The Babylonian conception and conventionalism about laws in physics

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Abstract

In this paper I discuss two features of laws in physics and ask to what extent these features are compatible with different philosophical accounts of laws of nature. These features are (i) that laws in physics fit what Richard Feynman has dubbed the "Babylonian conception" of physics, according to which laws in physics form an interlocking set of 'theorems'; and (ii) that the distinction between dynamics and kinematics is to some extent contextual. These features, I argue, put pressure on any philosophical account of laws that presupposes that the laws of physics have a unique quasi-axiomatic structure, such as the Mill-Ramsey-Lewis account of laws and metaphysical accounts of laws that assume that there is a privileged explanatory nomological hierarchy.

1. Introduction

During much of the eighteenth and nineteenth centuries Newton's laws of motion were taken to be the paradigm of scientific laws, thought to constitute universal and necessary eternal truths. But since the turn of the twentieth century, we know that Newton's laws are not universally valid. Does this mean that their status as laws of physics has changed? Have we discovered that the principles, which were once thought to be laws of nature, are not in fact laws? Or have we merely learned that the domain of application of Newton's laws is more restricted than we once thought, while the laws' role within their proper domain is unaffected by this discovery? What is more, with the demise of Newtonian physics as universal theory the entire paradigm of lawful predictability appears to have reached its limits—not only with the discovery of quantum probabilities but also with the emergence of the physics of nonlinear and complex systems, for which the notions of determinism and predictability come apart. How do these developments affect our philosophical conception of laws of nature? Are laws of nature the (perhaps probabilistic) determinants of how the world evolves? Or are they rather our best predictive tools, where what is best does not only depend on the ways the world is but also on who uses the laws in what context and for what purpose? That is, are the laws of nature fully objective and context-independent fundamental features of the world to be discovered by us, or is what the laws are at least partly also a reflection of our human cognitive capacities and of particular contexts of investigation? In this paper I want to make progress towards a philosophical understanding of the role of laws in physics by closely examining a number of features of how putative laws are treated in physical theorizing.

In the next section I will distinguish three broad philosophical conceptions of laws that play a particularly prominent role in contemporary philosophical discussions of laws of nature. These are, first, views that take nomological necessities to be metaphysically basic, including 'governing conceptions' that treat laws as metaphysically fundamental drivers of the temporal evolution of the world; second, Humean views, that take laws to be reducible to patterns of instantiations of non-modal properties; and, third, a cluster of conventionalist or even instrumentalist views that understand laws at least partly as a reflection of a particular perspective of investigation and as part of the epistemic toolkit for building models, which represent aspects of the world from a particular and partial perspective, relative to certain goals and interests.

Sometimes philosophical discussions of laws of nature are situated at several removes from examinations of the actual use of putative laws in physics, taking as their starting points purely philosophical reflections on the nature of laws, with only tenuous support from actual scientific practice. By contrast, I here want to approach the issue from the other end, as it were, by first examining several features that I take to be characteristic of laws in physics (taking methodological reflections of eminent physicists as a cue) and then asking to what extent these features are compatible with various philosophical conceptions of laws. The two features of physical theorizing on which I will focus in particular concern the place of axiomatization in physics (in sections 3 and 4) and the relation between dynamics, kinematics, and initial conditions (in sections 5 and 6). To anticipate somewhat, there is a conventional and context-dependent element in the way in which laws are treated in physics. Different sets of laws provide us with different perspectives from which to model or represent the phenomena, partly serving different purposes or answering different questions. And while laws at different levels are related in many and intricate ways, and hence there is little evidence for an image of physics as consisting in completely balkanized, disjoint groups of research activities, there is equally little evidence for a conception of physics as providing us with a single hierarchical and uniquely axiomatized structure. Thus, I will argue that even within physics there is support for a view of laws that is more frequently associated with the so-called 'special sciences', according to which laws function as domain- and context-specific generalizations (see, e.g., Mitchell 2009).

2. The Metaphysics of Laws

Laws of nature, according to one common philosophical understanding of that notion, are universal and necessary truths. The necessity in question is taken to be distinct from logical necessity and sometimes also from (other brands of) metaphysical necessity. The various ways of fleshing out the view that laws are universal truths can be distinguished along different dimensions. First, we can distinguish views that take modalities to be a non-reducible part of the basic inventory of the world from views that understand nomological necessity to be ultimately reducible to non-modal features of the world. And, second, we can divide the former further into views that take laws to be reducible to necessities that reside in the fundamental properties that objects instantiate and views that take laws to be primitive or basic (see Loewer 2012; Chen and Goldstein, this volume).

Dispositional essentialist, such as Alexander Bird (see Bird 2007), are among those who maintain that laws are reducible to or supervene on necessities that reside in fundamental dispositional properties of objects. For example, on this view massive objects possess the disposition or power to attract other masses and it is this disposition that grounds the law of gravitational attraction. On Bird's view, dispositional essences underwrite counterfactual conditionals, to which the laws are reducible. On Heather Demarest's more recent view (Demarest 2017; 2021), the initial distribution of particles and their dispositions (or potencies) ground the subsequent behavior of the particles and the instantiation of dispositions, which determine the laws. One should note, however, that there are also defenders of a dispositional fundamental ontology, like Nancy Cartwright, who deny that these dispositions ground universal laws.

