one of which is the ability to compute and exchange the effects of an engagement. The interoperability of Command and Control (C2) systems with combat simulation systems can probably reuse the standard described here but it would have to be adapted to support the requirements of C2 systems for instance.

As stated before, this process can be viewed as bottom up or top down. In general, a standard lives in the quintuple of problem situation, problem, solution, domain and requirement. In terms of M&S and M&S standards, it means that a standard is a solution to a problem, not the solution to a problem situation which is the area of interest of M&S. In other words, a problem is a modeling question and a standard is one of the possible solutions to that question. As noted earlier, a standard is always associated with a worldview shaped by the quintuple in which it lives which means that by the very nature of M&S, we are bound to have a multitude of solutions for a given problem situation and not an end all be all standard that solves all of the possible problems that can be derived from a problem situation. Consequently, current and future standards must be modular and be able to work together as a cohesive whole. They must be developed and managed as piece-parts of a overarching solution to a problem situation. This is especially true for language based standards (XML-based standards) which are more and more prevalent. For this family of standards, the recommendation is to start from an ontology of the problem situation that can be refined until it becomes an agreed upon problem. A language can then be generated as potential solutions for aspects of the problem. The semantic rules representing the requirements of each domain can be captured separately by another language to express the context in which the standard is applicable.

5 CHALLENGES IN STANDARDIZATION OF M&S LIFE CYCLE PROCESSES (BALCI)

A life cycle for Modeling and Simulation (M&S) is defined as a framework for organization of the processes, work products, quality assurance activities, and project management activities required to develop, use, maintain, and reuse an M&S application from birth to retirement (Balci 2011). A *process* is defined to refer to a set of activities, actions, and tasks within the life cycle. Balci (2011) presents a life cycle for M&S and describes more than 20 life cycle processes including requirements engineering, conceptual modeling, architecting, design, and certification.

Certainly, not every life cycle process qualifies to have a Standard. Some may have a Best Practice, Recommended Practice, or Guide/Guidebook. We define these terms below.

- *M&S Process Standard:* An authoritative and formal specification of an M&S process, which is substantiated or supported by documentary evidence and accepted by most authorities in the M&S field.
- *M&S Process Best Practice:* The definition of an M&S process that has proven to provide the best results based on the consensus opinion in the M&S field.
- *M&S Process Recommended Practice:* The definition of an M&S process that is recommended by an organization or society.
- *M&S Process Guide / Guidebook:* Tutorial information or instruction on how to conduct an M&S process.

The use of the above terminology is inconsistent in the published literature. Many Standards exist when in fact they are Best Practices or Recommended Practices.

We face many technical, managerial, and organizational challenges in developing M&S Standards including the following:

1. A Standard is created by using a complex set of activities as outlined below:
    a) Research and drafting of a Standard
    b) Consensus development in M&S community
    c) Approval and declaration of the Standard
    d) Publication of the Standard
    e) Application of the Standard by M&S developers
    f) Accreditation of M&S developers
    g) Certification of M&S applications created under a Standard
2. A Standard can be developed only under the leadership of a society or organization, e.g., DoD, IEEE, ISO, NATO, NIST, SISO.

3. Effective leadership by a society or organization is required to develop Standards by establishing M&S community consensus on a solution to a commonly encountered problem.
4. Development of a Standard, Best Practice, Recommended Practice or Guide must be considered for a particular M&S life cycle process.
5. A Standard should be created in such a way that it does not prevent innovation.
6. A Standard, Best Practice, Recommended Practice or Guide must be developed to be applicable for all areas (types) of M&S described by Balci et al. (2011). Creating a Standard to be applicable for all types of M&S poses significant technical challenges.
7. What is dictated by the phrase "The wonderful thing about Standards is that there are so many of them to choose from!" must be avoided.
8. Standards age due to technological advancements and therefore require periodic updates. Management of the evolution and maintenance of a Standard is known to be very challenging.

Future M&S standardization must not only address these issue, the M&S life cycle processes will also guide future M&S standard development.

6 DEVS STANDARDS AT SYNTACTIC, SEMANTIC, AND PRAGMATIC LEVELS (SARJOUGHIAN, ZEIGLER, AND HU)

Modeling and simulation (M&S) standardization efforts have been underway since 1980s. Standardization efforts have primarily focused on simulation interoperability (Wainer and Mosterman 2011). Recently, standards targeted at the levels of generic and domain-specific models have been proposed (Sarjoughian and Chen 2011). Interest in relating M&S standards to external standards such as those of Service Oriented Architecture (SOA) (Sarjoughian et al. 2008) and Open Geospatial Consortium (OGC) has been expressed as well.

