Studies in History and Philosophy of Science 44 (2013) 408–415

Contents lists available at SciVerse ScienceDirect

Studies in History and Philosophy of Science

journal homepage: www.elsevier.com/locate/shpsa

Three principles of unity in Newton

Katherine Brading

University of Notre Dame, United States

ARTICLE INFO

Article history:
Available online 4 December 2012

Keywords:
Newton
Unity
Laws
Parts and wholes

ABSTRACT

I discuss three principles of unity available in Newton's physics, appealing to space and time, causal interaction, and law-constitution respectively. I compare these three approaches with respect to aggregation (how a collection of entities can compose a whole) and multiplicity (how the world as a whole can contain a multiplicity of genuine unities), outlining the problems faced by the first two approaches and arguing that the third looks a promising candidate for further philosophical investigation.

When citing this paper, please use the full journal title *Studies in History and Philosophy of Science*

1. Introduction

Does the world contain a multiplicity of genuine unities? If it does, how do they together form a *whole,* rather than being merely a collection? The division of the world into genuine unities, and conversely the stitching together of a collection of unities into a genuine whole, are problems of early modern philosophy which live on to figure prominently in Kant's work. Newton's physics offers three potential sources of unity, two familiar, one less so. The first grounds unity in space and time. The second grounds unity in causal interaction. The third, distinct from the second in ways I shall articulate, grounds unity in the laws. I will argue that this third option is the most successful *prima facie*. This is interesting when we consider how best to solve the problems we inherit from our philosophical predecessors, not least because it was not the route taken by philosophers in the period following Newton's work.

The first two approaches to unity are a well-known part of our philosophical inheritance from the early modern period. They come in a wide range of varieties, and the names of Leibniz, Spinoza, Locke, Hobbes, Hume—and of course Kant—among others, will come readily to mind at different points during the course of the following discussion. These connections will not be made explicitly in this paper because my purpose is to focus your attention elsewhere: on philosophical moves made but *not* taken up in the philosophy that we have inherited today.

Newton's *Principia* is a difficult book, as a mathematical text, as a text in physics, and as a philosophical text. Physics and philosophy parted company in important ways not long after its publication, and the *Principia* is not on today's list of compulsory reading for all philosophers, or even for those who specialize in early modern philosophy or who work on philosophers influenced by Newton and the Newtonian tradition. Indeed, only since the mid twentieth century have we begun to understand how to read the *Principia* as a philosophical text speaking to traditional problems of philosophy.[1] Even so, I believe that the text is far richer philosophically than has been appreciated to date: we have a long way to go. In this paper, I offer one example of a philosophical topic—unity—that we are forced to re-visit through paying careful attention to the moves Newton made in the *Principia*.[2]

E-mail address: kbrading@nd.edu

[1] Recall Burtt's early twentieth-century assessment of Newton ("In scientific discovery and formulation Newton was a marvellous genius; as a philosopher he was uncritical, sketchy, inconsistent, even second-rate"), and compare it with more recent efforts to understand the philosophical import of Newton's work (see Janiak & Schliesser, 2012, and references therein). The quotation is from (Burtt, 1954, p. 208); the first edition of this book was published in 1924. Much of the challenge in reading Newton as a philosopher is due to the difficulty of the mathematics and the physics, which has led philosophers to concentrate on the few paragraphs of the *Principia* that are explicitly philosophical, but the mathematics and physics must be mastered to a large degree in order to work with the complete text when reading the *Principia* as a contribution to philosophy. This we have now begun to do.

[2] The point, therefore, is not Newton exegesis as such. We have learned much about the *Principia* and its implications in the 350 plus years since its publication, and a great deal of what we have learned is relevant when we try to read the *Principia* today as a contribution to philosophy, which is the exercise of which this paper is a part.

0039-3681/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.shpsa.2012.10.005

I begin (in Section 2) with a presentation of wholes and parts that sets up the problems of unity as I will treat them in this paper. I then discuss how space and time (Section 3) and causality (Section 4) can be understood as serving as principles of unity in Newton's physics, and the problems that these approaches to unity face. Section 5 brings me to the third approach, which I term ''law-constitutive'', and which I argue is the most successful of the three. I end with a two-part question: how, if at all, does the availability of this third option open up moves that Kant might have made but didn't, and what are the implications of this?[3]

