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PANEL DISCUSSION: WHAT MAKES GOOD RESEARCH IN MODELING AND SIMULATION: SUSTAINING THE GROWTH AND VITALITY OF THE M&S DISCIPLINE

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ABSTRACT

The aim of this panel session is to promote discussion on emergent challenges and the need for advancements in the theory, methodology, applications, education in M&S. The changing landscape in science and engineering (e.g., industrial and defense application, medicine, predictive homeland security, energy and environment) introduces new types of problems and challenges into the M&S domain. In light of these emergent needs how can M&S stay relevant as new critical fields such as global climate change mitigation, energy restructuring, genetic engineering impacts on society and universal health care emerge and come into prominence? Surely the systems point of view and the tools that M&S brings to the table are key to these new directions. So, what are the critical issues and challenges facing M&S community in the face of change and need for rapid discovery?

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1 INTRODUCTION

The members of the panel (organized by Levent Yilmaz) are: Paul Davis, Paul Fishwick, Xiaolin Hu, John Miller, Tuncer I. Ören, Paul Reynolds, Hessam Sarjoughian, and Andreas Tolk. The position statements of the panel members are given separately. However, it is noteworthy that the visions underlying the statements provided by panel members share specific common perceptions regarding the research directions to meet the challenges posed by the emergent landscape in simulation-based science and engineering. Levent Yilmaz and Paul Reynolds point out the significance of addressing ambiguity, deep uncertainty, and unpredictability revolving around the analysis of complex adaptive systems, including but not limited to policy analysis for disease spread, crisis and disaster management, and conflict resolution. Paul Davis acknowledges the same problem and suggests ***exploratory analysis*** as a strategy to address various forms of uncertainty. Levent Yilmaz suggests advancing the theory and methodology of M&S to tackle the problem by promoting *autonomic simulation systems* concept as a coherent framework that has the potential to address ambiguity and uncertainty in creative problem solving.. Another issue raised by Paul Reynolds involves improvement of *efficiency of model development*, which has been also considered indirectly in the position statements of Paul Davis and Hessam Sarjoughian via explicit discussion on the need for the improvement of *composability*, as well as transparency, understandability, and modularity of simulation models.

Both Paul Fishwick and Paul Davis recognize the significance of *model variety* and the utility of integrated and compatible families of models that capture different aspects of the same phenomena while enabling alternative modalities of interaction for different stakeholders.

John Miller considers the interdisciplinary nature of M&S to examine the pros and cons of providing institutional support to sustain the *M&S discipline*. He also observes and analyzes various M&S educational programs to draw a conclusion on the characteristics of successful initiatives. Andreas Tolk's position statement emphasizes the importance of explicit characterization and documentation of the core competencies of M&S to sustain it as a discipline. He also points out the importance of avoiding the pitfalls of focusing exclusively on M&S applications, which may have undesirable consequences of stagnation and decline in relevance of M&S to emergent problems, for which conventional M&S methodologies may fail to respond effectively. By recognizing the role of education in supporting the vitality of the M\&S profession and its discipline, Xiaolin Hu, suggest proper enculturation of apprentices or students via strong comprehensive educational programs based on core foundations to facilitate growth and continuity of the discipline. Finally, Tuncer I. Ören lays out a comprehensive framework that delineates desirable activities and research to sustain the growth, relevance, and vitality of the M&S profession and its discipline.

2 COMPUTATIONAL CREATIVITY: TOWARD AUTONOMIC INTROSPECTIVE SIMULATION SYSTEMS (LEVENT YILMAZ)

While M&S has been widely used in engineering and computational sciences to facilitate empirical insight, optimization, prediction, and experimentation, the role of simulation in supporting creativity received less attention. The position advocated in this statement is based on the observation that supporting creative problem solving requires new novel M&S methodologies that take the characteristics of creative problem solving into account. Normative uses of simulation focuses mostly on convergent thinking, while creativity requires what-if analysis that incorporates not only convergent but also divergent thinking by addressing ambiguity in problem formulation and model finding, as well as uncertainty and variability. The challenge is to find out means to advance the theory and methodology of M&S to provide computational aids to encourage scientific and engineering creativity. One possible direction is to understand the role of ambiguity and uncertainty in creative problem solving, while courting creative success through judicious tradeoffs between constraints and flexibility.