It is useful to consider a coordinated set of standards at the syntactic, semantic, and pragmatic levels under the DEVS formalism and framework (Zeigler and Hammonds 2007). Coordinated development of these standards would help address well known challenges in the M&S world that independent development of separate standards would not be capable of. For example, use of a standardized simulation tool can help increase composability, reuse, and creditability of models at the same time. We, therefore, propose developing a coordinated set of standards at (i) *Syntax Level:* simulation interoperability standard using DEVS simulation protocol, (ii) *Semantics Level:* generic modeling standard using DEVS model specification, and (iii) *Pragmatics Level:* domain-specific modeling standard based on application domains which may also have their own standards

We use the term *simulation system* as it is commonly used to designate a simulation component or federate in a distributed simulation. We use this term in the sense that the underlying assumptions and constraints used in building simulation systems must be properly aligned to assure meaningful results (Davis and Anderson 2004, Muguira and Tolk 2006).

A *simulation interoperability standard* should enable simulation systems to be federated to execute together under a middleware providing specific time management and data exchange services (IEEE 2010). This requires defining interface signatures that the middleware expects from both services. The standard must provide a class of simulation systems for which the resulting simulation would be demonstrably correct. To achieve these needs, the DEVS simulation standard which employs the DEVS simulation protocol (Zeigler, Praehofer, Kim, 2000) is proposed for time and data management. The simulation protocol is provably correct for models that are specified in the DEVS formalism.

The benefits of a simulation interoperability standard include:

- A class of simulation systems exists for which the resulting hierarchical I/O behavior can be guaranteed to be syntactically correct.
- Internal functions of simulation systems can be treated proprietary (i.e., black boxes) with only their standardized I/O operations exposed.
- Simulation systems, as web services (Seo and Zeigler 2009), could be discoverable and composable to achieve a desired behavior to the extent that their I/O behaviors are well characterized.

The limitations of a simulation standard include that verification is limited as there is no guarantee the resulting behavior is correct, the validation is limited as there is no guarantee that resulting behavior is the one desired, and the reuse is limited in granularity to the simulation system as a black box. A modeling standard would address some of these deficiencies.

A *modeling standard* provides a formal syntax and semantics for simulation models. The internals of simulation systems can be identified and claims made on the structure and behavior of a real-world or referent system. A DEVS-based standard would provide a large (universal for dynamic systems) class of models to which the simulation interoperability standard applies (Sarjoughian and Chen 2011). Separate and compatible DEVS-based modeling, i.e., DEVS formalism, and simulation, i.e., DEVS protocol, standards offer a basis for developing generic DEVS modeling and simulation tools and benefit the process of building and using simulation systems. Benefits of a modeling standard include:

- The internals of simulation systems can be exposed to the degree enabled by the standard.
- Tools can perform syntactic and semantic checking on model specifications to improve verification and validation.
- Mappings can translate from one implementation language to another allowing more flexibility in implementation and finer granularity reuse and sharing.

Limits of a modeling standard include that it is insufficient to directly represent domain knowledge. By itself, it cannot account for interoperable and efficient simulation execution. Domain-specific modeling standards would help to address some of these deficiencies.

Domain knowledge must be included in models in order to be of practical use. To achieve this, *domain-specific modeling standards* are needed. Furthermore, modeling standards for standardized application domains, e.g., SOA-compliant DEVS (Sarjoughian et al. 2008), can be developed. These serve a key role since standardized application-domain knowledge is standardized from the modeling and simulation perspective. Developing such standards as extensions of the DEVS modeling standard would in effect provide a significant start toward standards at the pragmatic level where the ultimate alignment of constraints and assumptions of simulation systems must be aligned to achieve meaningful results.

Benefits of a DEVS-based domain-specific modeling standard include:

- The standard can account for domain-specific data types, functions, logical, and physical structures of systems.
- Standards can be specialized for external (non-simulation) standards (i.e., develop domain-specific model libraries).
- Standards can support developing simulation profiles consistent with domain-specific application standards.

Limits of a domain-specific modeling standard include that the standard cannot guarantee consistency among a family of model abstractions in a given application domain, and the standardized domain-specific applications may not necessarily be compatible with each other although there would be better prospects that they would be developed in a coordinated manner as being based on the underlying DEVS modeling standard.

Combination of standardizations that are based on a theoretical modeling and simulation have the potential to improve carrying out each of the facets of the M&S Life Cycle (Balci 2011). They can help developing robust, scalable, and efficient simulation systems while furthering their usage and credibility through unified verification, validation, and accreditation. Treating the syntactic, semantic, and pragmatic levels independently has advantages, perhaps easing adoption through separate development activities. However, employing the DEVS formalism and framework, can achieve a coordinated set of standards with critical benefits to support the complete M&S Life Cycle.

