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REVIEW

MAURO DORATO
The Software of the Universe: An Introduction to the History and Philosophy of the Laws of Nature
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The catchy title of Mauro Dorato's *The Software of the Universe* (subtitled *Introduction to the History and Philosophy of Laws of Nature*) promises a new, accessible look at a subject that is central within analytic metaphysics of science and in the many strong parts of the book the reader will not be disappointed.

Two of the topics covered are most welcome because they are not often discussed in the literature on laws: Dorato's first chapter is a historical overview of how the concept of *laws of nature* was used (or absent from some discourse) from the Hellenistic period through the medieval ages down to the modern scientific era starting with Newton; the second chapter introduces (and partially aims to answer) the question why (many) laws are mathematical and, particularly, how the application of maths to empirical phenomena should be possible at all. These questions are indeed puzzling given that one might believe that mathematics is either a mere construction of the mind or, if existent in its own right, it resides in its own abstract non-spatiotemporal world.

Related to the issue of the mathematical structure of many laws, it is one of the great virtues of Dorato's book that it tries to sideline the often superficial representations of law statements we find in many philosophers' writings: 'All Fs are Gs' or 'Fs nomologically necessitate Gs'. These formulations tempt us to ignore the mathematical, functional form of many laws as we find them in the sciences, most strikingly in physics. Dorato can take credit, also in other respects, for aiming to be true to actual scientific practice throughout the book.

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The other chapters (3–5) concern more common (but, of course, also essential) topics related to laws of nature: Chapter 3 compares the concept of laws to the closely related topics of prediction and explanation, necessity, causality, determinism, counterfactual conditionals, truth, symmetry, and universality and asks whether laws can be reduced to one or other of these concepts and/or whether we could formulate necessary and sufficient conditions for lawhood on their basis. Dorato denies these possibilities.

It is only in Chapter 4 that Dorato turns to an outline and critique of the orthodox philosophical theories of laws of nature as, for example, the Mill–Ramsey–Lewis best system view; Armstrong, Dretske, and Tooley's necessitarianism; and the more recent natural kinds dispositional essentialisms. A variant of the latter is the view Dorato himself defends.

Chapter 5 takes a closer look at the laws of special sciences and focuses particularly on psychological and psycho-physical laws.

I will now pick out, from each chapter, issues that I found particularly interesting or claims for which I would like to see a more detailed defence.

First, however, a critical remark on the title of book: although Dorato lists some authors in a footnote (p. 3, fn 6) who have also used some kind of software metaphor (omitting David Braddon-Mitchell's 'Lossy Laws' [2001]), I don't think that it is 'most commonly used to explain natural laws' (p. 3). While this could, in principle, count in favour of the title and the book—because of the relative novelty of a metaphor that is potentially useful—it does not actually do so: Dorato himself rejects the metaphor just a third of the way into the book (cf. p. 39). In short, the idea of laws as *The Software of the Universe* is not entirely new, not widely used, and not defended in the book.

There's a second way in which the book's (sub-)title and, actually, its foreword are slightly misleading. Dorato writes: 'what will follow is an introduction to the history and philosophy of the laws of nature that does not require any previous background in either science or philosophy' (p. xiv). Yet, my suspicion is that the beginner will find most chapters too challenging. Some knowledge of both science (especially physics) and philosophy of science is certainly beneficial when reading the book.

In the introduction to his book, Dorato distinguishes three main modern conceptions of laws: 'the neo-regularism of Humean ascent, the recent anti-empiricist "revolt" by various "necessitarian" philosophers, and the skeptical eliminationism' (p. x). As we learn from the detailed first chapter on the history of the concept of laws, traces of the three stances on laws (although not always under the name 'laws') can be found already in the pre-Newtonian, pre-scientific ages. It should be mentioned, however, that the wealth of historical facts to be found in this chapter might overwhelm the reader who is looking for a quick, leisurely overview.