Figure 1 presents the dimensions depicting possible problem characteristics in creative problem solving. While the variability in parameters of interest in simulation exercises is well captured by probability distributions and experiment design, uncertainty that pertains to lack of knowledge in a given problem representation is difficult to represent using tools of statistical modeling and analysis. Methods such as Exploratory Modeling (Bankes 1993) and Exploratory Analysis (Davis 1988) are useful in dealing with deep uncertainty.

Ambiguity, which is more difficult to address, involves lack of knowledge pertaining to function, structure, behavior, and use of problem solving algorithms. In this case, characteristics of a situation in which the set of relevant variables, as well as their functional relationships are in need of determination.

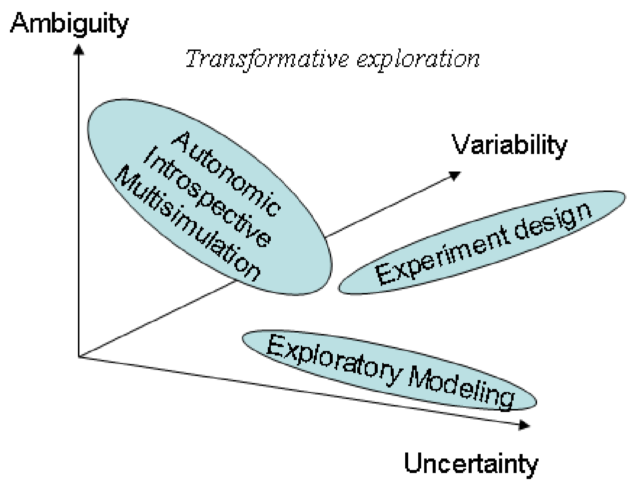

Figure 1: Problem Characteristics in Problem Solving

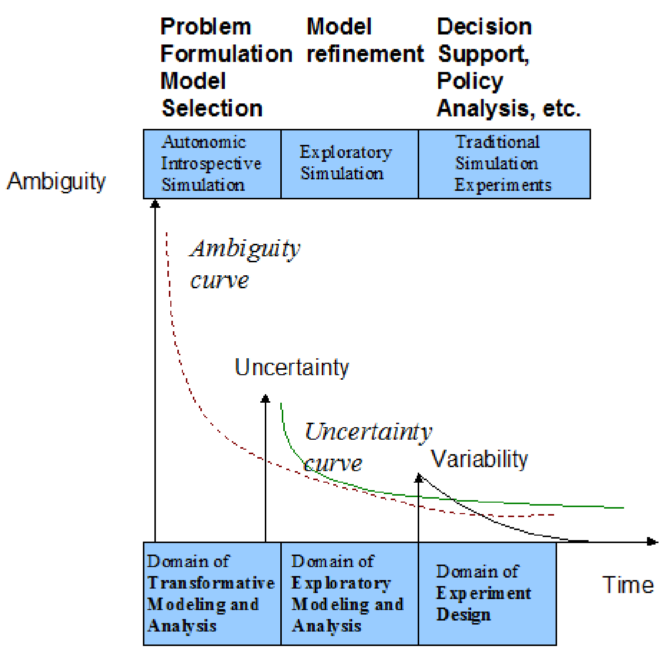

Figure 2: Transformative Analysis with Autonomic Introspective Simulation

During foresight and problem finding phases of the broader creative complex problem solving process, ambiguity pervades. During these phases, creative leap is more likely to ensue through not only searching the problem space, but also opportunistic alteration of problem representation as new data and observations are gathered. Creative processes often involve a broad idea generation phase. followed by a selection/evaluation stage. Since creativity requires novel yet useful solutions, appropriate tradeoffs between constraints and flexibility is needed over the problem representation to make creative leaps. Hence, exploratory and *transformative* modeling and analysis should co-exist at this important stage of problem solving (see Figure 2). Ambiguity often occurs due to shifting, ill-defined, and competing goals. Model variety (see Paul Fishwick's position statement) and exploratory analysis (see Paul Davis' statement) with such varieties suggest directions to resolve uncertainties, once ambiguity is reduced to manageable levels. Here, I would like to focus on ambiguity and suggest that proper advances in M&S has the potential to provide a basis for computational discovery aids to encourage scientific and engineering creativity, which manifests itself in various situations, including the following:

- The nature of the problem may change as the simulation unfolds. Initial parameters, as well as models can be irrelevant under emergent conditions. Relevant models need to be identified and instantiated to continue exploration.
- Our knowledge about the problem being studied may not be captured by any single model or experiment.
- Dealing with ambiguity is paramount to analyzing complex evolving phenomena. Adaptivity in simulations and scenarios is necessary to deal with emergent conditions for evolving systems in a flexible manner.

