Epistemological Aspects of Simulation Models for Decision Support

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ABSTRACT

In this paper, the author explores epistemological aspects of simulation with a particular focus on using simulations to provide recommendations to managers and other decision-makers. The author presents formal definitions of knowledge (as justified true belief) and of simulation. The author shows that a simple model, the Kuramoto model of coupled-oscillators, satisfies the simulation definition (and therefore generates knowledge) through a justified mapping from the real world. The author argues that, for more complex models, such a justified mapping requires three techniques: using an appropriate and justified theoretical construct; using appropriate and justified values for model parameters; and testing or other verification processes to ensure that the mapping is correctly defined. The author illustrates these three techniques with experiments and models from the literature, including the Long House Valley model of Axtell et al., the SAFTE model of sleep, and the Segregation model of Wilensky.

Keywords: Epistemology, Kuramoto Model, Model Parameters, Simulation, Validation, Verification

1. INTRODUCTION

In recent times, there has been a growing interest in epistemological aspects of simulation (see e.g. Becker et al., 2005). Do simulation produce knowledge, and if so, how? Some writers suggest that simulations raise new epistemological issues, while Frigg and Reiss (2009) argue that “simulations ... raise few if any new philosophical problems. The philosophical problems that do come up in connection with simulations are not specific to simulations.” In other words, epistemological analysis of simulations can draw on studies of the philosophy of knowledge going back to Plato’s Theaetetus. In this paper, we explore epistemological aspects of simulation with a particular focus on simulations which are used to provide recommendations to managers and other decision-makers, especially in the area of organizational and social modeling. Should these decision-makers ask the question “Do you really know that?” then the simulation modelers must have a reply to hand.

Under what circumstances do simulation models produce knowledge? Taking the classical definition of knowledge as justified true
belief, we outline some basic epistemological principles, and describe a number of techniques by which simulations can provide knowledge to decision-makers. In particular, we consider how the architecture or theoretical basis of a model may be justified, how the parameter values “plugged into” a model may be justified, and how verification can justify the belief that a model has been implemented correctly. We illustrate these techniques with some simple simulations, including the Kuramoto model of coupled oscillators (Strogatz, 2000), the Long House Valley model of Axtell et al. (2002), and the Segregation model of Wilensky (1997b). First, however, we must clarify precisely what we mean by “knowledge.”

1.1. What is Knowledge?

In this paper, we assume a correspondence theory of truth (Audi, 2003, p. 246; Schmid, 2005). Statements derived from a simulation model are true if they correspond to the real world. Theories of truth based merely on coherence are likely to be seen as inadequate by decision-makers seeking evidence for a simulation-based recommendation (although such theories may be the most appropriate in more exploratory research). In contrast to Kleindorfer et al. (1998), we take an objectivist view of simulation since, in the context of the decision being made, there is generally a body of empirical data which is taken by the decision-makers to be objectively “real.” Similarly, the decision-makers are unlikely to be questioning the fundamental body of knowledge of their discipline, let alone the foundations of mathematics and logic. Instead, assuming that knowledge, they will be seeking answers to specific questions.

Following the classical definition in Plato’s Theaetetus, we take knowledge to be justified true belief (Audi, 2003, p. 220). This definition of knowledge has received some criticism. For example, Gettier (1963) gives an example where a partially justified but false belief in \( P \) is combined with a justified true belief in the logical rule \( P \rightarrow (P \lor Q) \). Since, in the example, \( Q \) coincidentally happens to be true, Gettier suggests that this gives a justified true belief in \( P \) or \( Q \).

We avoid this problem by insisting on sufficiently strong justifications so that our “knowledge” cannot be “accidentally” correct (Audi, 2003, p. 222). In particular, we require a justification to consist of a chain of reasoning in which all steps are held to a high standard. In formal terms, justification involves reasoning with epistemic (modal) logic, where the modal term \( \text{JTB} (P) \) means that there is a justified true belief in \( P \). The key axiom of epistemic logic is the modal equivalent of modus ponens:

\[
\text{If } \text{JTB} (P) \text{ and } \text{JTB} (P \rightarrow Q) \text{ then } \text{JTB} (Q)
\]

The chains (or, more accurately, trees) of reasoning that result from applying this axiom incorporate justified true beliefs about the world (which rely on scientific, sociological, or other investigations); justified true beliefs about computer software and about model-building techniques (which rely on testing or on mathematical proof); and justified true beliefs about the specific simulation model at hand (which rely on testing and various kinds of rigorous reasoning). Cioffi-Revilla (2010) discusses some of these categories of justified true belief in more detail. “Does cell or patch geometry matter?” is in the second category, for example, and the effect of terrain on social interactions is in the first.

Given this high standard of justification, is it possible to have knowledge – that is, justified true belief – about a simulation model? At least sometimes, the answer will be “no.” For some models, there will be some steps in the reasoning chain which are not fully justified, and so the simulation provides no justification (and hence no knowledge) even when its output is correct. Recommendations produced by the model are therefore simply beliefs (which may be true or false). This means that the simulation
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