The often quoted passage from Galileo's *The Assayer* serves Dorato to highlight the origins of the mathematisation of laws: 'the great Book of Nature "which is continually open before our eyes (I say the universe) [. . .] is written in mathematical language, and the letters are triangles, circles, and other geometrical figures" ' (p. 21; quoted from [1968]). This essential aspect of laws—'a law of nature is a quantitative relationship between phenomena expressed by a mathematical function' (p. 21)—is, of course, also advanced by Descartes and Newton, the former of which conceptualizes laws, according to Dorato, for the first time as 'immutable and universal in the sense that *they are valid in all places and in all times*' (p. 23).

The second chapter deals with the important and often neglected question why (many) laws of nature are mathematical and, more generally, why the abstract realm of mathematics should at all be apt to describe the concrete physical world. Here, Dorato reintroduces his software metaphor, makes it more precise, and (first) aims, with the help of it, to answer the above questions. As far as I understand Dorato, the idea is this: a law, i.e. an equation, permits us to calculate from the initial input data the prediction output in a finite number of steps and in a mechanical fashion. Then, he writes:

> affirming that the laws governing the temporal evolution of a physical system serve as the *software* of the system is tantamount to presupposing the following analogy: Just as the physicist, who in order to pass from initial measurements to predictions, performs calculations with formulas expressing natural laws, *a well-identified physical system*, in passing from one initial state to a successive one on the basis of how these states are *causally* connected, *in a certain sense* '*performs a calculation*'. If the observable universe in its entirety can be treated as this sort of system, one could say that the universe passes from one state to a successive one by 'calculating' it on the basis of its laws, which we can therefore call *the software of the universe*. (p. 37)

There are two objections to the usefulness of the software metaphor the second of which Dorato takes to be so serious that he rejects the metaphor. The weaker (unsuccessful) reason to reject it is that while humans might *purposefully calculate* on the basis of mathematical equations the world itself cannot be said to perform any such intentional action. Yet, here, Dorato argues, computers can serve as a middle man: 'A computer that manipulates symbols actually carries out a few physical transformations that *we interpret* as calculations, on the basis of a task that *we* have its operating system perform in relation to its central processing unit' (p. 37). But if we can justifiably apply the calculating metaphor to a computer, i.e. a physical system of specific kind, then we should be able to do so to any physical system (cf. p. 37).

Dorato's ultimate reason for rejecting the calculation/software metaphor is the following, second objection: a calculation is a process in time. Yet, not all laws of nature are laws of succession. Rather, many are laws of co-existence. The idea, however, of comparing laws to either human calculations or to software running on machines can only be adequate for the succession laws. Thus, Dorato concludes:

> It follows that the *identification between laws and algorithms*, as impressive as it may be, *is not sufficiently general, given that the notion of algorithm manages to account for only the laws of succession, but not for those of coexistence.* As a consequence, it would seem legitimate to conclude that this identification should be seen at best as a heuristic instrument, and that it cannot be utilized to explain why the laws of nature are mathematical (p. 39).

(Dorato discusses a rescue attempt that tries to reduce the laws of coexistence to those of succession but he ultimately rejects it (cf. pp. 44–8).)

I believe it is possible to undermine the case for the software metaphor for another reason. We could argue that, in fundamental physics, laws are time-symmetric and thus that, in nature, there really is no arrow or flow of time anyway. Yet, if there is not time the distinction between laws of coexistence and laws of succession gets blurred and the computer algorithm model is challenged once more. (This argument depends, of course, on the debated status of the second law of thermodynamics, which arguably does introduce time-asymmetry.)

Now, if the software metaphor is no good to explain why mathematics is applicable to the world, then there has to be a different bridge between numbers and physical stuff. The problem becomes particularly intriguing when considering that no matter which 'current philosophical position on the ontology of mathematics [we favour] over another [. . .] the applicability issue creates puzzles for all such positions' (p. 32). The constructivist must explain why a creation of ours enables us to explain and predict what goes on in the physical world which is not created by us. The Platonist has to explain why the physical, concrete world should reflect the causally inert world of abstract entities. Even the naturalistic explanation which sees mathematics as the evolutionary fruit of long-term adaption is in need of an explanation why mathematics reaches out even to those areas of the natural world to which we surely have not adapted, like the very small (the quantum world) and the very large (cosmology) (cf. p. 32).