The lack of knowledge pertaining to the environment, as well as the problem may invalidate the current model, as it may not have been designed a priori to cope of with unexpected and unforeseen changes. For such problems, a simulation system with the following characteristics will prove useful.

- Be aware of not only the status of its own components, but also the resources it uses and the context in which it is used.
- Be able to sense, perceive, and understand the environmental conditions to notice change and/or interactive user feedback so that its structure/behavior can be tailored and fine tuned to respond in ways that improve its functions (e.g., novelty).
- Be able to plan and facilitate change by altering its own configuration and status via dynamic update and composition so that (re)selected or emergent goals can be satisfied.

By leveraging the principles and techniques from the autonomic computing paradigm in conjunction with computational intelligence mechanisms provided by agents, M&S community may start developing next generation simulation theories, methodologies, and proof-of-concepts under the umbrella of Autonomic Simulation Systems to cope with ambiguity, as well as uncertainty.

In summary, for problems with inherent ambiguity, the use of predictive authoritative, as the lack of knowledge or uncertainty underlying the basic assumptions of these models makes them useless when they contradict the knowledge gleaned later in the process. Simulation systems that are capable of identifying strategies that exhibit robust behavior across alternative assumptions are likely to provide more confidence in the recommendations inferred from simulation studies. The effectiveness of such simulation systems will rely heavily on their ability to start behaving robustly across large number of plausible hypotheses, constraints, and propositions, followed by optimization for a narrow and limited range of conditions constrained by the knowledge gleaned during the simulation process. Applications for which Autonomic Introspective Simulation Systems will prove useful include in developing creativity support tools scientific problem solving, online symbiotic simulation, real-time decision support in asymmetric and irregular environments, adaptive experience management for training, crisis and disaster management, and dynamic data-driven application systems.

3 UNCERTAINTY AND RISK ANALYSIS IN M&S (PAUL REYNOLDS)

Simulation has joined theory and experimentation as a primary avenue of scientific pursuit. Its use is ubiquitous. It is used to gather insight, validate models and experiments, train humans, support statistical analyses, drive computer animations, control real time processes, predict potential outcomes, test and evaluate new systems, and support what-if analyses, among others. Simulation is transforming the way researchers think and explore and the way all of us live. Armed with a broader range of studies, students, analysts and decision makers gain insight, become better informed and reduce risk in their analyses and decisions.

Given its breadth of application, widespread impact, and broad set of implementation issues, simulation shares many of the research challenges faced in general purpose software research. There are software engineering questions related to simulation reuse, composition, validity and interaction with humans. There are systems questions related to its use on various computing platforms. There are graphics and HCI questions related to its interface with humans. Beyond mainstream computer science issues, simulation research is touched by every application field (many!) in which it is applied. Questions related to uncertainty and risk analysis must be addressed because simulations are used so widely to support decision analysis and policymaking. There are philosophical questions relating to meaning and causation that remain unexplored. The set of questions modern use of simulation engenders is broad and deep.

As with most quality research paradigms, good and creative simulation research begins with the identification of impactful issues, the generation of promising ideas to address them and the rigorous, open exploration of their validity and utility. My research group has identified *model uncertainty* and *developer efficiency* as most important issues. Results of modern disease spread studies reveal the effects of uncertainty. Epidemiologists have addressed the question of government level actions and reactions regarding the spread of smallpox and bird flu. Should a comprehensive vaccination program be initiated? How and to what degree should infected individuals be isolated, and for how long? The range of simulationists' answers to these questions is broad and full of conflict. Elderd (2006) has shown analytically that just four among hundreds of critical independent variables in these studies induce extreme sensitivity in model predictions, leading to serious conflict regarding remedial approaches involving billions of dollars and millions of people. Our answer? Design and implement the first simulation language to support expression of a scientist's understanding of model uncertainty, quantitatively.

Developer efficiency is an equally challenging topic. The time simulationist's spend adapting their simulations for reuse, composition and ultimate validation is huge! Anyone researcher in simulation technology knows many fellow researchers who spend years of their lives tinkering with simulations to gain insight and to meet requirements the modeled phenomena dictate. Can we make this process any more efficient? My research group has been pursuing methods for increasing the efficiency of insight acquisition, but there are many other possible avenues: better simulation languages, better methods of testing simulations, better methods for gathering reliable statistics on model output, and others.