7 CORRELATION OF CHARACTERIZING ATTRIBUTES AND SUCCESS IN MILITARY M&S STANDARDS (PETTY)

A crucial enabling factor in the success of defense-related M&S has been the development and use of standards. Interoperability standards (e.g., DIS, TENA, and HLA), natural environment standards (e.g., SEDRIS), simulation development process standards (e.g., FEDEP), and many others have all made contributions to enhancing the interoperability, reusability, and capability of defense-related M&S systems. The technical capabilities of these standards are important predictors of their success. However, the governance structures and processes and other non-technical characteristics of the various standards have also affected their acceptance and utilization and ultimately their success and impact.

An initial study was conducted to identify possible correlations between characterizing attributes of military M&S standards and the success of those standards. A total of 22 standards in 9 categories were studied and 10 attributes of those standards were identified and evaluated. The attributes were name, category, status, year, type, form, governance type, governance formality, and technical specificity. Of special interest were the latter two; governance formality, defined as "degree to which the process of setting and changing the standard is controlled by formally prescribed processes," and technical specificity, defined as "degree to which the standard defines or provides content which is implementable or executable as written," were conjectured to positively correlate with the success of a standard. Values for these two attributes were defined on a 1–5 scale, with higher values indicating more formality or specificity respectively. Table 1 lists the standards studied and a subset of their attributes.

Table 1. M&S standards studied.

Name	Category	Governance type	Governance formality	Technical specificity
SIMNET	Distributed simulation	Closed	1	4
ALSP	Distributed simulation	Architecture management group	3	4
DIS	Distributed simulation	Standards body	5	3
HLA	Distributed simulation	Standards body	5	4
TENA	Distributed simulation	Architecture management group	3	5
XMSF	Distributed simulation	Architecture management group	2	3
MILES	Live training	Closed	1	4
CTIA	Live training	Architecture management group	3	4
RPR FOM	Object modeling	Standards body	5	4
BOM	Object modeling	Standards body	5	3
DIS Enumerations	Enumerations	Standards body	5	3
UML	Conceptual modeling	Architecture management group	3	2
DoDAF	Conceptual modeling	Architecture management group	3	3
SDIS	Synthetic environment	Closed	1	4
SEDRIS	Synthetic environment	Standards body	5	4
NFDD	Synthetic environment	Standards body	4	3
FEDEP	Simulation development	Standards body	5	2
VV&A RPG	Simulation development	Closed	2	2
VV&A Overlay	Simulation development	Standards body	5	2
DSEEP	Simulation development	Standards body	5	2
MSDL	Scenario definition	Standards body	5	3
C-BML	Command and control	Standards body	5	3

The standards' success was assessed by two groups of standards experts, totaling 39 persons. The first group (18 persons) were selected for their known expertise by the study author; the second group (21 persons) attended a workshop on M&S standards organized by Old Dominion University. The experts used a Likert-type scale to assess the success of each standard; the success scale values were: Very Unsuccessful (VU), Somewhat Unsuccessful (SU), Neither Unsuccessful Nor Successful (NUNS), Somewhat Successful (SS), and Very Successful (VS).

The standards' attribute values for governance formality and technical specificity were examined for correlation with the experts' assessments of standards' success. Conventional correlation statistics (e.g., Pearson's correlation coefficient) were not calculated because converting the discrete Likert assessment values into numerical scalars was considered methodologically questionable. Instead, categorical or qualitative correlation was tested by defining a band of corresponding values for each attribute as correlating.

Tables 2 and 3 summarize the results for the 22 standards. The green portions of the tables show values considered to correlate and the red portions show those that do not correlate. For 16 of the 22 standards, governance formality was found to correlate with standards success. For 14 of the 22 standards, technical specificity was found to correlate with standards success.

Table 2. Correlation of governance formality and success in 22 military M&S standards.

	1	2	3	4	5
VS	🟥 1	🟥	🟥 1	🟩	🟩 4
SS	🟥 1	🟥 1	🟩 3	🟩	🟩 6
NUNS	🟥 1	🟩 1	🟩 1	🟩 1	🟥 1
SU	🟩	🟩	🟩	🟥	🟥
VU	🟩	🟩	🟥	🟥	🟥

🟩 Correlated	**16**
🟥 Non-correlated	**6**
Total	22

Table 3. Correlation of technical specificity and success in 22 military M&S standards.

