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Computer simulations and experiments: The case of the Higgs boson

Michela Massimi [a,*], Wahid Bhimji [b]

[a] School of Philosophy, Psychology, and Language Sciences, University of Edinburgh, Dugald Stewart Building, 3 Charles Street, Edinburgh EH8 9AD, United Kingdom
[b] School of Physics and Astronomy, University of Edinburgh, Kings Buildings, Mayfield Road, Edinburgh EH9 3JZ, United Kingdom

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ABSTRACT

Simulations have been at the center of an important literature that has debated the extent to which they count as epistemologically on a par with traditional experiments. Critics have raised doubts about simulations being genuine experiments, on the ground that simulations seem to lack a distinctive feature of traditional experiments: i.e., the ability to *causally interact* with a target system. In this paper, we defend the view that simulations are indeed epistemologically on a par with traditional experiments. We first identify three possible ways of understanding the *causal interaction claim*. We then focus on the use of simulation in the discovery of the Higgs boson to show that in this paradigmatic case, simulations satisfy all three possible readings of the causal interaction claim.

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1. Introduction. Simulating and experimenting

Over the past few years, computer simulations have attracted the increasing attention of philosophers of science working on models and the epistemology of experiments. This is a blossoming research field, where pressing issues about the calibration, validity, and reliability of computer simulations are raised in areas as sensitive as climate science, for example. But what is so special about computer simulations? Are computer simulations the twenty-first century face of experimentation? Do computer simulations enjoy a distinct—and more debatable—status compared to ordinary experiments? This is the key *epistemological* question that we address in this paper.

While the systematic use of computer simulations—from climate science to high-energy physics—is undeniable, the epistemology of simulation is more of a contentious issue. Computer simulations seem a new kind of experimental activity in need of a distinctive epistemology (for some early work in the field, see Humphrey, 1991, 1994). Yet critics have drawn sober conclusions about the allegedly special epistemic role of computer simulations (for a survey, see Frigg & Reiss, 2009). How do computer simulations differ then (if at all) from ordinary experiments?

The recent detection of the Higgs boson is one of the most illuminating examples of how computer simulations have become an integral part of experimentation in high-energy physics. It also raises interesting questions about the epistemic status of simulations and their interplay with ordinary experiments. Our paper has a twofold aim. First, we illustrate the use of simulations in two key features of the discovery of the Higgs boson: namely, the background determination (necessary for identifying the occurrence of a novel particle), and the interpretation of the novel particle as the Higgs boson. Second, we look at the case of the Higgs boson to explore three possible ways of understanding an important claim, the so-called *causal interaction claim* (CIC henceforth). CIC has recently been invoked to justify the epistemological priority of ordinary experiments over computer simulations. Our final goal is to show that in the case of the Higgs boson no suitable qualification of CIC licenses the epistemological conclusion that simulations do not count as genuine experiments because they lack causal interaction with the target system.

A wide and narrow notion of simulation can be found in the literature[1]. According to a widely accepted notion, simulations are

* Corresponding author.
E-mail addresses: michela.massimi@ed.ac.uk (M. Massimi), wahid.bhimji@gmail.com (W. Bhimji).

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continuous with computations. The term simulation is interchangeable with machine-aided computation. In climate science, for example, simulations are routinely employed as computational techniques that allow predictions in situations where no experiment can be performed (i.e. to predict the mean surface temperature changes within 0.5 degrees in the next fifty years under a certain emission scenario, to use the example of Steele & Werndl (2013, p. 613). In this context, it is natural to think of simulations as falling within the remit of computations, rather than proper experiments. In this first wide sense, simulations are synonymous with computations. Leaving here aside the thorny and somehow orthogonal issue of what a computation is, and what might count as a computation (e.g. does the human mind perform computations?), one can distinguish a second notion of simulation.

According to this second notion, simulations are representations. As we see it, this second notion—albeit conceptually and logically distinct—is downstream of the wide notion of simulation as computations. For computations have after all a *representational function.* Computations performed by a computer can *represent* (e.g. a computer game representing real life situations) as much as computations performed by the human mind can *represent* (e.g. mental representations). This second notion of simulations *qua* representations has been recently brought to the fore by Parker (2009, pp. 486–7), who defines computer simulations as "a time-order sequence of states that serves as a representation of some other time-ordered sequence of states". Parker does not present this second notion of simulation as downstream of the first wide notion of simulation-qua-computations. But both simulations-qua-computations and simulations-qua-representations contrast with ordinary experiments, which Parker defines as "an investigative activity that involves intervening on a system". On Parker's definition, simulating is a way of *representing* a target system, while experimenting is a way of *intervening* on a target system. Thus, on a wide (twofold in our view) notion of simulation (i.e. qua computation, or qua representation) simulations are at a distance from experimenting.