Good and creative research? Opportunities abound in simulation, partly because the field is so broad and partly because there are so many unanswered questions! In a jar full of stones, the best way to empty it is to choose the biggest stones first; then the smaller stones can be removed by the fistful. Find the big issues, find promising ways to attack them, and charge ahead!

4 MODULAR AND COMPOSABLE SIMULATION (PAUL DAVIS)

Among the characteristics of good and creative research in M&S are:

1. Addressing seriously troublesome problems (rather than just finding new clever ways to do old things). Such problems include:

- Improving transparency and comprehensibility (some refer to explanation)
- Improving the ability to conceive, publish, and transform modularly developed models in a varie-

ty of context--without requiring commonality of environment or even language.

- Composability
- Improving the ability to construct, test, and use multiresolution models (in the sense of my definition of MRM), recognizing that such MRM systems will almost always be mere approximations of reality and that finding the appropriate approximations is fundamental to the effort.
- Improving the ability to conduct broad, synoptic, "exploratory analysis" (in the sense that I use that term in my own writing routinely in applications.

2. Moving toward more universal sets of representations and automated translations, and doing so in a way that ties into developments by people who may think of themselves as software engineers or design engineers, rather than M&S practitioners.
3. Moving toward foundational discussions and related non proprietary tools that can be understood and used by multiple disciplines.

5 COMPOSABILITY and MULTI-FORMALISM (HESSAM SARJOUGHIAN)

Simulation tools are commonly used for engineering and operations of numerous systems. Most successful simulations in use can be considered to be grounded in monolithic frameworks where structures and behaviors of a system are formulated using a single theory with various extensions. In many other instances, some combination of simulation interoperability with partial model composability is used. Yet, in other situations, concepts and methods from computer science, and in particular software engineering, have resulted in what might be called pseudo modeling and simulation notions and tools.

The above difficulties have led researchers in pursuit of developing frameworks that can characterize complexity and scale of systems using disparate modeling formalisms (Davis and Anderson 2004; Mosterman and Vangheluwe 2002). Toward this goal, hybrid frameworks classified as super-, meta-, and poly- formalism have been proposed (Sarjoughian 2006). This is because practitioners, engineers, and scientists find use of a mono-formalism framework unacceptable. A major reason is that a single formalism severely limits conceptualization of model abstractions that are best represented in different formalisms. Lack of composable model semantics across disparate formalisms is a root cause for the difficulties that are experienced across modeling and simulation lifecycle phases including conceptual modeling, formal model specification, simulation model implementation, simulation execution, and experimentation. For example, for simulating a realistic supply-chain system, it is crucial to not only use discrete event simulation and optimization models, but also to model their interactions in a separate formalism. Without accounting for the syntactic and semantic differences of two disparate modeling formalisms, the mapping of domain knowledge into models is ad-hoc and generally results in simulations that are difficult to develop and use.

Use of multiple modeling and simulation approaches and tools where each has its own theoretical underpinning and pragmatic utilization require research in visual modeling, domain-specific model libraries, and persistence model storage. Overcoming these challenges can result in hybrid modeling and simulation environments that are robust, semantically expressive, computationally scalable, and accessible to relatively large classes of users. We contend that no framework or tool exists that offers visual development of generic formal models, customizable domain-specific modeling, automatic simulation code generation, flexible experimentation, run-time visualization of simulations, and maintenance of consistency in model repositories. With the realizations of such end-to-end capabilities for mono- and super-formalisms, researchers should be better positioned to tackle these kinds of problems that are radically more challenging for meta- and poly-formalism modeling and simulation frameworks.

6 MODEL VARIETY AND HUMAN INTERACTION (PAUL FISHWICK)

People build models to better understand the environment around them. Our discipline of modeling and simulation (M&S) is centered on the design, implementation, and analysis of these models. Some of the models may be of the physical scale variety, but most of them are digital and require implementation in the form of a computer program. We have a wide variety of model types, shapes, forms, and formalisms. Two problems that arise as part of our research are:

(1) our discipline is not as widely noticed and as integrated as we would prefer, and
(2) our efforts are somewhat splintered across different groups who prefer their own models and methods. Even though we may be experts in modeling as a discipline, many groups do not look to us for guidance; they have their own domain experts and modeling techniques.

If one considers the role of modeling in software engineering, for instance, there are significant movements in standardizing models (e.g., Unified Modeling Language). Is there a role for M&S in this activity? Who decides which model types are to be used in an implementation - model developers or participants who engage the models?