Other proponents of the view that take modalities to be irreducible to non-modal features of the world take laws themselves to be metaphysically fundamental and to constrain or *govern* the patterns of instantiations of accidental or categorical properties in the world. The laws are primitive. On one such 'primitivism' about laws, fundamental dynamical laws govern how spatiotemporal objects evolve from one moment to another (see Maudlin 2007). Tim Maudlin's conception of primitivism includes a commitment to a primitive direction of time. The fundamental dynamical laws—the fundamental laws of temporal evolution—on his view, generate later states of the universe from earlier ones. Eddy Chen and Sheldon Goldstein (this volume), by contrast, defend a view they call 'minimal primitivism', according to which the laws govern not by producing or generating later states from earlier ones but merely by constraining the space of physical possibilities. Nomological constraints may take the form of differential equations that allow us to determine future states from past ones. But the constraints can have other forms as well. As they put it "laws govern by constraining and constraining is what they do." (Chen and Goldstein, this volume) And even if the laws in question are dynamical laws, the laws govern by constraining metaphysical possibilities and not by producing later states from earlier states.

All metaphysically 'weighty' accounts of laws stress the role of modalities, and in particular nomological necessity, in explanation. For the dispositional essentialist explanations ultimately bottom out with an appeal to the dispositions, powers, or potencies of objects. The world evolves the way it does, on these accounts, in virtue of objects realizing their dispositions. The laws supervene on these dispositions and their realizations. On primitivist governing conceptions, laws play a more central role in explanation. On Maudlin's primitivism, laws govern the evolution of the world from its initial state and in virtue of their generative or productive role explain how later states evolve from earlier states. Minimal primitivism holds that laws explain by constraining possibilities.

Primitivists are in agreement on a hierarchical view of laws of nature. According to both Maudlin's account and minimal primitivism, we can distinguish metaphysically fundamental laws that provide ultimate explanations of the world evolves from derived or less fundamental laws that are grounded in the fundamental laws. Crucially for the primitivist, the truth of the fundamental laws, as well as their lawhood and their fundamentality, are independent of our beliefs, our psychologies, or our practices.

Views that nomological necessities are part of the basic inventory of the world contrast with *Humean conceptions* of laws according to which laws and nomological necessity supervene on the totality of particular non-modal matters of fact. Nomological claims, according to Humeans, are true in virtue of certain patterns of fundamental properties being instantiated. One way to spell this out further is the account associated with John Stuart Mill, Frank Ramsey and David Lewis (MRL) (Lewis 2001). According to the MRL-account, laws provide us with that summary of the mosaic of particular matters of fact that best balances simplicity and strength. The MRL-account asks us to consider different ways of organizing statements about particular matters of fact into deductive systems. The strength of a system is a measure of how many truths the deductive system allows us to derive, while a system's simplicity is both a measure of the system's number of axioms and of the axioms' syntactic complexity. The laws are the axioms of that deductive system that best combines simplicity and strength.

While the traditional Humean account, which identifies laws with the regularities exhibited by the 'Humean mosaic,' appears to offer a reductionist but fully objective account of laws, the MRL-account arguably introduces a pragmatic element. As defenders of the view themselves emphasize, *both* the criterion of simplicity itself *and* what the proper relative weighting of the criteria of simplicity and strength is cannot be spelled out in a purely objective, mind-independent manner: overall goodness ultimately is goodness *for us*. Thus, according to the MRL account what the laws are depends at least partly on us and our cognitive capacities. While this does not mean that what the laws are is arbitrary, it does contrast with primitivists' accounts, which emphasize that which laws govern the world is a "fundamental, objective, and mind-independent fact." (Chen and Goldstein, this volume)

Ron Giere, among others, has traced the history of the notion of scientific laws as universal and necessary truths to the idea of God as divine law-giver—an idea one can find for example in Newton (Giere 1999). The universality of the laws is a consequence of God's supreme power, which ensures that nature has to obey Her laws everywhere and everywhen. Independently of whether Giere's account accurately captures the history of the concept of law of nature, the image of God as law-giver can provide a useful illustration of the contrast between the governing and Humean conception of laws (see also Cartwright1999). The difference between the governing-law conception and the Humean conception concerns the question whether laws are metaphysically fundamental or whether what the laws are is reducible to—or supervenes on—the totality of particular matters of fact. According to the former conception, when God created the world, She had two tasks: She had to decree what the fundamental laws of the world would be; and She had to specify what the initial state of the universe shall be. Nothing more was required of Her. Once the initial state was created, the universe evolved forward in time governed by the laws of nature. At least this would be so, if we assumed that the laws are deterministic and contain no 'gaps.'

On the minimal primitivist's conception God's tasks similarly only involves the task of specifying the laws plus appropriate conditions on some initial value surface. But on this conception, God's act of creation is an atemporal act: By specifying the fundamental nomological constraints plus data on some appropriate surface (which need not be a surface at the beginning of the universe) the entire history of the universe is given. Contrary to Maudlin's primitivist conception, the laws do not temporally asymmetrically govern how the universe evolves.

By contrast with both of these conceptions, the Humean God is not a law-giver but rather a pointillist painter, who set Herself the rather more involved task of sprinkling the universe's four-dimensional space-time canvas with particular matters of fact. The Humean God does not merely have to decree what the universe's initial state should be but has to paint all of space-time—that is, all of space throughout all times—with a mosaic of events. What the laws of nature are, is then given by the totality of particular matters of fact. According to the traditional Humean, the laws strictly supervene on the pattern of particular matters of fact. According to the MRL view, what the best way of summarizing the mosaic created by God might be *for us* also partly depends on our cognitive capacities.

