

Models, Simulations, and Experiments

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Abstract: I discuss the difference between models, simulations, and experiments from an epistemological and an ontological perspective. I first distinguish between “static” models (like a map) and “dynamic” models endowed with the capacity to generate processes. Only the latter can be used to simulate. I then criticise the view according to which the difference between models/simulations and experiments is fundamentally epistemic in character. Following Herbert Simon, I argue that the difference is ontological. Simulations merely require the existence of an abstract correspondence between the simulating and the simulated system. In experiments, in contrast, the causal relations governing the experimental and the target systems are grounded in the same material. Simulations can produce new knowledge just as experiments do, but the prior knowledge needed to run a good simulation is not the same as that needed to run a good experiment. I conclude by discussing “hybrid” cases of “experimental simulations” or “simulating experiments”.

1. INTRODUCTION

Empiricist philosophies of science draw a sharp distinction between descriptive or representational devices (scientific theories) and what is described or represented (the natural or social world). Models and simulations are customarily placed among the representational tools, whereas experiments are considered parts of the natural or social world that have been carefully designed in order to answer some specific question. There are, however, bits of science that do not fit neatly, and for which a different scheme

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of classification may be more appropriate. In this paper I shall try to show that it is sometimes useful to think of models, experiments and simulations as tokens of the same kind, somehow located between our statements about the world (call them scientific laws, principles, theories, axioms), and the world itself (see also Guala, 1998). Borrowing from Margaret Morrison and Mary Morgan (1999), we may say that such entities “mediate” between theory and reality.

First, let us notice that everyday scientific talk often does treat experiments, models and simulations as tokens of the same kind. In one of the earliest papers in the field of experimental economics, for example, the term “simulation” appears three times only in the first page (Smith, 1991, p.8), alongside other expressions such as “experiment” and “experimental game”. Or take medicine. Experimental physiologists make extensive use of animals in their investigations, for well known (although controversial) ethical reasons. Most often, these activities fall under the label of “animal experimentation”. But it is not uncommon to hear or read the expression “animal models”, especially when experimenters fear that the findings will not be easily transferable from animal subjects to human beings.

Why do scientists slip from “experiment” talk, to “model” and to “simulation” talk? A plausible answer is that the difference is purely epistemic in character: “experiment” and “theory” being the pillars upon which all proper science should stand, scientists signal their epistemic doubts using a special terminology. An incomplete or less than certain theory becomes a “model”; a dubious experiment becomes a “simulation”, and so on. However, perhaps there is something deeper to be said, and the rest of the paper is devoted to explore this possibility.

2. MODELS AND SIMULATIONS

Models have been at the forefront of research in the philosophy of science for at least two decades now. Indeed, the latest orthodox “theories of scientific theories”, the so-called “Semantic View” of theories, *identifies* theories with sets of models. The Semantic View is more a family of doctrines than a single, unified philosophical theory, but all its versions share a distaste for the older “syntactic” approach, according to which theories are basically sets of statements or laws. In the semantic approach the fundamental component of a theory, the model, is in contrast a *structure* - a set of objects with properties and relations among them and/or their parts - that satisfies the linguistic components of the theory. The latter are secondary, in the sense that they can be formulated in various equivalent ways, as long as they are satisfied by the models. The axioms, laws, etc., may change de-

pending on the language and system of axioms scientists choose, but the models won't. The models must be put at work by means of a "theoretical hypothesis", stating that they stand in a certain relation (of similarity, isomorphism, analogy, etc., depending on which version of the Semantic View one subscribes to) with real-world entities or systems. Since the Semantic View is presently the received explication of the concept and role of scientific models, I shall take it as my point of departure here. The next question is: what is a simulation?

Mario Bunge (1969) defines simulation as a relation between two entities, x and y , where x simulates y if (1) there exists a correspondence relation between the parts or the properties of x and y ; and (2) the analogy is valuable to x , or to another entity (z) that controls x (p. 20). The first striking feature of this definition is its anthropocentrism. It makes no sense to say that a natural geyser "simulates" a volcano, as no one controls the simulating process and the process itself is not useful to any one in particular. I shall assume for the sake of this paper that the second part of Bunge's definition captures some important connotations of the term simulation. But the first part is unsatisfactory, because it leads to include things that we would not intuitively call "simulations" at all. Consider a map: if it has been drawn adequately, there must exist some correspondence relation between its parts and parts of the territory it is aimed at representing.¹ Since the map is also somehow "controlled" by someone (its user or its creator), and is certainly valuable to her, it does fulfil all of Bunge's criteria. Yet, it would be odd to say that a map "simulates" the territory.