We may respond to these queries by using the time-tested approach of specifying requirements and then building a model to meet those requirements. This approach is still valid, but we must be wary of building a set of individual models that have narrow audiences. If one considers how we interact with a web browser, we rapidly obtain information at a variety of different levels for a topic--all the way from a sentence down to photos, videos, and possibly equations and flowcharts. To take a type of model: hurricane catastrophe risk assessment, there are many people who are interested in these models. The general public may wish to see a few sentences in natural language, or perhaps an artifact that grabs their attention as might be found in a science or art museum. A risk analyst may wish to view a high level flowchart, and the scientist wants to see the equations and FORTRAN code. The goal should be to link all of these models together not only at the formal level, but at the level of human interaction. Teaching a sixth grader how a hurricane causes damage may involve a different look-and-feel to the model than teaching a university student, or a politician. Different media may be appropriate -- videos, games, or multi-user virtual environments depending in which space the consumers are located.

It may be tempting at first to imagine building separate environments for separate people, but at some point we need to connect these different ways together to empower the user to choose the model type that they want. This issue of "who chooses" has been active in the education community for decades--is it best to learn through top-down lecturing or through bottom-up constructive exploration? The same types of questions need to be asked within an M&S framework: can we build models that connect together to support both types of learners without enforcing one modeling paradigm?

7 SHOULD M&S BECOME ITS OWN DISCIPLINE (JOHN MILLER, MARIA HYBINETTE)

What is necessary for a field to become a discipline? All academic disciplines of academic study arise from the study of philosophy established 2500 years ago by Socrates, his pupil Plato, and the father of metaphysics Aristotle. At that time one person could feasibly master all scientific knowledge. But as science grew, the corpus of knowledge expanded, and new disciplines were recognized. The rate at which new disciplines emerge corresponds roughly to the rate at which the body of scientific knowledge grows. And the breadth and depth of each discipline corresponds roughly to what one very intelligent person might master and contribute to in a career. Another way to view it is that a definition of "discipline" serves to classify the many possible directions of intellectual pursuit into reasonably sized chunks. Today we recognize many disciplines including physics, biology, psychology, and chemistry, all with their origins in Greek philosophy.

Most new disciplines established over the last few hundred years have been "incubated" by another discipline, from which they split upon reaching critical mass. The various engineering disciplines are good examples. The history of Computer Science (CS) as a discipline is different; it emerged as an interdisciplinary field at the intersection of Mathematics and Engineering. Its birth was accelerated by the Second World War, during which significant advances were made outside universities (e.g., Britain's work to crack the Enigma led by Alan Turing). After the war, universities recognized the importance of this new area, but struggled to find a place for it. At some institutions, CS was initially a component of Mathematics; at others it was a branch of Engineering (consider, for instance the departments of EECS at the University of California, Berkeley and the Massachusetts Institute of Technology).

It is worthwhile to consider the evolution of CS at Carnegie Mellon University (CMU) in particular. Their CS Department was established in 1965 as a part of the College of Science. The Department was eventually elevated to the status of "School" in 1988, which enabled it to contain its own component departments. Today, CMU's School of Computer Science houses several departments and PhD programs including: Computer Science, Robotics, HCI, Machine Learning, Language Technologies, and Software Engineering. The CMU model has been followed also at the Georgia Institute of Technology, which established a College of Computing in 1990. They now have three departments: CS, Interactive Computing, and Computational Science and Engineering. The point is that the case can be made that CS is spawning new disciplines with staying power.

In a manner similar to CS, Modeling and Simulation (M&S) has been highly interdisciplinary from its formation in the 1940's. The primary fields that support the development of new modeling and analysis techniques and methodologies are Computer Science, Industrial Engineering, Management Science, Statistics, Mathematics and Physics. Of course, many scientific and engineering disciplines, that are too numerous to list, utilize, customize and extend the techniques and methodologies developed by the primary disciplines. Given this highly interdisciplinary nature, there are likely to be advantages and disadvantages for turning M&S into its own academic discipline. Perhaps it should remain principally interdisciplinary and supported by multiple traditional academic departments. One could argue that too much of a home department mentality might reduce the vitality of the field, since without the influx of new challenges and problems to address the field may stagnate.

Once thought of as a method of last resort, simulation models are playing an increasing role due to the fact that problems are often too complex to solve by other means and that the capabilities of today's computer hardware along with advances in software tools and techniques for modeling and simulation have increased dramatically. The new experts are likely to be computer models (e.g., weather models, climate change models, economic models, network traffic models, air traffic control models, systems biology models, etc.).