The image of God as pointillist painter does not yet tell us how easily the patterns on the canvas can be summarized. Lewis's God and the God of the standard MRL account of laws appears to have been kind to physicists searching for universal regularities on Her canvas: Her painting contains global patterns, is systematic and highly organized so that we can justifiably hope to be able to summarize the goings-on on the entire canvas with the help of a relatively small number of relatively simple fundamental physical laws. But we can also imagine a less systematic painter—a messy and mad genius who painted different parts of the canvas in ways that resist being unified within a single simple framework. Any description of the goings-on on the mad genius's canvas that is both true and universal might be absurdly complex—so complex that our best strategy might be to hunt for small pockets of order that permit being summarized in terms of simple 'lawish' statements rather than aim for a single unified description. If God was messy and the world was 'dappled', we would have to lower our ambitions: instead of aiming for a single best system, we might have to rest content with a multiplicity of domain-specific and perhaps even interest-specific systems. Instead of hoping to discover universal laws, we would search for ways to summarize small pockets of regularities. And instead of hoping to discover laws that are strictly true, we might have to make due with 'lawish' statements that fit the patterns we observe reasonably well to a certain degree of approximation, and aim for domain-specific systems of laws that best combine simplicity, strength and fit and serve our context-dependent purposes as well as possible.

The metaphor of God as a mad genius, who paints a dappled world on Her canvas, represents a third conception of laws—a conception that gives up the idea of laws as universal, context-independent truths and instead takes what the laws are to depend both on the ways the world is and on our interests and purposes—which I have here presented as a variant of the MRL-account (see Cohen and Callender 2009; Callender and Cohen 2010; Frisch 2011). The conception replaces the idea of a single best system with that of a multiplicity of systems, reflecting different perspectives and interests, and instead of demanding that laws be true takes goodness of fit to be just one criterion by which to evaluate a system, to be jointly maximized together with the competing criteria of simplicity and strength. A closely related view insists in addition that the relationship between laws and the world is more indirect than the accounts surveyed so far would have it: the primary role of laws, on this view, is to aid us in the construction of models of the phenomena. The representational role of science, on this view, is ascribed not (or at least not primarily) to the laws but rather to the models constructed with the help of laws: laws are tools for model-building (Cartwright 1983; Giere 1999). Instead of providing us with the uniquely correct fundamental underpinnings of how the world evolves, laws are taken to be part of "expanded understandings of both the world and our representations of it as a rich, variegated, interdependent fabric of many levels and kinds of explanations that are integrated with one another to ground effective prediction and action," (p. 19) as Mitchell puts it.

Just as Humeanism can come in different flavors, from a fully objective account of laws to the MRL account with its irreducibly pragmatic element to Callender and Cohen's "better best systems" account allowing for a multiplicity of systems, so can dispositionalist accounts. In fact, dispositionalism seems to allow for the same range of views as Humeanism does, with the main difference between it and Humeanism, of course, concerning the ontological basis the two different types of view postulate: a mosaic of localized non-modal matters of fact as opposed to a fundamental dispositional properties, potencies or powers.

This concludes my brief sketch of the conceptual landscape concerning laws of nature. Which of these three conceptions should we adopt? In what follows I want to describe two features of laws of physics, which, I want to submit, can provide us with some clues that allow us to assess different answers to this question.

3. The 'Babylonian' conception of laws

The first putative feature of laws in physics I want to discuss is what Richard Feynman calls the "Babylonian" character of laws in physics. In *The Character of Physical Law* Feynman discusses the mathematized statements at the core of physical theories and asks whether there is "one set of statements that is more fundamental and one set of statements that is more consequential" (Feynman 2001, 46). According to what Feynman calls the "Greek" or "Euclidean tradition," physics and the mathematized sciences should be thought of as having an axiomatic structure, similar to that of Euclidean geometry, in which the entire content of a theory is derivable from a simple set of fundamental axioms. That is, the Euclidean tradition takes the laws of physics to exhibit a unique and context-independent hierarchical structure with a set of simple, fundamental laws as axioms from which all other laws can be derived. Feynman contrasts the Euclidean view with what he calls the "Babylonian tradition." Feynman says that in the Babylonian tradition general rules were arrived at by working through a large number of examples: rules are arrived at inductively rather than through derivations from more fundamental axioms. But more important for our purposes here is Feynman's suggestion that even once we know all the rules, theorems, or laws, the Babylonian is not interested in the question whether these laws can be arranged into an axiomatic structure. Rather, the Babylonian's main focus is on "calculating things out." And, as Feynman says, the most "efficient way of getting around in the territory" is not necessarily always to start from axioms. This does not mean that he takes the theorems of physics to be disconnected from one another. Rather, the laws of physics provide us with an interconnected (and over-connected) structure, which, however, Feynman stresses, allow no unique and context-independent way of singling out certain of its parts as the most fundamental principles. Thus, Feynman says, we could "start with some particular ideas which are chosen by some kind of convention to be axioms" (47), but we could have chosen a different starting place as well. By contrast with the Euclidean conception, the Babylonian conception of science is non-hierarchical and less tightly organized: "I happen to know this and I happen to know that, and maybe I happen to know that, and I work everything out from there. Tomorrow I may forget that this is true, but remember that something else is true, so I can reconstruct it all again. I am never quite sure of where I am supposed to begin or where I am supposed to end. I just remember enough all the time so that as the memory fades and some of the pieces fall out I can put the thing back together again every day." (*Ibid.*)

Feynman's evocative presentation of the conception might suggest a view that is concerned either with the question of how laws are discovered or with the purely epistemic question how we might recall or rediscover what the laws on the books are. But I take it the view is meant to be more general than that and is, as the title of Feynman's book suggest, concerned with the character or nature of physical laws: the laws of physics, according to the Babylonian conception do not exhibit a uniquely axiomatizable structure.