Now consider a map together with a set of flags and miniaturized soldiers and tanks, of the sort you find in military head-quarters or in games such as "Risk". If the toy-flags, mini-soldiers and mini-tanks are moved on the map according to the appropriate rules, we can properly claim that a battle or a military campaign is being simulated. Why? Whereas the map alone is somehow "inert", the same map, plus the miniatures, plus the players or officials moving the miniatures according to the rules, make a "dynamic" system. I shall here follow Stephan Hartmann (1996) and distinguish *static* from *dynamic* models. A static model can only represent a system at rest. A dynamic model can also represent the time-evolution of the system (p. 82).² A dynamic model, then, can be in different states at different times, and usually each state will correspond to a specific combination of values taken by the variables in the model. Such a model will be able to be in as many different

¹ I am here referring standard maps on paper only. Giere (1999, pp. 44-47) provides a detailed discussion of the function of maps as models.

² I am paraphrasing Hartmann here, for he speaks of models as if they were linguistic entities (made of "assumptions", for example), whereas in this paper I follow the Semantic approach and take them to be objects.

states as all logically or physically possible permutations of the values its variables can take. Only “dynamic” systems of this sort can properly speaking simulate. “A *simulation imitates one process by another process*” (Hartmann, 1996, p. 83), where a “process” is a time-ordered sequence of states a system takes in a given time period.³

This characterization opens some interesting questions. Consider my previous example: in order for the map-plus-miniatures to be a simulating device, the system must be capable of taking different states (the miniatures must change their position on the map, for instance). This means that there must be an agent prompting the changes in the system itself. Such a role may be played for instance by the officials in the army’s head-quarters. Thus, counter-intuitively perhaps, the officials must *belong to* the simulating device itself. If “simulation” is an anthropomorphic or more in general agent-dependent notion, as Bunge seems to suggest, we should not be troubled by this. It is just natural that what is to be included and what to be excluded in a simulating system is partly arbitrary and/or dependent on one’s interest. Simulations are not in nature, it is us who “see” them and often build them according to our purposes. Similarly, a checkerboard and some pawns cannot by themselves simulate anything - although they can *represent* something: for example the state of a given battle at time *t*. A checkerboard, some pawns, *and two players* can simulate a battle or a war (albeit at a very high level of abstraction) by representing a sequence of states of that battle or war. Most often, a simulating device will have some mechanism built into it, which once triggered will make the system go through a series of states automatically. The agent’s role, then, will be merely that of setting the initial state and starting the process, which will keep running until it is exogenously interrupted or runs out of steam.

3. SIMULATIONS VS. EXPERIMENTS: THE EPISTEMIC ACCOUNT

The distinction between simulations and experiments is more tricky than the one between models and simulations. In everyday scientific talk, such a distinction is certainly loaded with epistemic connotations: simulations are supposed to be somehow less fertile than genuine experiments for the production of scientific knowledge. Their results are often qualified as “mere” simulations not to be mistaken for the “real thing” (i.e. the real-world system whose behaviour is being simulated, or an experiment on the real-world

³ I am here modifying slightly Hartmann’s (1996) own definition of “process” as “some object or system whose state changes in time” (p. 83).

system). The interesting question, however, is whether the epistemic difference is fundamental, or whether it is just a by-product of some more basic difference between experiments and simulations.

I should make clear that I am not interested in conceptual distinctions *per se*. My primary aim is to make sense of some tools that are widely used in science. And this is no mere philosophical quibble: scientists worry about the same issues - probably even more than philosophers do. Take the sort of laboratory work done by psychologists and economists interested in behavioral decision making. The psychologist Baruch Fischhoff represents practitioners' worries by means of a graphic example. In the psychology lab, choices look like this:

Choice A. In this task, you will be asked to choose between a certain loss and a gamble that exposes you to some chance of loss. Specifically, you must choose either: Situation A. One chance in 4 to lose \$200 (and 3 chances in 4 to lose nothing). OR Situation B. A certain loss of \$50. Of course, you'd probably prefer not to be in either of these situations, but, if forced to either play the gamble (A) or accept the certain loss (B), which would you prefer to do? (Fischhoff, 1996, p. 232).

But in the real world, choices look like *this*:

Choice B. My cousins [...] ordinarily, I'm like really close with my cousins and everything. My cousin was having this big graduation party, but my friend - she used to live here and we went to [...] like started pre-school together, you know. And then in 7th grade her stepdad got a job in Ohio, so she had to move there. So she was in Ohio and she invited me up for a weekend. And I've always had so much fun when I'd go up there for a weekend. But, it was like my cousin's graduation party was then, too - like on the same weekend. And I was just like I wanted to go to like both things so bad, you know. I think I wanted to go more to like up Ohio, you know, to have this great time and everything, but I knew my cousin - I mean, it would be kind of rude to say, "Well, my friend invited me up, you know for the weekend." And my cousins from out of town were coming in and everything. So I didn't know what to do. And I wanted mom to say, "Well, you have to stay home", so then I wouldn't have to make the decision. But she said "I'm not going to tell you, you have to stay home. You decide what to do". And I hate when she does that because it's just so much easier if she just tells you what you have to do. So I decided to stay home basically because I would feel really stupid and rude telling my cousin, well, I'm not going to be there. And I did have a really good time at her graduation party, but I was kind of thinking I could be in Ohio right now (Fischhoff, 1996, p. 232).

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