	1	2	3	4	5
VS	🟥	🟥 1	🟥 2	🟩 2	🟩 1
SS	🟥	🟥 4	🟩 3	🟩 3	🟩 1
NUNS	🟥	🟩	🟩 4	🟩	🟥 1
SU	🟩	🟩	🟩	🟥	🟥
VU	🟩	🟩	🟥 1	🟥	🟥

🟩 Correlated	**14**
🟥 Non-correlated	**8**
Total	22

Although it cannot be claimed that this approach can easily be generalized based on the currently limited experiences, it seems plausible to assume so. In any case, such metrics are necessary to measure success or failure of standardization efforts to support management decisions.

8 COMPARISON OF STANDARDS MANAGEMENT PROCESSES (LOPER)

A number of distributed simulation architectures are commonly used today. Each was developed by specific user communities and each owes much of its success to well defined standards. Unfortunately, live, virtual, and constructive (LVC) federates that choose different architectures can't natively interoperate. An overarching study was conducted in 2008 called LVC Architecture Roadmap (LVCAR) to define a proposed "way ahead" for improved interoperability across the major distributed simulation architectures and protocols. One component of the LVCAR study dealt with standards development, including the associated standards organizations and standards development processes that would best meet the needs of the broader LVC distributed simulation community.

The methodology applied in the standards study is shown in Figure 4. It took the existing LVC distributed simulation standards, characterized their current state, and defined an "idealized" model against which they could be compared. The standards study began by examining the various types of standards and products developed by the LVC architectures, the organizations responsible for developing those standards (commercial and government), process attributes used to maintain and evolve standards, and the compliance certification approaches used by each architecture.

The next step in the study was to characterize the vision state of future LVC standards evolution and management. To do this, several questions had to be addressed, including whether to use a commercial or a government standards approach, how to balance the need for stable standards with the need for timely evolution, and how to make the standards easily available to the M&S community. These questions resulted in a set of desirable attributes for future LVC standards. By comparing the desirable attributes with the existing organizations and processes in use today, the standards study team was able to identify the gaps that need to be addressed in order to meet the needs of LVC standards development.

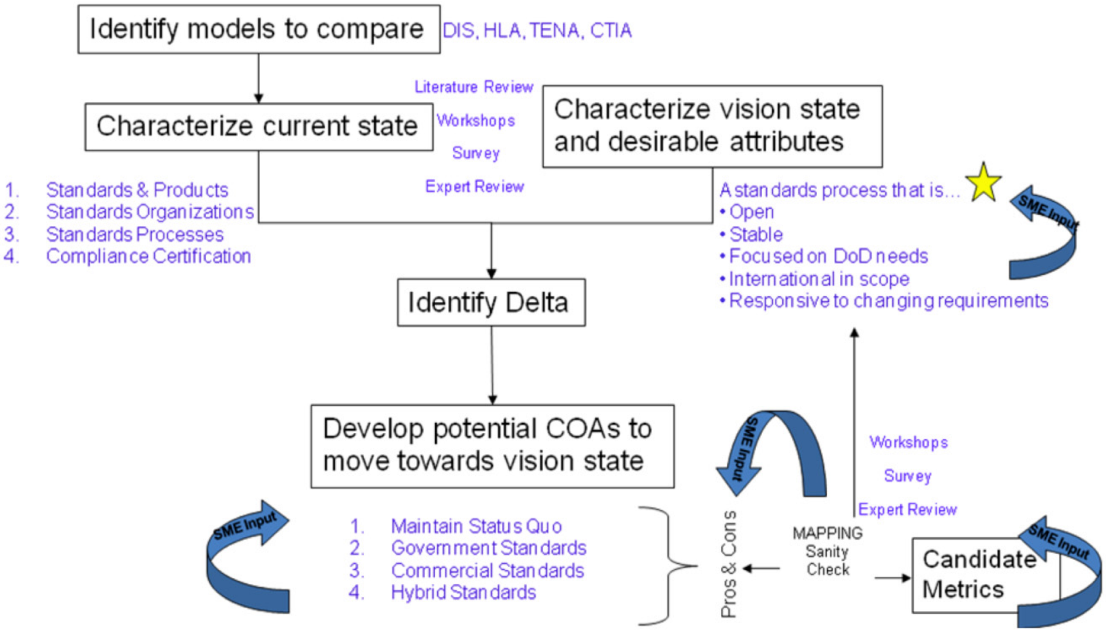

Figure 4: Analytic framework for standards evolution and management

Based on the vision state characterization and the analysis to identify gaps in existing organizations and processes, a set of courses of action (COA) were developed to characterize a potential solution space for LVC standards evolution and management:

- COA 1: Maintain Status Quo.
- COA 2: Government Standards Management Approach.
- COA 3: Commercial Standards Management Approach.
- COA 4: Hybrid Standards Management Approach.