Feynman's own illustration of the Babylonian conception is the relation between Newton's three laws together with the law of gravity, on the one hand, and Kepler's second law and angular momentum conservation, on the other. As Newton showed, we can derive Kepler's law that equal areas are swept out by a planet in equal times from Newton's laws, which might suggest that the latter are more fundamental than the former. However, Kepler's area law can be thought of as a special case of the principle of angular momentum conservation and the latter applies much more broadly than just to gravitational forces. In fact, according to Noether's theorem, which establishes a connection between symmetries and conserved quantities, angular momentum conservation follows from the fact that the Lagrangian of a system is rotationally symmetric. Thus, one might think that the symmetry principle and angular momentum conservation is the more fundamental principle and should be an axiom instead of the gravitational law. Yet while this principle provides a constraint on the possible form forces between bodies might take, it does not entail Newton's inverse-square law: we cannot make due with the symmetry principle alone.

Another example of the phenomenon to which Feynman points is the relation between the Lorentz force law and the principle of energy-momentum conservation in classical electrodynamics. We can begin by postulating the Maxwell equations and the expression of the principle of energy-momentum conservation for electromagnetic systems and from these together derive the Lorentz force law. Alternatively, we can take the Maxwell equations and the Lorentz force law for continuous charge distributions as starting points to derive that electromagnetic energy and momentum are conserved, given the standard expression for the field energy and momentum. Finally, there is a third view point: We can posit the Maxwell equations together with the Lorentz force law and demand that energy-momentum ought to be conserved in electromagnetic interactions and use these assumptions together to define the electromagnetic field energy in terms of the electromagnetic field vectors. On the first two approaches we assume that we already know what the expression for the energy of an electromagnetic field is, while the third approach uses the demand of energy conservation to find what combination of electric and magnetic field strengths represents the energy contained in the field. Analogously to Feynman's own example, we are faced with the choice of either taking a general principle, such as the principle of energy conservation, as fundamental starting point or beginning with the specific dynamical laws governing the phenomena, such as the Maxwell-Lorentz equations.

Feynman concludes from his discussion that there is no unique answer to the question which of the different starting points is "more important, more basic". Rather in order to understand physics "one must always have a neat balance" (50) between the different possible starting points—in particular, we must balance approaches that begin with broad, general principles with ones that focus on the particulars of the dynamics for a system. Feynman's view echoes a view expressed by Hendrik A. Lorentz, more than half a century earlier, who maintained that approaching physical phenomena *both* from the perspective of broad and general principles, such as the principle of energy conservation, *and* from what Lorentz calls 'the mechanism of the appearances'—that is the particular dynamical laws, can be fruitful (see Frisch 2005; 2011). Like Feynman after him, Lorentz maintained that neither of the two approaches is privileged and stressed a pragmatic dimension to any preference for one approach over the other: "there are multiple ways by which we try to understand natural phenomena [...] Individual characteristics and inclinations determine the choice for each scientist" (Lorentz 1900, 333).

Feynman also allows for the possibility that "some day when physics is complete and we know all the laws," there may be a privileged set of axioms (p. 49). Thus, Feynman does not want to conclude from the fact that present-day physics does not consist in a uniquely axiomatizable interconnected structure that a final physics would also not allow for a privileged Euclidean axiomatization. But if Feynman is correct in believing that current physics does not fit the Euclidean conception, this raises the question as to what our grounds for assuming that a final physics might fit the conception are. Moreover, Feynman's argument centrally appeals to the use to which laws of physics are put: we are interested in using laws primarily to account for and explain physical phenomena—and do so efficiently. And if Feynman is right that these interests are best served by adopting a Babylonian conception, then it is difficult to see how this situation might change if some day physics were complete and all the laws were known. Even within current physics it is possible to take various starting points as more fundamental (even though Feynman would deny that any such starting point is uniquely privileged). Thus, Feynman's suggestion seems to be that simply in virtue of the fact that a collection of physical laws couldn't be given a yet more fundamental foundation it follows that this collection exhibits a uniquely privileged axiomatic structure.

Conversely, one might try to argue, *pace* Feynman, that we do not have to wait for the completion of physics and that physics already has a hierarchical, quasi-axiomatic structure. Such an argument might appeal to the role of symmetry and conservation principles and to the connection between the two, to argue for the following hierarchical picture: we begin with certain symmetry principles, such as time-translation invariance as meta-laws. These principles explain, via Noether's theorem, which posits a connection between symmetries and conserved quantities, the "great conservation principles", as Feynman calls them. Since the symmetry principles have the status of meta-laws, every particular dynamical law has to satisfy the conservation laws. Thus, we have an explanatory hierarchical scheme beginning from symmetries to conservation laws to particular fundamental dynamical laws.