2. Wholes and parts

Consider first the aggregation of a collection of entities into a unified whole. If the world contains entities that are really distinct from one another, in virtue of what does that collection of entities form a genuine whole? A necessary condition is that the entities stand in relations of some kind to one another. Failing this condition, we have a *mere* collection. (It makes no sense to say that the world as a whole is a *mere* collection: if the members stand in no relations to one another, then to call them members of the same world is to say nothing—one might just as well say each member is itself a world. So if the assertion that the members are part of the same world is to have content, it must be an assertion that the members stand in some relation or other to one another.) As a necessary condition, this is a weak claim: we have said nothing about the nature of these relations (perhaps they are logical, perhaps they are physical; perhaps they are real, perhaps they are ideal; we have not committed ourselves). But if the world is a collection of members, then it is no mere collection: the members stand in some relation or other to one another. Beyond this, if such a collection is to form a world then a stronger condition must also be met: the relations between the members must be *sufficient* for a world; the collection must form a genuine unity.

The converse of this problem—does the world *really* contain a multiplicity of entities?—finds vivid expression in the work of Descartes, where we seek in vain for the resources by which to divide indefinite extension into parts that are genuine unities. On the one hand, it seems we lack the metaphysical resources for real division at all; on the other hand, since extension is conceptually divisible *ad infinitum*, no part of extension seems a candidate for a genuine unity.[4] It seems, therefore, that the world does not contain a multiplicity of entities that are themselves genuine unities.[5]

In what follows, I describe three approaches to the aggregation and multiplicity problems found in Newton's physics. I will argue that only one has the potential to solve both problems.

3. Space and time as a principle of unity

On the first approach, space and time provide the framework within which everything that is material exists. In this way, they are the ground of the unity of the universe: what makes this material universe *one* universe is the unity of the space and time framework within which the matter is located. The collection of all material things is no *mere* collection because all material things stand in spatial and temporal relations to one another, and this is necessary and sufficient for the collection of material things to form a genuine unity. In Newton's physics, space and time can be understood as playing just this role. In Newton's *Principia*, absolute space and absolute time are the framework within which all material bodies exist. Moreover, in Newton's physics, space and time can be understood as playing the role of a *metaphysical* principle of unity, as follows.

The characteristics of absolute space and time are familiar from the scholium to the definitions of Book I of the *Principia*. By definition 1, bodies have volume, which means they take up space, and the place of a body is, according to Newton in the scholium, ''the part of space that a body occupies'' (Newton, 2004, p. 65). The motions of all bodies are with respect to this space. So there is a straightforward sense in which the physics is constructed with space and time as the principle of unity for the universe described in the *Principia*. If we turn our attention to the manuscript 'De Gravitatione,'[6] we can flesh out the metaphysical picture.[7] Here, space and time are emanations of God. Newton writes that space is neither substance nor accident, but has its own manner of existing: it is ''as it were an emanative effect of God and an affection of every kind of being'' (Newton, 2004, p. 21). Thus, it derives from God, and every kind of being is in some way spatiotemporal.

The first point—the emanation—is important because it tells us about the metaphysical status of space and time. Newton argues that the existence of space and time must follow directly from God's existence: they must do so in order for God to be present everywhere and everywhen, for otherwise when God created time and space he would either not be present in time and space, or he would have changed his own way of being such that he became present in time and space (''he created his own ubiquity,'' for example, Newton, 2004, p. 26). Moreover, certain features of this emanated space follow as a consequence of God's nature: Newton says that ''space is eternal in duration and immutable in nature because it is the emanative effect of an eternal and immutable being.'' It remains distinct from God (it cannot act, it has no will, etc.), but is nevertheless a direct consequence of God's existence.[8]

The second point—the ''affection''—tells us about the relationship of all things to space and time. Not only is God everywhere and everywhen, but *all* things are spatiotemporal, and are thus somewhere and somewhen.[9]

3 A useful place to start is Eric Watkins' recent book, *Kant and the Metaphysics of Causality*: this book attempts to set out the logical space in which Kant was working, in the context of his predecessors, making it possible for us to pinpoint moments in the evolution of Kant's thought at which the availability of the law-constitutive approach puts an alternative on the table not considered by Kant.

4 See (Holden, 2004) on the problem of matter's divisibility in the seventeenth century. By ''conceptually divisible'' I mean that, regardless of whether extended matter in fact has a spatially discrete structure, we can conceive of any such minima as having spatially extended parts. For my purposes here, I do not need the finer distinctions offered by Holden. There is a large literature on the topic of matter's divisibility specific to Descartes; for recent discussion see for example (Lennon, 2007), (Normore, 2008) and (Rozemond, 2008).