The pros and cons of each COA were analyzed, and recommendations about future LVC standards development organizations, standards processes, and compliance certification were developed. Based on the analysis and subsequent pruning of the possible strategies for the standards dimension, the standards study team believed that *COA 4: Hybrid Standards Management Approach* was the best standardization approach for future LVC architectures. In order to realize this COA, the following recommendations were developed to address the standards management and evolution aspects of the LVC Roadmap. These recommendations included:

- Engage the Simulation Interoperability Standards Organization (SISO) and the broader LVC standards community
- Make IEEE standards more accessible to the LVC community
- Coordinate activities and fund participation in commercial standards development groups
- Increase the sphere of influence in SISO
- Develop an evolutionary growth path for LVC standards
- Develop a hybrid compliance certification process

Since this study concluded, several of these recommendations have been implemented. For example, all active members of SISO have access to the IEEE M&S standards that were developed under the SISO standards activity committee (including the Distributed Interactive Simulation (DIS) and High Level Architecture (HLA) series of standards). Details about the standards study were documented in a final report (Loper and Cutts 2008) and can be found in the M&SCO online library.

9 CONCEPTUAL AND COMPUTATIONAL LIMITS FOR M&S STANDARDS (REYNOLDS)

The utility of standards for informing design processes and engineering practices can be seen in an abundance of examples. For example, modern societies rely heavily on common standards for weight, distance and time. Consequently, there is significant appeal to extending a standards-driven process to domains in which, unfortunately, the undesirable influences of *complexity*, *uncertainty*, and *uncomputability* play a growing role. The modern computer programmer understands the limits well: just because a program meets all of the syntactic standards enforced by a comprehensive, type checking compiler does not mean the same program makes the least bit of sense for its target application. Electrical engineers working in a highly standardized world of components understand similar limits as well. There are provable limits to what can be tested for conformance and there are limits to the utility of rules set down in the face of unknowns, ambiguities and uncertainties. Here, the standards development process meets its match.

Standards development should begin with identification of a *mission* and of a *reference model*. Mission defines context and scope, and a reference model provides a common worldview, comprising terminology, structure, world objects and processes describing how objects interact. For example, a mission could be to establish accurate, reliable and reproducible measurements of weight for objects in a common spatial frame of reference, say Earthborne. The reference model could be the set of all weighable objects, all relevant ways they can interact with their world, and all methods for weighing the objects.

Standards, themselves, comprise prescriptive and proscriptive rules and often a set of conformance tests. When the mission and reference model are largely unambiguous and uncontested, a standards development process can generally proceed smoothly. In the object weight example, standards would identify methods and conformance tests for establishing accurate, reliable and reproducible measurements of weight of Earthborne objects. A sufficiently unambiguous mission and reference model can be established in this example and thus enable creation of standards ensuring reliable, accurate and reproducible methods for weighing objects.

A standards development process is much more likely to suffer or fail when the mission and/or the reference model are ambiguous. Ambiguity is a natural artifact in a standards development process when it encounters challenges here named “the heavy C’s”: complexity, uncertainty and uncomputability. My thesis is that increased presence of any part of the heavy C’s in any part of the standards development process (mission, reference model, standards) diminishes the likelihood of a useful outcome. As a corollary, modeling and simulation standards of any extent (e.g., those envisioned for model reuse and interoperability) are challenging to realize because of the common presence of the heavy C’s in that which we wish to model and in related components of the simulation development process (mission, reference model and standards).

Consider, as a case in point, models of human behavior and the mission to make such models reusable and interoperable. It is possible to develop standards and test for conformance at a simple level, for example a standard that human models communicate using a common language. However, a more meaningful standard, say, that a listening human model must always understand as a speaking model intended, encounters heavy C’s. The portion of the reference model relating to human interactions is complex and rife with uncertainty, making the meaning of a common understanding difficult to define. Additionally, a conformance test for whether two humans share a common understanding is uncomputable (Test for equivalence in two *formal* languages is uncomputable. Natural language only makes things worse.) Similar conclusions occur regarding interoperability standards for economic, environmental, systems biology and internet commerce models. Complexity, uncertainty and uncomputability prevent identification of standards that can guarantee the kinds of interoperability and reusability users seek.