Yet, even if it were possible to organize theories hierarchically in this manner—from symmetry principles to conservation laws to dynamical laws—the 'anti-Babylonian' needs to establish that this scheme is uniquely privileged and is not merely one among several, and it is not clear that this can be done. For, first, Noether's theorem presupposes a Lagrangian formulation, but not all dynamical systems can be represented in this manner (see Brown and Holland 2004; Wigner 1954). Second, where Noether's theorem does apply, it establishes an equivalence and not an explanatory priority of the symmetry principles. That is, in perfect Babylonian fashion one can take either symmetry or conservation principles as starting point.[1] Third, we can in principle take two different viewpoints on the relation between conservation and symmetry principles, on the one hand, and particular dynamical laws, on the other. We could take the general principles to be more fundamental and provide a meta-nomological constraint on the form any dynamical law has to take. But it also possible to take the opposite viewpoint, as Harvey Brown and Peter Holland suggest: "the real physics is in the Euler-Lagrange equations of motion for the fields, from which the existence of dynamical symmetries and conservation principles, if any, jointly spring." (Brown and Holland 2004) It is compatible with this second viewpoint that we adopt the general principles as heuristic guides in our search for new dynamical laws, without treating them as meta-nomological constraints. Again, the coexistence of these two viewpoints (even if it is not always perfectly peaceful) supports Feynman's Babylonian conception.

I want to end this discussion by pointing to an area of physics that provides perhaps particularly vivid support for a Babylonian conception: the physics of non-linear and complex systems. The physics of complex systems concerns the aggregation of smaller objects into higher-level systems with a very large number of degrees of freedom that can exhibit new types of behavior not present at the lower level. Complex systems exhibit a certain robust organization that arises out of the interplay of underlying randomness and interactions of many elements that result in the higher-order structure (see, e.g., Anderson 1972; Ladyman et al. 2013) The emergence of new properties in these macroscopically ordered structures involves the breaking of symmetries of the underlying micro-dynamics, which can be characterized as a phase change.

According to one notion, complex systems are systems whose behavior cannot be algorithmically predicted from the micro-dynamical equations governing the system. An example of this is fluid turbulence, which can be modeled at a higher level of description by the so-called 'Burgers equation', an equation that can be solved exactly for arbitrary initial condition. At a more fundamental level fluids are governed by the Navier-Stokes equation. Yet turbulent behavior cannot be predicted by integrating the Navier-Stokes equation, since turbulence involves the interactions of different features at different length scales—of big whirls, little whirls and lesser whirls, as the applied mathematician Lewis Richardson has put it—and the

[1] Marc Lange (2007; this volume) proposes a formal framework which allows the symmetry principles to be meta-laws, which explain the conservation principles. But Lange does not provide an argument for the explanatory priority of the symmetry principles but only shows how, once we *presuppose* an explanatory asymmetry between symmetry and conservation principles, we can spell out the meta-nomological character of the symmetry principles.

locations and times at which these features emerge is sensitive to the precise microscopic initial conditions (see Scott 2007). That is, complex chaotic phenomena, such as fluid turbulence, pose an entirely new challenge for Laplace's demon in his attempt to predict the universe's evolution: not only does he need to have unlimited computational power, but he also would have to know *exactly* what the universe's *precise* micro-state at some time was, since approximate knowledge of the state, however ever close to the actual state, could result in arbitrarily large divergences in his predictions for the future.

This means that independently of the question whether complex systems might be *ontologically* reducible to their constituents, they are in general not *epistemically* reducible and a description of the higher-level patterns exhibited by the system in terms of higher-level theories is essential. We can be committed to the view that complex systems are in principle governed by the fundamental micro-dynamical laws, yet due to non-linearity, sensitivity to initial conditions, the existence of feedback effects, and the overall computational complexity of the problem, we cannot derive higher-level patterns and laws from the micro-dynamics.

From the perspective of an underlying micro-theory, higher-level descriptions will involve abstractions and idealizations. Nevertheless, to the extent that higher-level features and patterns are robust, have explanatory power and are predictive reliable, they can be thought of as real (see Dennett 1991; Wallace 2003). Even if nature were hierarchically organized, this does not entail an explanatory reductionism and a uniquely hierarchical structure of the laws of nature. The physicist Philip Anderson, echoing Feynman's Babylonian conception, expresses this hierarchical yet non-reductionist view as follows:

> The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe. [...] The constructionist hypothesis breaks down when confronted with the twin difficulties of scale and complexity. The behavior of large and complex aggregates of elementary particles, it turns out, is not to be understood in terms of simple extrapolations of the properties of a few particles. Instead, at each level of complexity entirely new properties appear, and the understanding of the new behaviors requires research which I think is as fundamental in its nature as any other. (Anderson 1972, 393)

4. The Babylonian conception and philosophical accounts of laws

I now want to ask what consequences a Babylonian character of physics has for the different philosophical accounts of laws we distinguished above. If we assume that Feynman's account is correct, what would this imply for what account of laws we could adopt? Feynman's view is obviously incompatible with any account that posits the existence of a uniquely privileged axiomatization of physical knowledge. Thus, the

Babylonian conception is in tension with the standard MRL view. If Feynman's depiction of physics is correct, then there is no unique context- and interest-independent answer as to what the axioms of the Best System and, thus, what the fundamental laws are. Lewis thought that the world would be such that there would be a uniquely privileged deductive system whose axioms were the laws. The Babylonian conception denies this.