5 In the preceding paragraphs and throughout this paper, I use the term ''entity'' in the most minimal sense, as a placeholder, free of metaphysical and logical commitments as to whether such entities must be individuals and so forth. Similarly, ''collection'' is being using minimally, in the sense of ''mere collection'' described in the preceding paragraph. Indeed, while the subject-matter under discussion here is the physical world, no commitment as to the physicality of the entities and collections considered is presupposed.

6 This Newton manuscript was re-discovered in the mid-twentieth century and has now become very famous. Although untitled it is commonly referred to as ''De Gravitatione.'' See (Newton, 2004).

7 Newton's views on various things evolved between ''De Grav'' and *Principia*, and I am not excluding the following account from that evolution. However, for our purposes there is significant continuity, as the General Scholium of the *Principia* makes clear. Here, Newton writes about God's relation to space and time, and to the things in space and time, as follows (Newton, 2004, p. 91): ''He is not eternity and infinity, but eternal and infinite; he is not duration and space, but endures and is present. ... God is one and the same God always and everywhere. He is omnipresent... In him all things are contained and move...''

8 For further discussion of space as an emanative effect of God see (Slowik, 2009) and references therein.

9 With respect to space, Newton writes (Newton, 2004, p. 25) that ''Space is an affection of a being just as a being.''

It is important to note in connection with these two considerations that space and time together form a unified whole. Newton is explicit that each temporal moment is spread throughout all space, whilst remaining spatially indivisible (just as God is present throughout all space whilst not having spatial parts or being spatially divisible).[10] From our modern perspective, we are tempted to start from such three-dimensional time-slices and ask about how these are to be sewn together. In Newton's case, however, the problem goes the other way around. Absolute space and time contain the structure required to yield determinate trajectories, thereby solving a problem Newton associated with Descartes's physics (viz. that there are no determinate trajectories given Descartes's definition of motion (see Newton, 2004, pp. 20–21). Rather than "space and time," we have in Newton's physics the unified entity "space&time." The possibility of slicing up this entity into time-slices and allowing "shear" or "slippage" between the slices, as it were, is a later re-conceptualization of the requirements of the theory.[11]

It follows from the above considerations that everything is in some way related to the one space&time, which emanates from God. Thus, space&time is the metaphysical ground of the unity of the created world, and of the relation of that world to God.

If we focus on material bodies in particular, we know that as created beings these are necessarily spatiotemporal. In 'De Grav' Newton offers us more specifics about the spatiotemporal character of bodies. He suggests that we can think of bodies as regions of space endowed with certain conditions (such as impenetrability). These conditions make the bodies distinct from space (bodies are *in* space, not *part of* space), but bodies inherit the spatial characteristics (such as the size and shape) of the region in which the conditions are impressed. Moreover, in virtue of the intimate relations between space and time already mentioned, such regions of space are inherently spatiotemporal, and thus bodies too are inherently spatiotemporal. Indeed, the "conditions" with which they are endowed to make them bodies (about which I will say more below) include mobility, and thus time. All bodies are therefore embodied in the single whole that is space&time, and it is in virtue of this space&time that they belong to a single universe. In this way, space&time provides the solution to the aggregation problem for the entire material world, such that we have no mere collection of material things, but a metaphysically unified whole. In Newton's 'De Grav' there is a very strong sense, therefore, in which space and time are the metaphysical ground of the unity of the world, including the material world.

If we turn our attention now to the multiplicity problem, we can ask whether space and time can also provide a principle of unity for material bodies individually: is there a multiplicity, and are the members of this multiplicity themselves genuine unities? In the end, the answer will be no, space and time cannot ground a multiplicity of genuine unities, but it is instructive to see how far we can get.

Newton sums up his tentative account of bodies (Newton, 2004, p. 28) by saying that we can define them as "determined quantities of extension" that are (1) mobile, (2) impenetrable, such that they reflect off one another "in accord with certain laws," and (3) sensible and movable by us. If such material bodies form genuine unities in Newton's picture, can space and time ground this multiplicity and this unity?