Those times when standards committees forge ahead in the face of the heavy C's to define a set of standards for, say, model interoperability (for interesting models), the heavy C's persist! Consider a complex reference model, for example our model of communicating humans. Complexity in the reference model can lead to

- Omissions of standards due to a failure to appreciate a need,
- Complexity of the standards,
- Use of abstraction as a method for concealing complexity, and
- Conflict among committee members over the design of the standards.

These in turn can lead to ambiguity and/or compromise in standards development, and abandonment of standards or splintering of standards development efforts. Ambiguity, abandonment, splintering and compromise can lead to uncomputability of standards conformance tests, user uncertainty about the meaning of standards and increased costs in both the standards development process, and in subsequent use of the standards. In sum, start with complexity in a reference model and end with uncomputability, uncertainty and increased costs in the standards development process (and their subsequent use). One can build similar chains that begin with uncertainty in standards or uncomputability of conformance that lead to uncertainty regarding the utility of a reference model and/or related standards, with eventual abandonment of the standards, or splintering of standards development efforts, leading to increased costs and uncertainty about the standards process.

The dismal outcomes characterized here are not meant to deter standards development efforts. Many standards efforts produce useful results. However, those useful results tend to occur when the reference model is well understood and widely agreed upon, or when standards committees deal with heavy C's by embracing modest expectations about what can be standardized. Standards development efforts are limited by the complexity and uncertainty associated with a reference model, the uncomputability of conformance to many desirable standards and the recurring appearance of heavy C's when standards committees become too ambitious. Participants in a well-managed standards development process recognize these limitations and perceive themselves as part of a discovery process for reducing complexity and uncertainty and coping with the limits of uncomputability.

10 SUMMARY

This collection of position statements is the compilation of inputs from M&S experts with significant standardization experiences and shows some of the highlights and the variety of ongoing standardization efforts. However, the list can neither be complete nor exclusive. There are many other worthwhile standardization activities going on. As limited as the list is, it shows the trend that a more methodological approach is needed. It also shows that the focus may have to shift from simulation interoperability to the often neglected activity, processes, and products of the modeling part of M&S, as many challenges require a solution on the conceptual level, not just temporary on-the-spot solutions on the implementation level. However, standards are needed for the simulation level, the modeling level, and also for the application level. These efforts have to be well orchestrated, while reducing complexity and uncertainty and coping with the limits of uncomputability, and metrics are needed to measure success. This requires a common theory to align the methods that will drive standardized solutions, and may require a shift in our culture as well.

ACKNOWLEDGMENTS

Significant parts of the work presented here are funded by or prepared in support of a federally funded three year study entitled 'Standards in Modeling and Simulation' which is being led by the Virginia Modeling Analysis and Simulation Center, Old Dominion University, Suffolk, VA.

REFERENCES

Balci, O. 2011. "A Life Cycle for Modeling and Simulation." *Technical Report*, Department of Computer Science, Virginia Tech, Blacksburg, VA.

Balci, O., J. D. Arthur, and W. F. Ormsby. 2011. "Achieving Reusability and Composability with a Simulation Conceptual Model." *Journal of Simulation* 5: 157-165, doi:10.1057/jos.2011.7.

Collins, A. J., S. Y. Diallo, S. R. Sherfey, A. Tolk, C. D. Turnitsa, M. D. Petty, and E. Weisel. 2010. "Standards in Modeling and Simulation: The Next Ten Years." In *Proceedings of the MODSIM World Conference and Expo,* Hampton, VA, October 13-15.

Davis, P. K., and R. H. Anderson. 2004. "Improving the Composability of DoD Models and Simulations." *Journal of Defense Modeling and Simulation* 1(1):5-17.

Fishwick, P. A. 1995. *Simulation Model Design and Execution: Building Digital Worlds*. Prentice Hall, Inc.

Fishwick, P. A. 2007. "The Languages of Dynamic System Modeling." In *Handbook on Dynamic System Modeling*, edited by P. A. Fishwick, 1-10. CRC Press.

Fujimoto, R. M. 2000. *Parallel and Distributed Computing Systems.* Wiley Interscience.

Hester, P. T., and A. Tolk (2010). "Applying Methods of the M&S Spectrum for Complex Systems Engineering." In *Proceedings of the Emerging Applications of M&S in Industry and Academia (EAIA) Spring Simulation Multiconference,* 17-24. April 11-15, Orlando, FL.

IEEE. 2010. *IEEE 1516-2010 Standard for Modeling and Simulation (M&S) High Level Architecture (HLA)*. IEEE Standards Association. Accessed May 1. standards.ieee.org/findstds/standard/1516-2010.html.

