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Do We Need M&S Science?

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1. INTRODUCTION

What is Modeling and Simulation (M&S)? The question seems to be odd when featured in an article of the magazine of the Society for Modeling and Simulation. However, several recent discussions the authors had with colleagues during workshops, symposia, or simply project meetings showed that it may be worthwhile to capture some answers. The observations lead to the need for a deeper evaluation of what M&S looks like from various perspectives.

The authors of this paper come from three different backgrounds. One is a traditional computer scientist applying software engineering principles for years to write and use simulation systems. The next one has a formal education in modeling and simulation on the graduate and postgraduate level. The third author received his education from the engineering management and systems engineering perspective and is rooted in system science. Showing the viewpoints side by side may help to better understand why all three come to the conclusion that M&S Science is needed.

But what is M&S Science? Academia distinguishes traditionally between theory, methods, and solutions. Theory builds the foundation of a discipline. It collects the axioms and rules that govern the discipline. Doctoral students aiming for a philosophical doctor in a discipline are required to contribute to the body of knowledge in this realm. Methods are derived from the theory. These are a sequence of formal steps justified in the underlying theory and applicable to problems in various domains. When a method is applied in a concrete context, it delivers a solution. This taxonomy and definitions motivate the following interpretation of M&S as a discipline:

- *M&S Science* contributes to the Theory of M&S, defining the academic foundations of the discipline.
- *M&S Engineering* is rooted in Theory but looks for applicable solution patterns. The focus is general methods that can be applied in various problem domains.
- *M&S Applications* solve real world problems by focusing on solutions using M&S. Often, the solution results from applying a method, but many solutions are very problem domain specific and are derived from problem domain expertise and not from any general M&S theory or method.

In all three fields of the discipline we have experts, and their perspectives are very different as well. For M&S to remain a coherent discipline, the authors believe that it is time to recognize these differences and generate mutually supportive views instead of a potentially destructive competition.

2. M&S FROM THE COMPUTER SCIENCE PERSPECTIVE

Computer scientists know the ongoing discussion in the M&S domain quite well, as their discipline is still young and many members remember the debate regarding whether computer science is really a science. Peter J. Denning and colleagues published a series of papers coping with questions like *"Is computer science its own disci-*

pline?" [1], "*Is computer science science?*" [2] or "*Is computer engineering engineering?*" [3] The arguments in these papers brought up against computer science as a scientific discipline and computer engineering as an engineering discipline are similar to the arguments used in the current discussion against M&S being a scientific or engineering discipline, or even being a discipline at all. Without reiterating these well known arguments, the authors argue that the recognized *diversity* and *inter-disciplinarity* of M&S coupled with the *multiplicity* of application domains show the significance of the M&S discipline. The friction between different branches and application domains is often rooted in the fact that the focus lies in the M&S application realm. The experts in that case are M&S users and consumers and prefer to contribute to the theory of the problem domain, not to M&S engineering or M&S science, as it is unlikely that they will receive any academic rewards from their own community for such contributions.

Following the definition for computer science as a discipline in [1], a view on M&S science could be: The discipline of M&S is the systematic study of *modeling processes* and *simulation processes* that describe and transform *conceptualizations*. In essence M&S is the study of conceptualizations, their theory, analysis, design, efficiency, implementation, validity and verification, and application. The fundamental question underlying all of these efforts is: *What can be efficiently and meaningfully modeled and simulated?*

There are many fields in M&S that require scientific evaluation, showing the need for M&S Science. Computer science deals with computability, M&S science on the other hand, has to evaluate simulatability? One of the burning questions that link Computer Science with M&S is the trade-off between computability and sumulatibility. Simply put, if we have to limit our models to computable models to ensure the applicability of digital computer simulations what happens if we mix computable models with non computable models as we do when we mix live systems with simulated systems in common computer supported exercises for military forces.

Not all M&S experts share this view, and many do not recognize M&S as a discipline. Again, this observation is well known from computer scientists as well. One of the better known examples is Paul Graham, who wrote: *"I never liked the term 'computer science'. … Computer science is a grab bag of tenuously related areas thrown together by an accident of history, like Yugoslavia. … Perhaps one day 'computer science' will, like Yugoslavia, get broken up into its component parts. That might be a good thing. Especially if it means independence for my native land, hacking"* [4, p. 18]. Many experts in the M&S domain expressed a similar feeling towards M&S as a discipline and the need for M&S science. They perceive M&S not as a new interdisciplinary field, but as a multidisciplinary field defined by reuse of what is already out there without contributing something new.