Yet Feynman's motivation of the Babylonian conception actually bears some similarities to the manner in which Lewis motivates his account of laws. A single axiomatization, according to Feynman, does not offer the most efficient way of accounting for getting around in the territory or for accounting for physical phenomena. One way to understand this, is that a single axiomatization is less simple, since it requires overly lengthy and cumbersome derivations. The loss in simplicity in one sense, by allowing for multiple starting points and in effect positing a not tightly axiomatized structure of laws, is more than made up for, or so Feynman can be understood as arguing, by the gain in simplicity in another sense, by cutting down on the length of derivations needed in different contexts. Lewis had hoped that God were kind and that there would be a single deductive system that would clearly and uncontroversially come out ahead as far as a balance in simplicity and strength are concerned. Feynman's discussion suggests that this hope might have been in vain.[2]

There is a further problem for the standard MRL view: it is not clear how one might reconstruct a nomic structure consisting of putative meta-laws, such as symmetry or conservation principles, together with dynamical laws within the traditional MRL account. Intuitively, it would seem that such principles should be among the laws of physics. Yet it is not clear how they could be, according to the account. On the one hand, a set of axioms consisting *only* of these principles would be too weak, since it would not allow us to derive any specific dynamical laws and, a fortiori, no particular matters of fact about the mosaic. On the other hand, if we enlarged our set of axioms to include the dynamical laws, then the general principles would become superfluous: a system including both symmetry principles and dynamical laws would be less simple without any increase in deductive strength compared to a system consisting of the dynamical laws alone.

The Babylonian conception is also in tension both with the view that there exist fundamental laws that ultimately govern how the world evolves and with the view that the laws are consequences of the physical essences possessed by things. The problem for the latter view is that according to the Babylonian conception it is unclear which set of laws directly reflects the underlying essences. Is it, for example, part of the essence of massive objects to respond to forces, or is it rather in their essence to conserve energy and

[2] This Lewisian motivation for Feynman's conception echoes the manner in which advocates of a "Better Best System's view motivate their departure from a Lewisian single best system. See Cohen and Callender 2009; Callender and Cohen 2010; Frisch 2011).

momentum or move along a path that minimizes the action (as a Lagrangian picture suggests)? The problem for Maudlin's or Chen's primitivism is that both accounts posit a unique hierarchical conception of laws, according to which there are truly fundamental laws, which ground all other laws.

Now one might reply that this incompatibility is so much the worse for the Babylonian conception. Chen and Goldstein, in particular, appeal to an account of explanation in support of their hierarchical conception of laws. If laws play a central role in explanation in physics and if explanations require a unique hierarchy of laws bottoming out in truly fundamental laws, then the Babylonian conception of false. While a general defense of the Babylonian conception is beyond the scope of this paper, I want to argue that the core of Chen and Goldstein's own account of explanation does not in fact require a commitment to truly fundamental laws. Laws explain, according to Chen and Goldstein, "by constraining the physical possibilities in an illuminating manner." (this volume). So-called "constraint explanations" (see Ben Menahem 2018) are one type of broadly counterfactual explanations that explain by embedding a phenomenon into a pattern of counterfactual dependencies and by answering "what-if-things-had-been-different questions" (Woodward 2005). Chen and Goldstein argue that constraint explanations require a metaphysically and modally richer notion of law than a Humean account can provide. But one may concede *this* point without also accepting that modal, nomological constraints need to be hierarchically structured and that there exist unique *fundamental* laws. Indeed, the two additional demands Chen and Goldstein place on explanations in addition to that of appealing to nomic constraints—metaphysical fundamentality and simplicity—may pull in different directions and may even be incompatible with each other. Arbitrary constraints, Chen and Goldstein say, "do not always provide satisfying explanations", since "many constraints are complicated and thus insufficient for understanding nature. What we look for in the final theory of physics is not just any constraint but simple, compelling ones." (this volume) But if genuine explanations need to invoke laws that are truly metaphysically fundamental, we don't get to choose: we will have to make do with whatever laws turn out to be truly fundamental, no matter how complicated any explanations invoking them may turn out to be. By contrast, considerations of simplicity (as well as the additional desideratum mentioned by Chen of Goldstein that explanations be unexpected and striking) are quite congenial to Feynman's Babylonian conception: depending on context and on our interests, we might find different explanations of a phenomenon, starting from different laws particularly illuminating, since they might be particularly simple or may be particularly striking in light of what else we assume in a given context. This tension disappears if we adopt Feynman's Babylonian conception: This conception allows us to retain a constraint or counterfactual account of explanation and also allows us to (if we are so inclined) to assume a metaphysically richer notions of modality than Humeans would allow. But at the same the Babylonian conception allows us to retain what Chen and Goldstein identify as the "epistemic ingredient" in their own account—a commitment to simplicity-while giving up a notion of metaphysical fundamentality. Thus, Feynman's Babylonian conception, it seems to me, does better justice to Chen and Goldstein's view on explanation than their own minimal primitivism does.