Since M&S is growing in importance (Swain, 2005), there will be an increasing need for students with better training in M&S. In the past, students would get a degree in, for example, Computer Science with maybe one or two courses in M&S. They should have more than two, but more importantly, they should have the flexibility in their program to take courses from other departments to broaden their knowledge of application domains. At this point in the evolution of M&S, it may be most beneficial to establish degree programs (Crosbie 2000; Szcerbicka et al. 2000; Sarjoughian et al. 2004) as well as research groups and centers within one or more traditional academic departments. Indeed, this is the recent trend that has been taken place. The list below indicates universities that offer such programs.

- Modeling and Simulation Graduate Program, Old Dominion University.
- Interdisciplinary Graduate Programs in Modeling and Simulation, University of Central Florida.
- Master of Engineering in Modeling & Simulation Degree, Arizona State University.
- Graduate Certificate Program in Modeling and Simulation, University of Alabama, Huntsville.
- Graduate Education Program in Defense Modeling and Simulation, Modeling, Virtual Environments, and Simulation (MOVES) Institute, Naval Postgraduate School (NPS).
- Simulation Science, California State University, Chico (CSUC).

There are also programs in Computational Science that have a heavy emphasis on Modeling and Simulation, such as the Computational Science and Engineering program at the Georgia Institute of Technology.

Looking at the course offerings and core requirements in these programs, the following are common to most of them: an introductory course in Modeling and Simulation, a course in Discrete Event Simulation and a course in Continuous Systems Simulation. Since some of the entering graduate students may not have the prerequisites needed, many programs offer a migration class to quickly boost their background knowledge of Mathematics and Statistics as well as, in some instances, Programming. Several more advanced courses are also offered covering topics such as Interactive Simulation & Training, Stochastic Systems Modeling, Analysis of Simulation Experiments, HCI/Visualization in M&S, Computer Animation, Virtual Environments and Gaming, Parallel and Distributed Simulation and a project course. A course topical area cross graduate program matrix is given on the following Web page (Miller and Hybinette 2008). The matrix indicates which of these dozen courses are offered by the six graduate programs listed above. In addition to M&S courses, students should take courses from application areas within science, engineering or business.

Increasing the number of graduate programs is critical in establishing M&S at least as its own sub-discipline, yet much more is necessary. At the same time, more research centers and institutes should be established to link together researchers in multiple departments interested in M&S, as well as, create a presence that university administrations and funding agencies will become aware of. There are several examples of such centers listed in (Miller and Hybinette 2008) that could serve as models for other universities to follow. These research centers would be in a position to seek funding in two ways. They could seek funding for basic research in M&S and as components of larger grants in science and engineering. As these centers gain greater visibility, direct funding of M&S research will likely increase. Many of these centers have also created graduate programs in M&S. The two go hand in hand.

Beyond increasing the number and quality of graduate programs in M&S and research centers focusing on M&S, there are several additional factors of importance. The discrete event and continuous systems simulation communities should become more integrated. These communities have evolved largely independently, but at some point should combine forces. As has been mentioned by other authors, M&S needs more textbooks to be written. Of course, this is slowed by the chicken and egg problem. However, as more graduate programs are added, this situation should resolve itself. Modeling should be elevated. Model sharing should occur at an implementation independent, high level, much like algorithms are shared. Models should be described semantically to enhance understanding, ability to discover and compare models, improve interoperability and composability (Miller and Baramidze 2005). Finally, M&S should continue to broaden its scope and keep looking for new approaches (e.g., Web-Based Simulation, Agent-Based Simulation, Multi-Scale Modeling) as well as new application areas.

In conclusion, we believe that M&S is beginning to make the transition from a field to a discipline and that the trends of introducing new graduate programs and research centers should continue. In the not too distant future, the question of establishing mainstream academic departments of Modeling and Simulation should be seriously considered. Even then, its highly interdisciplinary nature should not be sacrificed.

8 M&S EDUCATION (XIAOLIN HU)

An equally important issue to modeling and simulation (M&S) research is the educational aspect of M&S. Successful education of M&S will not only produce the work forces needed for M&S research, but also help consolidate the state of knowledge in M&S and thus benefit the M&S community in general. In the following discussion, instead of responding to the question of "what makes good and creative M&S research", I consider a different, but certainly related topic: what makes good and effective M&S education.