King, R. D. 2009. "On the Role of Assertions for Conceptual Modeling as Enablers of Composable Simulation Solutions." Ph.D. Dissertation, Batten College of Engineering, Old Dominion University, Norfolk, VA.

Kuhl, F., R. Weatherly, and J. Dahmann. 1999. *Creating Computer Simulation Systems: An Introduction to the High Level Architecture.* Prentice Hall, Inc.

Loper, M. L., and D. Cutts. 2008. *Live Virtual Constructive Architecture Roadmap (LVCAR) Comparative Analysis of Standards Management.* Final Report, M&S CO Project No. 06OC-TR-001.

MATLAB. 2011. Accessed June 10, 2011. http://www.mathworks.com/products/matlab.

Muguira, J., and A. Tolk. 2006. "Applying a Methodology to identify Structural Variances in Interoperations." *Journal of Defense Modeling and Simulation* 3(2):77-93.

Neyland, D. L. 1997. *Virtual Combat: A Guide to Distributed Interactive Simulation.* Stackpole Books.

Page, E. H., R. Briggs, and J. A. Tufarolo. 2004. "Toward a Family of Maturity Models for the Simulation Interconnection Problem." In *Proceedings of the Simulation Interoperability Workshop*, April 18-23, Arlington, VA. IEEE CS Press.

Peterson, J. 1981. *Petri Net Theory and the Modeling of Systems.* Prentice Hall, Inc.

Reynolds, P. F. 2008. "The Role of Modeling and Simulation." In *Principles of Modeling and Simulation: A Multidisciplinary Approach,* edited by J. A. Sokolowski and C. M. Banks, 25-43. John Wiley & Sons.

Sarjoughian, H. S., and Y. Chen. 2011. "Standardizing DEVS Models: An Endogenous Standpoint." In *Proceedings of the Spring Simulation Multi-Conference*, DEVS Symposium, 1-9. Boston, MA.

Sarjoughian, H. S., S. Kim, M. Ramaswamy, and S. Yau. 2008. "A SOA-DEVS Modeling Framework for Service-Oriented Software System Simulation." In *Proceedings of the 2008 Winter Simulation Conference,* edited by S. J. Mason, R. R. Hill, L. Mönch, O. Rose, T. Jefferson, and J. W. Fowler, 845-853. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Seo, C., and B. P. Zeigler. 2009. "Interoperability between DEVS Simulators using Service Oriented Architecture and DEVS Namespace." In *Proceedings of the Spring Simulation Conference*, San Diego, CA.

Sowa, J. F. 2004. The Law of Standards. Annotated Reprint Email to the Committee on Shared Reusable Knowledge Bases (SRKB). Accessed June 10, 2011. http://www.jfsowa.com/computer/standard.htm.

Tolk, A. 2009. "Interoperability and Composability." In *Principles of Modeling and Simulation: A Multidisciplinary Approach,* edited by J. A. Sokolowski, and C. M. Banks, 403-433. John Wiley & Sons.

Tolk, A., P. K. Davis, W. Huiskamp, H. Schaub, G. L. Klein, and J. A. Wall. 2010. "Challenges of Human, Social, Cultural, and Behavioral Modeling (HSCB): How to Approach them Systematically?" In *Proceedings of the 2010 Winter Simulation Conference,* edited by B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yücesan, 912-924. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Tolk, A., S. Y. Diallo, J. J. Padilla, and C. D. Turnitsa. 2011. "How is M&S Interoperability different from other Interoperability Domains?" In *Proceedings of the Spring Simulation Interoperability Workshop*, Boston, MA. IEEE CS Press.

Vennix J. A. M. 1996. *Group Model Building: Facilitating Team Learning Using System Dynamics*. Chichester: Wiley.

Wainer, G., and P. Mosterman. 2011. *Discrete-Event Modeling and Simulation: Theory and Applications.* Taylor and Francis.

Zeigler, B. P., and P. Hammonds. 2007. *Modeling & Simulation-Based Data Engineering: Introducing Pragmatics into Ontologies for Net-Centric Information Exchange*. Academic Press.

Zeigler, B. P., H. Praehofer, and T. G. Kim. 2000. *Theory of Modeling and Simulation: Integrating Discrete Event and Continuous Complex Dynamic Systems.* Academic Press.

AUTHOR BIOGRAPHIES

ANDREAS TOLK is a Professor for Engineering Management and Systems Engineering of Old Dominion University. He is also a Senior Research Scientist at the Virginia Modeling Analysis and Simulation Center. He holds a M.S. in Computer Science (1988) and a Ph.D. in Computer Science and Applied Operations Research (1995), both from the University of the Federal Armed Forces of Germany in Munich. He is senior member of IEEE and SCS and member of ACM, ASEM, MORS, NDIA, and SISO. His area of expertise is interoperability and composability and modeling and simulation based systems engineering. His e-mail address is atolk@odu.edu.