But there are other domains of inquiry where a narrow notion of simulation has found its way. According to this narrow notion, simulations are in fact continuous with experimenting. This third narrow notion of simulations qua experimental activity—and even qua complementary experimental practices *in their own right*—has proved helpful in areas where the traditional boundaries between experimenting and theorizing (or between data production and data interpretation) is typically blurred. High-energy physics is an example. The very nature of experimenting in high-energy physics challenges traditional philosophical notions of experimenting (as a form of intervening) versus theorizing (as a form of representing). It is not just manipulation or intervention that proves inadequate to describe what goes on in these experimental situations. But theorizing itself enters bottom-up in the very possibility of designing experiments and models of data capable of extracting meaningful signals from the "background" of events.

Consider a typical scattering experiment in high-energy physics, whereby a beam of particles (say, electrons or protons) is smashed against a target (say, electrons, protons or others). Smashing notwithstanding, the core and focus of the experimental activity does not reside in the collision itself, but in analyzing its decay products. Novel discoveries happen when scientists compare the "observed" data (produced by the collision) with the "expected" background (predicted by the relevant model for the scattering in question), and spotting eventual unexpected phenomena (in the form of a non-foreseeable plot of data, for example). Interpreting the non-foreseeable plot of data points as evidence for a new particle requires, in turn, a model that can interpret the spread of the plot, its height, and so forth, as evidence for a kind of particle with a certain mass, average life-time, and decay products, compatible with the expected background.

At no stage in this complex chain of events, is there a clear-cut division between intervening versus representing. And even at the simple experimental level of particle phenomenology, understanding the nature of the collision, its decay products, and being able to identify new phenomena involves systematics, i.e. the use of computer-aided techniques and theoretical assumptions to control background noise, potential sources of errors, and model data to extract meaningful signals from thousands of events resulting from the collision. It is in this context that the aforementioned narrow notion of simulation has emerged as a complementary experimental practice in its own right, continuous with the computer-aided modeling techniques that are such an integral part of the experimental landscape of high energy physics. In the rest of this paper, we concentrate our attention to this third narrow notion of simulation-qua-experimental activity, and to some of the pressing epistemological questions it poses.

The distinction between a wide and a narrow notion of simulation can somehow be found in Winsberg (2009), who has distinguished between what he calls simulation$_R$ and simulation$_A$. While simulation$_R$ is co-extensive with Parker's definition of simulation as a kind of representation, simulation$_A$ refers to computer simulations as "a kind of activity on a methodological par with, but different from, ordinary experimentation. (. . .) The contrast class for simulation$_A$ is ordinary experiment; there are ordinary experiments, on the one hand, and there are computer simulations and analog simulations, on the other" (ibid., p. 583). So, once more, we should ask what distinguishes simulations from ordinary experiments. Winsberg (2010, p. 71) defends the thesis of the epistemological priority of experiments over simulations on the ground that the amount of knowledge needed for model-building relevant to simulation depends—to a large degree—on experiments and observation[2]. So understood, the epistemological priority thesis asserts that the reliability of model-building methods used in computer simulations crucially depends on our experimental history. Good experimental knowledge is required to build reliable computer simulations. As such, experiments come first over simulations. Let us call this first way of thinking about the epistemological priority thesis EPT$_1$. EPT$_1$ is a claim about the reliability of our scientific knowledge, and its ultimate experimental foundations. Good simulations require reliable scientific knowledge, and reliable scientific knowledge rests on solid experimental grounds. An alternative, more poignant way of expressing EPT$_1$ would be to say that simulations are not the product of a priori knowledge. As such EPT$_1$ expresses a view that would be hard to deny, a view that we share, fully endorse, and will not discuss any further in the rest of this paper.

But there is another way of thinking about the epistemological priority thesis, which has also attracted attention in the recent literature, and which hinges instead on the alleged causality and materiality of ordinary experiments. Let us call it EPT$_2$. It is to this second way of thinking about the epistemological priority thesis that we want to focus our attention on in this paper. EPT$_2$ has appealed to the "materiality" of ordinary experiments as an argument for the epistemic priority of experiments over computer simulations. For example, Guala (2005, pp. 214-5) has argued that while in ordinary experiments we encounter the same "material causes" which are at work in a target system; this is not the case with computer simulations, where the relationship between the simulation and the target system is purely formal and abstract. Along similar lines, Morgan (2003, p. 217) has stressed the non-materiality of computer

[2] "For epistemic agents like us, experiments are epistemologically prior to simulations. In both simulations and experiments, you need to know something to learn something. But the knowledge you need in a simulation is always quite abstract and sophisticated, and it usually depends on things you have learned from a long history of experiment and observation. That is because we do not commit ourselves to the reliability of model-building principles unless they have been tested against experiments and observations" Winsberg, 2010, p. 71.