It is believed that good M&S education should promote the general theory of M&S while in the meantime provide hands on experience on M&S activities. This contrasts to the misled view of many that M&S learning is simply to learn how to use fancy M&S tools (unfortunately this view is shared by many professionals too, who view M&S as a tool instead of a discipline by itself). In my opinion, such a "tool-driven" approach of teaching/learning put M&S education in a wrong focus and downplays the role of M&S as a discipline. Most simulation tools are domains specific, designed for solving problems outside the M&S field. For good reasons, they hide details about core M&S concepts such as model abstraction and simulation protocol. Thus while these tools are certainly useful for specific domains, they are ineffective, if not act against, for learning the general theory of M&S itself. It is argued that any operational environment that supports learning of the M&S concepts needs to build on top of a general modeling formalism and simulation framework, such as the Discrete Event System Specification (DEVS) (Zeigler et al. 2000). A framework like that can embody the general theory of M&S as well as leverage students to focus on the core activities of M&S using its operational environment. This is analogous to the role that UML (and its supporting environment) plays in learning of software engineering concepts. The two aspects of M&S research and education, are closely related and depend on each other. It is hoped that in this panel discussion, opinions about M&S research will inspire ideas on M&S education, and the other way around.

9 UNDERSTANDING THE CORE COMPETENCE IN M&S (ANDREAS TOLK)

This position paper makes the case that good research in M&S cannot be limited to application domains. A recognized and accepted Body of Knowledge is needed as the common ground for research efforts. The areas of modeling, simulation, analysis, visualization, and application domains have been identified as a potential hub for curriculum development as well as a basis for research. Without being rooted in such application specific core competencies of M&S, good research is not possible, as the foundation is missing.

M&S is ubiquitous. M&S is applied in a variety of domains and disciplines that can only be compared with the use of computers or statistics. Research in all scientific fields and domains utilize M&S, but what is M&S as a discipline on its own? Szcerbicka and colleagues started the formal discussions nearly a decade ago (Szczerbicka 2000). Ören is and has been actively supported by many researchers and educators in collecting contributions to a Body of Knowledge (BoK) of M&S (Ören 2005a; 2005b). Banks summarized a series of panel discussions organized as Academic Nights during the Simulation Interoperability Workshops (Banks 2006a; 2006b). This list of references is neither complete nor exclusive, but it gives an overview what activities are currently conducted in the M&S community.

What are the implications for M&S research, and what defines "good" M&S research? *Good M&S Research must be rooted in and contribute to the BoK for M&S.* If this is not the case, it is not M&S research but the application of M&S means in support of the research conducted in the applying domain, such as biology, sociology, military operations research, etc. The situation is comparable with computer science several years ago. With the rise of affordable work stations and personal computers, computation on large scale suddenly became an option for all disciplines. But the applications were not limited to the academic community. Computers were applied everywhere. This drove the need for computer experts, engineers, programmers, etc. But academia was not prepared to support the market. Many "professionals" of these days were not academically prepared, but "self-declared" experts, often only "one step beyond" the customers. One of the results was the *"software crisis"* of computer science. Only after the software crisis, the problem was publicly recognized, the BoK for computer science in general and software engineering in particular was adapted, and formal education became more or less a requirement for "serious" computer science applications. Today, nobody would call someone who programmed a handful of Java applications a computer expert or computer scientist.

However, we are facing the same challenges in M&S again. The formal education in the core competencies of M&S is not required to be accepted as an "M&S expert." The danger is that we will run into an *"M&S crisis"* comparable to the software crisis soon. Such as stable software requires software engineering, stable and reliable M&S applications require in-depth knowledge in modeling – the purposeful abstraction of reality resulting in a formal specification of this conceptualization –, simulation – the execution of a model over time, knowing the computational constraints in particular of distributed execution –, analyses – including the means of operations research, statistics, experiment planning –, and visualization – including but not limited to human-machine interfaces, etc. This knowledge must be enriched by theory and methods for validation and verification, knowledge representation, composability, and enabling mathematics.

Only these core competencies of M&S can deliver the answer to the *"grand challenges"* of M&S that are not in the focus of applied M&S research. The challenge is comparable to statistics: while everyone applies probability and accepted tests, it is the discipline of statistics that needs to produce the general means. Without formally capturing and teaching respective core knowledge in M&S, good M&S research is not possible. Good M&S research must build the core foundation; otherwise it would just remain M&S application and the term M&S discipline was not justified.