There are some resources for us to work with. Newton's space&time (in both 'De Grav' and *Principia*) are geometrically rich, already containing all the shapes that bodies might have, all the trajectories along which they might move, and so forth. Concerning space and the relationship of bodies to space, Newton writes in 'De Grav':

> And hence there are everywhere all kinds of figures, everywhere spheres, cubes, triangles, straight lines, everywhere circular, elliptical, parabolical and all other kinds of figures, and those of all shapes and sizes, even though they are not disclosed to sight. For the delineation of any material figure is not a new production of that figure with respect to space, but only a corporeal representation of it, so that what was formerly insensible in space now appears before the senses. (Newton 2004, pp. 22–3)

The rich geometrical structure of Newton's space&time means that "same shape" and "same size" are well-defined for different locations in space across different times. Moreover, there are spatial paths, and the continuity of these, already present in space, might be used to ground continuous spatiotemporal trajectories of bodies. What makes this the same body at a later time? If same shape, same size, and continuous spatiotemporal trajectory are sufficient, then we can use space&time to ground the identity of the body over time. In other words, given a material body, we can appeal to properties of space&time in order to give an account of identity over time of that body. Insofar as identity over time plays a role in constituting the unity of a thing, this will be of some help to us.

It might seem, however, that we must *begin* with a material body that is a genuine unity *before* we ask about its identity over time. If that's right, then the above considerations are of no use because we face a prior question: in virtue of what, if anything, is that initial material body a genuine unity? Here we run into a notorious problem for all of the "new philosophers" of the seventeenth century who advocated a metaphysics shorn of the Aristotelian substantial forms that once grounded the unity of the individual. Following Descartes, we might take up the "geometric reductionist" project[12] and seek to provide a metaphysics and a physics in terms of geometric properties of matter and motion alone (shape, size, trajectories). Extension, however, is divisible indefinitely, at least conceptually, and the question arises as to whether this indefinite (or perhaps infinite) divisibility is associated with actual parts, or merely with potential parts.[13] If with actual parts, then bodies lack genuine unity: they are divided "all the way down." If with potential parts, then what distinguishes indefinite extension into actually divided parts (the genuine unities) and merely potentially divided parts (the potential parts of the genuine unities)? What is the metaphysical ground of the genuine unities?

One approach we might take towards solving this is to start with spatially extended (and therefore conceptually divisible) yet metaphysically indivisible atoms and declare these our basic, ungrounded, genuine unities. There are two important problems to notice about this proposed atomist solution. First, in making this move we introduce a second principle of unity into our metaphysics: space&time is unable to ground the unity of the basic material entities of our metaphysics, and an additional basic principle of unity must be added. Second, we secure in this way only our "atoms": we lack a principle of unity for composite entities, and the question remains as to whether there is anything that could

[10] See (Newton, 2004, p. 26).

[11] As George Smith has emphasized in his lectures on Newton, what is crucial for Newton's project in the *Principia* is that he can go from the observed motions to the forces.

[12] See (Jalobeanu, 2011, pp. 107–110).

[13] The actual parts doctrine (see Holden, 2004, p. 80) states that the parts into which a material body can be metaphysically divided (i.e. the parts into which God could break it, even if no natural process could) are *actual* parts, where *actual* parts are parts that are independent existents that exist prior to any act of division. The potential parts doctrine (see Holden, 2004, p. 79) states that the parts into which a material body can be metaphysically divided are *potential* parts, where *potential* parts are merely possible existents until actualized by an act of division. As Holden is at pains to emphasize, a crucial issue in the debate concerns the apparent conflict between the infinite divisibility of matter and the actual parts doctrine: conjoined, these two theses imply that every body is constituted by an actual infinity of parts, and this was held by most of those involved in the debate at the time to be seriously problematic.

aggregate these atoms into larger genuine unities (less than the entire material universe, for which space&time provide the principle of unity). If there are to be any composite entities that are genuine unities (smaller than the entire universe), it seems that we are going to have to introduce a *third* principle of unity. Another approach, most familiar from Leibniz, would be to supplement the "mechanical philosophy" with non-mechanical principles of unity. Either way, space&time as a principle of metaphysical unity is insufficient in itself:[14] while solving the aggregation problem for the universe as a whole, it cannot solve the multiplicity problem, nor the aggregation problem for composite systems smaller than the universe as a whole. If we want solutions to these problems, then we have to add at least one further principle of unity; perhaps this proliferation should raise suspicions about the viability of the space&time approach to unity.

In short, space&time, as a principle of unity, can be used to solve the problem of aggregation for the world as a whole, but it fails to solve the problem of multiplicity (there are no genuine unities less than the material world as a whole). Whether or not we add atomism to our picture, additional principles of unity are required.