However, in the authors' opinion, the desire for a distinctive M&S science that supports both M&S engineering and M&S applications by providing a solid theoretic foundations makes sense from the computer science perspective. It is actually perceived to be mandatory to scientifically deal with fundamental questions of M&S. Without such efforts, the validity of engineered solutions and the transfer of application knowledge between different application domains will remain guess work, and as simulation solutions are applied in many critical areas – such as defense, healthcare, transportation, and more – this is not acceptable.

3. M&S FROM THE SYSTEMS SCIENCE PERSPECTIVE

Just like M&S, Systems Science is an interdisciplinary field that seeks to understand the nature of natural and man-made systems. Also like Systems Science M&S has a strong system thinking component used to build models and simulations in a structured manner. In fact, one of the earliest theories of M&S (DEVS) comes from systems science. Further, we can go as far as to say that M&S is an evolutionary form of Systems Science as two of the main M&S paradigm, Discrete Event Simulation and System Dynamics are system-centric. The question is, where do they diverge? How is each one unique? Establishing M&S as a science requires answering three questions; namely 1) What makes M&S unique or what is its area of study 2) How does it generate knowledge and 3)? Why? Let's start by answering the last question first.

M&S as an Engineering Discipline

M&S is usually seen as an engineering discipline that groups computational tools. It is used by scientists and engineers for prediction or understanding of a phenomenon/system by its *replication*. The replication of phenomena/systems provides a great advantage to professionals across scientific/engineering areas. It allows the study of complex systems in settings that would be otherwise prohibitively expensive, unethical, or dangerous.

Consequently, the need for replication requires that M&S-based tools and practices be based in correspondence to an observed and well-bounded phenomenon/system. In this sense, M&S is highly rooted in empiricism as a way of supplanting live-experimentation with simulated-experimentation. Consequently, empirical canons of research are the most favored in M&S, especially in validity. Validity of simulations is established if the results from a simulation are *close enough* to those observed in reality.

The ideas of replication, empirical soundness, well-bounded systems are among others what have made M&S a useful engineering discipline. Largely grounded in systems science, M&S provides the ability of replicating well-bounded systems, while also relying on empirical canons of research for scientific soundness, and on computer science for computability

M&S Uniqueness

Establishing the uniqueness of a scientific discipline requires a longer explanation than one that can be provided in a few pages. The first question that comes to mind is how does one consider a discipline a science? For instance, psychology, by certain schools of thought, is not considered a science. In order to facilitate this process, we'll use four arbitrary parameters that showcase the *focus of study* of a scientific discipline and its driving *research question*. In addition, these sciences need to have *theories* that are used to drive further questions and *subareas* of study.

Table 1 Informal Factors to Categorize Uniqueness of Scientific Disciplines

	Psychology	**Biology**	**Systems Science**
Focus of study	Human behavior and mental processes	Life and living organisms	Natural and man-made systems
Main research question	What is mind?	What is life?	What is a system?
Theories/Principles	Theory of cognitive development	Theory of evolution	Principle of sub-optimization
Subareas	Clinical, behavioral, etc.	Genetics, Ecology, etc.	Systems analysis, cybernetics, etc.

The four factors presented in Table 1 provide a simple standard by which we can suggest the uniqueness of M&S as a science:

- M&S focus of study: *truth in models and simulations of a referent* (phenomenon/system we want to study). The referent can be captured through replication or through theories about the referent.
- Main question: *what is true within models and simulations?* Establishing what is true in M&S relies on either correspondence, coherence, or both depending on the modeling question. A model/simulation may or may not be truthful depending of what is being asked of it. This is an important distinction with systems science-based models that capture replicate well-bounded systems based on the premise of accessibility to that system. Whereas an M&S-based

model may reflect a theory about a system or situation from which we seek insight.

- Theories/Principles: There are few theories of M&S given that, to the opinion of the authors, M&S is a victim of its own success. By transitioning quickly from a need to a set of tools, M&S failed to cycle fully through a theory state. Theories of composability [5] and interoperability [6] have been proposed and they are M&S oriented.

- Subareas: M&S has distinct areas that have been developed separately. One area that has been developed largely by the systems science community is conceptual modeling (CM). CM relies on the need of capturing a referent in a simulation-independent format. Another area is Verification and Validation (V&V). This has been developed by many disciplines. Yet the underlying epistemology of V&V is empiricism, despite M&S being a rationalist endeavor more akin to mathematics than to physics. Composability and interoperability are the most recently developed subareas of M&S. They seek to combine models and simulations for reuse.