10 A FRAMEWORK FOR DESIRABLE ACTIVITIES AND RESEARCH IN M&S (TUNCER I. ÖREN)

I would like to start with the last sentence of another article Ören (2002): "Progress in any area is not possible by keeping the status quo –no matter how advanced it can be." Indeed M&S is already very advanced and is also an important–sometimes vital– enabling technology for many areas. However, we ought to continue advancing it for several reasons: (1) Consolidate and disseminate pertinent knowledge about M&S. (2) Assure requirements of professionalism. (3) Advance M&S science, methodology, and technology to continue solving problems in hundreds of traditional application areas and challenging new areas.

Position statements in this panel session cast light on several important issues. The framework offered here (which can be elaborated on and refined) may be useful in consolidating and refining the views expressed in this Panel and elsewhere to advance M&S, and also systematically monitoring the progress. Some activities would require R&D and some others would be other types of professional and dedicated activities.

My (over 100) publications, presentations, and other activities on advanced methodologies and normative views for advancements of M&S are listed at (Ören-normative views).

In the sequel, Table 1 summarizes the activities for the **consolidation** of M&S knowledge, Table 2 outlines **dissemination** of M&S knowledge, Table 3 is on the requirements of **professionalism**, Table 4 elaborates on **science, engineering, and technology** of M&S, Table 5 is on **trustworthiness, reliability,** and **quality**, and finally, Table 6 is on more challenging **applications**.

Table 2: **Dissemination** of M&S Knowledge

• (National, Regional, International) e-clearinghouse(s) of: - Resource libraries - Funding agencies, funding sources - Documents of funded research - Dissertations/theses (as sources of specialists & specialized knowledge) - Centralized dissemination of professional information (events, job market) - e-encyclopedia, e-books, M&S portals

Table 1: **Consolidation** of M&S Knowledge

• **Comprehensive view** (Big picture) of all aspects
• M&S **Body of Knowledge** (M&SBOK): Systematization of the index and preparation of a Guideline
• M&S **Dictionaries** - As inventory of M&S concepts - As systematic inventory of M&S concepts (ontology-based M&S dictionary)
• **Curriculum** development and international standardization for: - Degree programs (graduate, undergraduate) - Service programs for other disciplines - Professional development courses

Table 3: Requirements of **Professionalism**

• **Ethics**: widespread adoption & practice of Code of professional ethics (voluntary and/or require ment for individuals and/or M&S companies) • **Certification**: (voluntary and/or requirement for individuals and/or M&S companies) • **Maturity levels** of individuals and/or companies
Recognition of the M&S Discipline and Profession • US House **resolution** 487 (widespread dissemination: nationally, internationally) • **Simulation Systems Engineering** needs to be promoted • Consider **analogies** with history of dentistry & professional engineering and current status where non-simulationists doing simulation studies. • No need to be too humble (consider the use of the term "model" in art and in M&S as well as simulation-based engineering)

Table 4: Science, Engineering, and Technology of M&S

Proper **system theory based modeling and symbolic**

model processing based for simulation of complex systems Proper **simulation paradigms** and **practices** • **Model-based** simulation • **Mixed formalism** simulation • **Multisimulation** • **Concurrent** simulation • **Holonic agent simulation** for - Simulation of **coopetition** (cooperative competition) • Specification languages / environments for **interoperability** • Computer-Aided Problem Solving Environments with M&S abilities
Advanced **modeling formalisms** & **technologies** • with **abstraction** & **descriptive** power • **Theory-based** modeling formalisms for: - Variable structure models - Multimodels - Multiaspect, multistage, multiperspective, multiresolution, multiparadigm, and evolutionary modeling
Advanced **experimentation** / **scenario generation** • Automation of design & execution of Experiments as well as analyses of results

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Table 5: **Trustworthiness, reliability, and quality**

• **Built-in reliability assurance** prior to traditional validation & verification
• Proper computer-aided & computer processable **documentation** of simulation studies (including assumptions)
• **Taming**, monitoring, and assuring software agents in order for agents to behave in a trustworthy way

Table 6: **Challenging M&S Applications**

Reduce **time of simulation** (from conception to generation of alternatives for decision makers)
Formulate **new success metrics**
Applications • Use of simulation for machine **learning** • Use of **switchable understanding** in simulation (to avoid dogmatic thinking & to assure emotional intelligence) • **Proactive** system simulation • **Introspective** system simulation • Simulation of **emergent phenomena** • **Conflict management** simulation • **Security** training simulation • **Personality**, **emotions**, and **cultural backgrounds** in simulation

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