Due to their flexibility and their lowered ambitions, the revised MRL-view and the 'laws-as-tools'-view fare best in accommodating the Babylonian conception. The role of general principles, whose usefulness in model-building extends far beyond the domain for which they were originally proposed presents a challenge, however, for more extreme patchwork accounts of laws. What is needed, in order to do justice to the Babylonian character of physics, is an account that can provide a role *both* for general, overarching principles *and* for domain specific modeling assumptions. The Babylonian conception does not posit different relatively isolated 'best systems' that might even make incompatible predictions. After all, the structure Feynman describes encompasses areas interconnected and, indeed, overconnected through multiple bridges (47). The particular matters of fact that are derivable from different starting points in the structure are overlapping and compatible with one another, the laws posited are compatible, there only are different ways of organizing and structuring the set of laws.

5. Dynamics, Kinematics, and Initial Conditions

In the previous section I discussed Feynman's Babylonian conception of physics, according to which the distinction between fundamental and derived laws in physics is to some extent conventional or context-dependent. In this section I will discuss another area in which some physicists and philosophers have argued to have detected conventionalist elements: the distinction between dynamics, kinematics, and initial conditions. In a series of lectures the physicist David Gross presented twenty-five questions on the future of physics. Question #13 was the question whether "dynamics, kinematics and initial conditions can be separated". (Gross 2005) Gross's answer was that perhaps they cannot be disentangled. As Gross characterizes the distinction, kinematics constitutes "the framework for physics and its interpretation" while dynamics provides the "specific laws of nature." Kinematics, that is, specifies the formal framework within which specific dynamical interactions take place. The initial conditions are the values of those quantities specified in the kinematical framework that need to be given as input to obtain solutions to the dynamical laws.

Gross suggests that the distinction comes under pressure in contemporary physics and says: "I suspect that, as we learn to understand string theory and explore the nature of space-time, the distinction between kinematics and dynamics will be blurred." Yet several decades before Gross, the physicist Eugene Wigner suggested that the distinction between laws and initial conditions is, if perhaps not blurred, nevertheless not a fully objective distinction even for well-established physical theories and is a human artifact that we make use of in our representations of physical phenomena in order to distinguish a realm of regularities from one of randomness (Wigner 1979).

Consider the different frameworks for representing the physics of Newtonian interacting particles. In addition to representing the evolution of a mechanical system of Newtonian particles in terms of Newton's laws and the forces acting between the particles one can also represent the system within either a Lagrangian or a Hamiltonian framework (see, e.g., Belot 2006). The basic variables in the *Hamiltonian* framework are generalized position and momenta coordinates. Position and momentum, are thus treated on an equal footing and by introducing generalized coordinates the framework can be extended even to systems that cannot readily be represented in terms ordinary space-time coordinates. The state of a system consisting of n particles is represented in a $6n$-dimensional phase space, where a system's instantaneous state is given by the values of $6n$ variables representing the 6 linearly independent position and momentum coordinates for each of the n particles. We can think of phase space as the framework for representing the space of possible position-momentum pairs or the associated with a theory. This space determines the space of initial data for a system representing the possible instantaneous states allowed by the theory, which when plugged into Hamilton's equations for the system, nomically determine the evolution of a system. That is, in the Hamiltonian framework, the space of possibilities for a system is given by the space of possible instantaneous position-momenta states in phase space.[3] Hamilton's equations are equivalent to Newton's equations, but while Newton's equations represent the evolution of a system as the result of forces acting between particles, the Hamiltonian framework represents the system in terms of potentials to which a particle's motion responds.

The arena for *Lagrangian* mechanics is the $3n$-dimensional configuration space, corresponding to the $3n$ degrees of freedom of a system of n particles (assuming that there are no constraints reducing the number of independent variables). The space of possible states is the space of possible particle positions. Any arbitrary curve through this space is kinematically possible. The dynamically or nomically possible curves are stationary curves satisfying a variational principle. In the Lagrangian framework, the evolution of a system is derived from the state at two times and a constraint the system satisfies at times in between.

Thus, in the Lagrangian formulation the kinematics—that is the arena in which the nomological constraints operate—is the space of possible positions, while in the Hamiltonian formulation this arena consists in the space of possible position-momentum pairs. The difference in kinematics is compensated by a difference in the dynamics—Hamilton's equations provide first-order constraints on phase space, while the Lagrange equations provide second-order constraints—thereby making it possible for the Lagrangian,

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[3] Each state can further be assigned a kinetic energy T and potential energy V, which together encode all the physics of the problem.

Hamiltonian (and Newtonian) frameworks to make equivalent predictions for systems of gravitating particles. Differences between the frameworks arise for possible extensions to other domains and here it is unclear that one of the frameworks is clearly overall superior to the other two. Thus, comparing Lagrangian with Hamiltonian formulations of physics appears to support Wigner's view and the claim that there is a conventional element in how we want to carve up the territory between kinematics and dynamics.

The three different frameworks also may seem to suggest different causal structures. While the Newtonian formulation naturally suggests a causal picture of particles being pushed and pulled around by locally acting forces, and the Hamiltonian formulation is one of particles responding to local values of a potential, the Lagrangian formulation might seem to suggest a teleological explanation of a system's evolution, since the path of a system is represented as being determined not only by its initial state but by the conjunction of its initial and final states: as Feynman puts it, the system's particles "in some grand fashion [smell] all the curves, all the possibilities, and decide which one to take." (p. 52)

