On the Epistemological, Ontological, Teleological and Methodological Currents in Modeling and Simulation: An Overview

Ipek Bozkurt, Department of Engineering Management, University of Houston Clear Lake, Houston, TX, USA
Jose J. Padilla, Virginia Modeling, Analysis & Simulation Center, Old Dominion University, Suffolk, VA, USA

ABSTRACT

Modeling and Simulation (M&S) has been used to solve problems, make decisions, and understand complex phenomena. Scholars have tried to understand and formulate the epistemic value of gained insights through models and simulations. Questions such as how insights are considered knowledge, what the tradeoff between perspectives and objectivity is, what kind of purpose models and simulations fulfill, and how M&S is used within a research methodology paradigm are a starting point of discussing the philosophical underpinnings. The epistemological, ontological, teleological and methodological (E/O/T/M) considerations of M&S is the main motivation of this paper. A comprehensive literature review on E/O/T/M considerations provides an initial roadmap to study the nature of M&S leading to the following questions: How can the authors define canons of research for M&S based on E/O/T/M? How can they define an E/O/T/M-based meta-model to characterize models and simulations? And how can the authors study validation of models and simulations based on E/O/T/M considerations?

Keywords: Epistemology, Knowledge, Modeling, Ontology, Philosophy, Simulation, Teleology

1. INTRODUCTION

Modeling and Simulation (M&S) has been used in various contexts; it has been considered to be a tool, a methodology, and a discipline. Pragmatically, the usefulness of insights obtained using M&S applications cannot be denied. However, the increasing use of M&S in numerous disciplines, such as political science, meteorology, oceanography, economics, and healthcare, among others, calls for finding what common challenges and advantages exist across these disciplines. We suggest that one way of looking
at those commonalities is by looking at E/O/T/M foundations (premises and assumptions) of the use of M&S across disciplines.

From a high-level perspective, M&S uses models to represent a phenomenon of interest and simulates these models to gain insight or to predict. Gaining insight or prediction suggests that knowledge is generated from the modeling and/or simulation activity. This knowledge-generation activity has been under deliberation on questions such as: Can simulations generate knowledge? What kind of knowledge do simulations generate? Does simulation need its own epistemology? Although these are epistemological questions, they are not separate from ontological, methodological, and teleological issues regarding the modeler’s perspective, approach, and intent. Frigg and Reiss (2009), for instance, argue that despite simulation creating parallel worlds on more ideal conditions than the “real world”, this is not unique to simulation; ergo it does not warrant a new philosophy of science. Humphreys (2009), on the other hand, states that with the introduction of computational science new issues also have arisen within the discipline of philosophy of science, namely: epistemic opacity, semantics, temporal dynamics, and practice not principle. Epistemic opacity refers to cognitive agents’ limited access to knowledge; semantics refers to how simulations are applied to real system given the detachment of simulations from reality, how computer simulations are limited by syntax of computer code, and how semantics are subsumed under that syntax; temporal dynamics refers to the temporal representations of dynamic processes involved in simulation is an essential element for philosophy of science in terms of the speed of prediction, as opposed to deduction; and finally practice, not principle, refers to how computational methods have forced researchers to differentiate between what is practically applicable, and what can only stay as principle.

As it can be inferred, the gap between simulations and reality and how it is bridged in a manner that knowledge can be established has epistemological, ontological, methodological, and teleological implications. These implications include issues such as validation (Klein & Herskovitz, 2005), simulation model formulation and characterization (Lenhard, 2007), and ultimately, whether or not simulation generates and/or applies knowledge. In order to gain insight in these issues, we propose to look into how models and simulations can be characterized using E/O/T/M considerations. Turnitsa, Padilla, and Tolk (2010) have made an introduction into this proposition by overlapping E/O/T considerations with the semiotic triangle idea introduced by Ogden and Richards (1923). Their model is modified in this paper, as seen in Figure 1.

The following discussion also sets the grounds for the definitions of “object”, “model” and “simulation”, which will be used throughout the paper. The starting point of M&S is an object/phenomenon that can be real or imaginary. The model then becomes a conceptualization of this object. In other words, a model should capture the understanding of an object/referent/problem and facilitate its computer implementation. As such, a model can have many forms ranging from the informal to the formal: mental models, UML diagrams, ontologies, or mathematical equations. It is noted that the model does not have to be computable, but it should facilitate its computer implementation. This position is consistent with Robinson (2008) and Zeigler, Praehofer, and Kim (2000). This position of model as a conceptualization of an object/problem/ can also be traced back to Systems Science (Mitrof et al., 1974). In this instance, the model did not result in a simulation but in another model for which an analytical solution could be obtained.

The simulation is the computer implementation of the model (it is another model) and allows the study of a phenomenon overtime. As such, it has to be formal in nature in order to be executed in a computer. It is noted that we are referring to constructive simulations. There are simulations that are needed but are not computable. In those cases, live simulations are used. Assuming that the model is a representation of the object and the simulation...
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