Dorato's own favoured solution is a mix of the first and last positions (while rejecting the Platonist view). He argues for a non-arbitrary constructivism that is informed by our evolutionary development in such a way that there are isomorphisms between mathematical structures and the physical world (cf. pp. 54–7): 'The problem of explaining the applicability of mathematics to the natural world can be dealt with most plausibly in a constructivist philosophy of mathematics, which sees the latter as a non-arbitrary human invention, rooted in our spatio-temporal experience of the external world. In particular, all the complex applications of geometry to physics [...] presuppose a background of intuitive data *that originated with our experience of concrete objects*, and is therefore furnished by our perceptions of shapes, as codified in the perception of external objects by our visual and tactile apparatuses' (p. 64).

A critical point is that, while Dorato's theory can credibly explain how new phenomena *within the world we are adapted to* are also within the reach of mathematics, it remains a little mysterious how Dorato wishes to make comprehensible why mathematics even applies to the very little and very big world to which we have not adapted. Two options seem to be open to him (but are not explicitly defended in the book): we might either say that the structural template, which medium sized objects have left on us, also fits, as a matter of fact, smaller and larger entities; or we could push for a kind of evolutionary Kantianism: whatever the 'real patterns' of the unobserved and unfamiliar are (the quantum world and events like the Big Bang) we cannot but project the mathematical structures we have learned and (literally) 'incorporated' also into the unknown.

In the third chapter, Dorato asks whether the concept of laws can be reduced to any of other closely related notions (or groups of them) like prediction, universality, truth, necessity, causality, counterfactuality, explanation, and symmetry.

I will focus here on some aspects of universality. Dorato distinguishes three meanings of universality: (i) a 'generalization which is always and everywhere true', (ii) a 'generalization which is valid without exception', (iii) a 'generalization without restrictive clauses, or so-called *ceteris paribus* clauses' (cf. p. 72). Dorato identifies the second reading of universality, 'being without exceptions', with determinism, i.e. not being of statistical nature, and, therefore rejects it as a criterion for lawhood. He writes: 'After the probabilistic turn in modern physics, it seems particularly opportune to drop this requisite of a deterministic nature' (p. 76). While this is surely right about determinism versus non-determinism I do not think it is correct to link this issue to the topic of exceptions to laws. A smoker without cancer is, pace Dorato, no *exception* to the law '65% of smokers become ill with cancer' (p. 76). He himself later writes in contradiction to the earlier verdict that the law is 'obviously not valid for all smokers' (p. 76) that 'a law of probability also refers to those individuals who, in our example, have not contracted cancer, but have increased their chances of doing so by smoking' (p. 77).

In fact, both deterministic and indeterministic laws can be exceptionless or with exceptions (the two dichotomies are independent). It is easiest to see this if we focus on a propensities view of probability laws: it might, for example, be exceptionlessly true that all smokers have a 65% propensity to get cancer. Or not: an exception to this law would be a single smoker with only a 30%

propensity. (It is a little harder to see how, even for a frequencies-based account of probabilistic laws, we can distinguish between laws with exceptions and probabilistic laws but this, too, can be done, cf. Schrenk [2007].)