It is important to note that although the above mentioned subareas have been born in areas such as systems science, computer science, and software engineering they are consistently being studied under the M&S umbrella. This is especially true in the cases of composability and interoperability.

4. M&S FROM THE M&S PERSPECTIVE

The argument has been made earlier that even from the systems or computer science perspective that M&S science is needed. From an M&S perspective, "*Modeling And Simulation*" cannot be separated. *Modeling without Simulation is Systems Engineering and Simulation without Modeling is Computer Science*. M&S is an atomic structure around which Conceptual Modeling, V&V, Interoperability and Composability gravitate in a coherent way. M&S is a unique discipline that is concerned with understanding and exploring problem situations (problems whose space is not universally agreed upon).

However, one has to recognize that the state of art in M&S does not always present M&S in terms that are formal and rigorous. Furthermore, M&S approaches to problem situations are not always coherent and consistent or even repeatable. This is, in the authors' opinion, why M&S is not viewed as a science with its own theories and methodologies and why it is more prevalent as one of the engineering tools in the toolbox. The natural question that immediately arises is: If M&S is a science, what should it look like? The following reflects the authors' view. There are three main components that make M&S a unique science and shape what it should look like:

- Problem Situations: An M&S problem reflects the assumptions and constraints that went into transforming a problem situation into a problem. In general, all M&S problems are purposeful simplifications of a problem situation. Consequently truth is relative in M&S and the assignment of truth value depends entirely on the axiomatic structure imposed on the referent. Furthermore, M&S problems holistically and systemically combine natural language, mathematics and logic while also combining ontological, teleological and epistemological aspects of the situation. Natural language is required to communicate with subject matter experts or customers in order to capture the requirements and/or assumptions while mathematics and logic are needed to capture and communicate these requirements to machines when possible.
- Ontological, Teleological, and Epistemological Constraints: A problem situation can be explained in terms of structures and relationships its purpose, actual or intended and what is considered true within the situation. A model is a simplification of reality in a positivist view. In a post-positivist view, it is a purposeful simplification of a perception of a situation in order to generate a theory or an explana-

tion. A problem situation is bounded by the aforementioned constraints thus generating multiple equivalent and/or competing theories of a situation. Most often, some compromise has to be reached between the three in the form of assumptions and constraints in order to have a consistent model that represents the aspects of a problem situation that is viewed as a problem.

- Computational constraints: Some practitioners of M&S understand simulation to mean computer simulation and thus equate models to computable models or use the terms model and simulation interchangeably. However achieving a computable model requires some compromise between the richness of natural language in explaining the ontological, teleological and epistemological aspects of a model, the ability to mathematically represent a problem situation and the ability to capture the problem situation in a computable algorithm (Turing-computable). This compromise also affects earlier compromises about the nature of the problem situation. For M&S in general, since computers are limited to computable functions, they are insufficient in representing the complexity of nature, humans and their respective interactions. Consequently, we must extend the notion of simulation beyond the realm of computers in order to gain more insight into problem situations. In the military world for instance, the idea of mixing live, virtual and constructive simulations (LVC) is becoming more and more common. This is a clear recognition of the limitation of constructive simulations and the need for an extended view of simulation.

M&S must deal with problem situations within these constraints and M&S is therefore a science of compromise and trade-offs; i.e., what compromises are necessary and sufficient in order to reduce a problem situation to a problem and what is the nature of truth within that problem under the assumptions and constraints that result from the compromises. This is only possible if there is a science of M&S-not an art but a science with well defined, even formal laws, theorems and properties from which we can derive other laws theorems and properties by applying a formal reasoning apparatus.

In order to capture M&S as a science of compromise aimed at providing relative explanations of problem situations, we must provide a formalism that respects the atomicity of M&S and is open to the relative nature of truth. In essence, we need a formal way to capture the ontological, teleological and epistemological constraints of problem situations and express them logically and mathematically. As a result we will be able to not only capture the assumptions and constraints imposed on the problem situation but also evaluate the compromises that have to be made along with their consequences. This also allows us to identify what compromises have to be made between live, virtual and constructive simulations. A science of M&S is also useful in identifying conflicts when putting together models and/or simulations. Consequently, it is possible to derive a formal theory of interoperability and composability from a formal specification of M&S. A formal theory of interoperability and composability would serve as a basis for frameworks that guarantee consistency and repeatability. The same is true for V&V and Conceptual Modeling. This will help us identify existing applicable tools and identify gaps where new ones are needed. Finally an M&S science that is formal and rigorous can help identify intersections with other sciences which in turn allows for reuse of techniques, theories, methods and tools.

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