OSMAN BALCI is a Professor of Computer Science at Virginia Polytechnic Institute and State University (Virginia Tech). He received B.S. and M.S. degrees from Boğaziçi University (Istanbul) in 1975 and 1977, and M.S. and Ph.D. degrees from Syracuse University in 1978 and 1981. Dr. Balci currently serves as an Area Editor of *ACM Transactions on Modeling and Computer Simulation*, Modeling and Simulation (M&S) Category Editor of *ACM Computing Reviews*, and Editor-in-Chief of *ACM SIGSIM M&S Knowledge Repository*. His current areas of expertise center on software engineering, software/system architecting, and M&S. His e-mail and web addresses are balci@vt.edu and http://manta.cs.vt.edu/balci.

SAIKOU Y. DIALLO is Research Assistant Professor at the Virginia Modeling, Analysis and Simulation Center at Old Dominion University. He received his M.S and Ph.D. in Modeling and Simulation from Old Dominion University. His research interests are formal approaches to M&S interoperability and the application of semantic web tools and methods in support of distributed, heterogeneous simulation. His email address is sdiallo@odu.edu.

PAUL A. FISHWICK is Professor of Computer and Information Science and Engineering at the University of Florida. He received his Ph.D. from University of Pennsylvania. Fishwick's research interests are in modeling methodology, aesthetic computing, and the use of virtual world technology for modeling and simulation. He is a Fellow of the Society of Modeling and Simulation International, and recently edited the *CRC Handbook on Dynamic System Modeling* (2007). He served as General Chair of the 2000 Winter Simulation Conference in Orlando, Florida. His email is fishwick@cise.ufl.edu.

XIAOLIN HU is an Associate Professor in the Computer Science Department at Georgia State University, Atlanta, Georgia. He received his Ph.D. degree from the University of Arizona, M.S. degree from Chinese Academy of Sciences, and B.S. degree from Beijing Institute of Technology in 2004, 1999, and 1996 respectively. His research interests include modeling and simulation theory and application, agent and multi-agent systems, and complex systems science. Dr. Hu is a National Science Foundation (NSF) CAREER Award recipient. His e-mail address is xhu@cs.gsu.edu.

MARGARET LOPER is the Chief Scientist for the Information & Communications Laboratory at the Georgia Tech Research Institute. She holds a Ph.D. in Computer Science from the Georgia Institute of Technology, a M.S. in Computer Engineering from the University of Central Florida, and a B.S. In Electrical Engineering from Clemson University. Margaret has twenty-five years of experience in M&S and her technical focus is on parallel and distributed simulation. She is a member of ACM SIGSIM, SCS, SISO and IEEE. Her research contributions are in the areas of temporal synchronization, simulation testing, and simulation communication protocols. Her email address is margaret.loper@gtri.gatech.edu.

MIKEL D. PETTY is Director of the University of Alabama in Huntsville's Center for Modeling, Simulation, and Analysis. He received a Ph.D. in Computer Science from the University of Central Florida in 1997. Dr. Petty has worked in modeling and simulation research and development since 1990 in areas that include simulation interoperability and composability, human behavior modeling, multi-resolution simulation, and applications of theory to simulation. His email address is pettym@uah.edu.

PAUL F. REYNOLDS, JR. is a Professor of Computer Science at the University of Virginia. He has conducted research in Modeling and Simulation for over 30 years, and has published on a variety of topics including parallel and distributed simulation, multi-resolution modeling, and simulation. He is a Plank-Holder in the DoD High Level Architecture. His email address is reynolds@virginia.edu.

HESSAM S. SARJOUGHIAN is an Associate Professor of Computer Science in the School of Computing, Informatics, and Decision Systems Engineering at Arizona State University and Co-Director of the Arizona Center for Integrative Modeling and Simulation. His research focuses on multi-formalism model composability, system network co-design, collaborative modeling, and domain-specific modeling. His e-mail address is hss@asu.edu.

BERNARD P. ZEIGLER is Chief Scientist for RTSync Corp. Zeigler has been chief architect for simulation-based automated testing of net-centric IT systems with DoD's Joint Interoperability Test Command as well as for automated model composition for the Department of Homeland Security. He is internationally known for his foundational text *Theory of Modeling and Simulation*, second edition (Academic Press, 2000). He was named Fellow of the IEEE in recognition of his contributions to the theory of discrete event simulation. His e-mail address is zeigler@rtsync.com.