In Chapter 4, we find a defence of one of three leading theories of lawhood and the rejections of the other two. Dorato finds the neo-Humean regularist Mill–Ramsey–Lewis (MRL) view and the Dretske–Tooley–Armstrong (DTA) necessitarian theory wanting and he goes through many of the known shortcomings of these theories. The view of laws Dorato prefers to MRL and DTA is a variant of dispositional essentialism, a view that has gained considerable attention and more precise formulations in the past few years, especially due to the writings of dispositionalists and dispositional essentialists like Brian Ellis (esp. his *Scientific Essentialism* [2001] and his *The Philosophy of Nature* [2002]), Stephen Mumford (in his *Laws in Nature* [2004]), and Alexander Bird (*Nature's Metaphysics* [2007]), to name but a few. However, Dorato instead refers to earlier works of Ellis and, especially, to the writings of Rom Harré & Edward Madden (*Causal Powers* [1975]) and various publications by Nancy Cartwright, to advertise his own version of dispositional essentialism. Unfortunately, it is not clear whether Dorato's personal view merely eclectically collects the best parts of the work of each of these authors or whether and how his own view varies from and advances these established theories.

In any case, the version of dispositional essentialism advocated, as outlined on 14 pages of the book (pp. 104–17), seems to be this: natural kinds exist objectively (they are no matter of mere verbal classification) and they possess their real dispositional (and maybe also some occurrent) properties essentially. Laws, now, seem to record both the essential kind-dispositions correlations (cf. p. 107), as well as the causal processes dispositions give rise to when manifesting in the appropriate circumstances. I say that laws 'record' those phenomena because it seems that while Dorato wishes to maintain a strong realist position when it comes to the existence of kinds and their dispositions, he also sympathises with constructivism/instrumentalism when it comes to the laws: 'they refer to the world of phenomena by *approximation*; in other words, laws reproduce the structures of experience through partial isomorphisms dictated by mathematical models' (p. 113; cf. pp. 114–5). Something that *refers by approximation* and that *reproduces by isomorphism* cannot itself be what makes the world go round. The latter role is for the dispositions and powers.

Yet, this is my reconstruction and it remains a little unclear exactly what stance Dorato takes with respect to laws in the end, realist or antirealist. It is also not entirely transparent how the valuable distinction between laws of coexistence and causal laws of succession Dorato earlier makes can be mapped onto the natural kinds and dispositions theory. While it is fairly straightforward that the laws that describe how and when dispositions manifest are the succession laws it is not clear what a law of coexistence is in Dorato's view. A natural move would be to say that those are the laws that say which natural kind possesses which disposition(s). However, Dorato writes instead: 'Laws that are non-causal (or of co-existence) are instead obtained by considering the functional co-dependence of properties or the non-causal dispositions of bodies' (p. 113). Yet, what are those functional co-dependencies of properties in relation to the natural kinds and dispositions talk? More pressing: what is a non-causal disposition? And lastly, how does the talk of natural kinds and dispositions resolve the problems with (non-causal) quantum entanglement Dorato launched earlier against theories of lawhood that focus too much on laws of succession?

A theory that maintains that laws specify which dispositions certain natural kinds—or, here, especially chemical or biological systems—have seems to suit the special sciences particularly well. This is the topic of Chapter 5. Special science laws, ordinarily conceived, are said to be *ceteris paribus* laws: laws that do apply only in very circumscribed conditions but not when *other things aren't equal*. Dorato's point seems to be, now, that if laws say which *dispositions to behave* systems have then this is still true even if these dispositions do not (fully) manifest themselves when *other things aren't equal* (i.e. these laws would be *strict*; a similar point is made by Cartwright in many of her writings). Dorato's Chapter 5 also covers aspects of laws in economics and it touches the mind-body problem with the interesting suggestion to conceive of psycho-physical laws as laws of coexistence rather than of causal succession and so to solve the causal closure problem. Dorato tries to dispel worries that this might amount to a pre-established harmony view of mind and body by reference to the possibility that even in the absence of causal psycho-physical laws non-nomological singular causation could still be operating (cf. p. 131) but, as Dorato himself admits, his theses are only schematically advanced (cf. p. 132).

In sum, the book touches many interesting topics, some of which have seldom been covered by other works on laws. In this respect, Dorato certainly fills a gap in the discussion and I recommend the book to everyone working on laws who wishes to inquire into these issues—the history of the concept and the mathematical structure of laws—and look for a thought provoking starting point.

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