I want to briefly mention three other examples of the conventionality of the choice of background framework and of dynamical laws (see Spekkens 2012). First, gravitational effects are classically modeled in terms of forces, as in Newtonian gravitational theory. Alternatively, one can treat gravity as a geometric effect even non-relativistically, as is done in the Newton-Cartan theory (see Weatherall 2011). Second, spin degrees of freedom are treated differently in different versions of Bohm's quantum theory. According to Bohmian mechanics, particles follow classical trajectories, guided by a non-classical 'pilot wave' that satisfies the Schrödinger equation. Spin degrees of freedom can be introduced into Bohm's theory either by modeling the particle as having additional internal degrees of freedom or by taking the wave function to be a multiple-component spinor wave-function. And, third, systems governed by a stochastic dynamics can be alternatively represented in terms of a deterministic dynamics, where the system is modeled as interacting with an additional (hidden) noisy source.[4]

6. The distinction between laws and initial conditions and philosophical accounts of laws

While the Babylonian conception puts pressure on an account of laws that posits a hierarchy of laws bottoming out in truly fundamental laws, Wigner's suggestion that the distinction between dynamical laws and the kinematic framework within which the dynamics takes place is a matter of convention or choice, puts pressure on any account of laws that sees the distinction between nomological necessity and contingency as metaphysical basic. For a given set of phenomena there can be different, yet equivalent ways to characterize the set of possible states on which nomological constraints are imposed, with corresponding

[4] Nicholas Harrigan and Rob Spekkens discuss this equivalence in the context of quantum theories with hidden variables (Harrigan, N. and Spekkens, R. 2010).

differences in the nomological constraints. This does not mean that we would have to deny that there are irreducible modalities in the world, but it follows from Wigner's suggestion that there is no unique way to carve up physical goings-on into nomological constraints and the space of possibilities on which these operate.

Moreover, Wigner's view has the consequence that attempts to read off the essences of objects from different dynamical frameworks within which the evolution of these objects may be represented could result in conflicting answers. Is it in the nature of quantum particles with spin to possess additional internal degrees of freedom or is it part of their essence to be guided by a spinor-valued wave function? Is it part of the essence of material particles to follow geodesics in the absence of non-gravitational forces or do material particles essentially exert gravitational forces? And, to return to our main example, is it in the nature of particles to respond to local forces or to local potentials? Or is it in the essence of a system to satisfy a global variational principle? It is unclear whether physics itself can provide unambiguous answers to these questions.[5]

There is an additional problem for versions of a metaphysical primitivism about laws that take laws as being responsible for, or as producing, the temporal evolution of the state of a system. These conceptions may have difficulties in accommodating a Lagrangian framework, since initial states in configuration space are simply not rich enough for the laws to uniquely determine the state's future evolution. Of course, it is open to defenders of a productive account of laws to argue that the Lagrangian variational principle is a consequence of more fundamental forces acting along infinitesimal parts of a system's path (see Lange 2009). But such an argument in favor of the fundamentality of a Newtonian framework would presumably have to invoke extra-physical, metaphysical reasons for the priority of that framework.

As is the case for the Babylonian conception, a traditional Humeanism that posits the existence of a uniquely best system has difficulties accommodate Wigner's conventionalism, but Humeans who allow for multiple 'best systems' can readily accept that the distinction between kinematics and dynamics is to some extent conventional and that there might be multiple ways to carve out regularities and initial states in the Humean mosaic. Which framework is the most appropriate to choose can then be allowed to be a context-dependent and pragmatic matter, depending not only on the particular phenomenon we are modeling but also on possible extensions of the framework to other phenomena in which we are interested.

[5] Wolfgang Pietsch (2013) argues on the basis of a case study concerning recent developments in metrology that there is an additional element of conventionalism concerning laws: how units and fundamental constants are defined changes and with it the distinction between a theory's definitional presupposition and its empirical predictions.

7. Conclusion

My aim in this paper was to survey two features of laws in physics and ask to what extent these features are compatible with different philosophical accounts of laws of nature. These features are the following: (i) laws in physics form a 'Babylonian' interlocking set of 'theorems' among which we can choose different theorems as starting points or 'axioms', depending on the context, and which are connected by an interlocking web of more or less tight derivations; (ii) there are mathematically equivalent ways of carving up the phenomena into kinematic background framework and dynamical laws. These features put pressure on any philosophical account of laws that presupposes that the laws of physics have a unique quasi-axiomatic structure, such as the traditional MRL account and metaphysical accounts that assume that there is a privileged metaphysical and explanatory nomological hierarchy.

Due to its flexibility, a pragmatic revised MRL-account that allows for context-or perspective-dependent multiple best systems fares best in accounting for the features we have discussed. This, however, does not mean that the practice of physics supports a subjectivism about laws. What the laws are, within a certain context of investigation and for a certain domain of phenomena, is not up to us to decide.

Defenders of a 'better best systems' account, such as (Callender and Cohen 2010) tend to focus on the relation between the special sciences and physics (and the apparent independence of the special sciences from physics) as central motivation for their account. These authors allow that different 'best systems' may even resist being integrated with one another or may, in some sense, be in tension with one another. By contrast, I have here argued that there is a role for multiple 'best systems' within physics capturing the same range of phenomena. But these different systems allow us to derive compatible and strongly overlapping sets of facts about the world. They don't disagree about the phenomena but only about which laws are taken to be as starting points in derivations and how to carve up the distinction between kinematics and dynamics. Thus, even within physics the case for a strict and unique hierarchical conception of laws—be it a metaphysical primitivist conception or a traditional Humean account—is weaker than it may seem.[6]

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[6] This paper is a descendent of (Frisch 2014).

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