4. Causal interaction as a principle of unity

The second approach available in Newton's physics grounds the unity of the world in the causal interactions between the entities that make up the world. One way to implement this approach is to use the forces that appear on the left-hand side of Newton's second law of motion as the glue, both physical *and metaphysical*, by which the material world is genuinely one. Newton's law of universal gravitation ensures that every material body interacts with every other material body, and this makes gravitation look promising as a principle of unity. If we adopt universal gravitation as a *metaphysical* principle of unity, we can say that the material world is one *in virtue of* the gravitational interactions among its parts. Let us see how far we can get if we adopt this approach.

Recall that for Newton *only* inertia is an *essential* property of bodies. Gravitation, by contrast, is a universal property. That is, a body that lacked the quality of gravitation would remain a body, so long as it retained its inertial mass, whereas a body that "lost" its inertial mass would no longer be a body. This means that a collection of bodies not interacting gravitationally (because they lack gravitational mass) but which are nevertheless bodies (in virtue of their inertial mass) is possible. On the causal-interaction model of unity, such a collection would not constitute a genuine unity: they would not be part of the same world. However, given Newton's absolute space and time, the members of the collection could all be situated within the same space and time. It is therefore possible on the causal-interaction model of unity for there to be collections of bodies (possessing inertial mass but not gravitational mass) that are situated within the same space&time, but which are not "part of the same world."

If we conclude from this that something has gone wrong with our metaphysics, we might decide to make one of the following moves. One would be to reject causal interaction as the ground of unity and go back to the space&time approach of Section 3, above. But if instead we want to retain causal interaction as the ground of unity, then we have several options. One is to make spatiotemporal relations derivative from causal relations, so that non-interacting bodies are not situated in the same space&time; another is to eject space&time from our metaphysics; another is to make universal gravitation an essential property of bodies. Any of these will suffice as a first step in solving the problem, and particular implementations of one strategy may lead to endorsement of more than one of these moves.[15] Suppose that we solve this problem, one way or another, and successfully use gravitation as the ground of the unity of the material universe as a whole. This is a solution to the aggregation problem for the world as whole.

What of the multiplicity problem? Are there any material unities smaller than the entire material universe as a whole? Well, of course there *must* be, since the gravitational interaction acts between bodies, and these bodies must be at least as metaphysically robust as the whole that they constitute via their gravitational interactions. What is the ground of the unity of these bodies? Here the situation gets complicated. Take the Earth-Moon gravitational pair, and suppose that these are the only two bodies in the universe. Gravity has a role to play in holding the Earth together as a body, and in holding the Moon together as a body, as well as in holding the Moon in orbit around the Earth such that together the two form a whole (the entire material universe). The problem is this: the gravitational interaction cannot distinguish the Earth and the Moon into distinct individuals as well as aggregating the pair into a whole. In what follows I will indicate some of the difficulties involved in trying to address this problem.

One proposal might be to introduce additional short-range causal interactions that are the ground of the unity of the Earth as an individual body, rather than having gravitation playing that role. Certainly, Newton is committed to there being other interactions between bodies. Perhaps these short-range interactions are what glue sub-systems of the universe together, while universal gravitation grounds the unity of the material world as a whole. This may be right, but at best things are beginning to get messy.

Moreover, if there are parts of the Earth that are glued together by these additional interactions and/or gravity, what are they? In the end, on the causal-interaction approach there have to be basic unities to be glued together whose unity is not itself grounded in the forces appearing in the second law. Indeed, the general lesson here follows whether one appeals to the forces on the left-hand side of Newton's second law or to some other account of causality. The upshot is that once again we are driven to introduce a second principle of unity: we must introduce atoms (be they extended or point-like).

What are the properties of such atoms? If they are to be bodies, then for Newton they must have inertial mass, and hence (given Definition 1 of the *Principia*) they must be extended.[16] On the other hand, we might postulate a point-like atom, with indivisibility as the metaphysical ground of its unity. While such atoms would not be spatially extended, they must be such that spatially extended bodies can be built out of them via causal interactions. But if they are not extended, then they are not themselves bodies, and their properties lie outside the reach of the *Principia*. It seems to me that Newton did not think he needed to add anything to his physics in order to ground the unity of his atoms.[17] In the next Section I will describe an alternative approach that uses Newton's physics to offer metaphysical grounds for the unity of the universe as a whole, of composite sub-systems of the universe (such as the Earth), and *also* of atoms (i.e. non-composite sub-systems of the universe).

For now, our conclusion is that while universal gravitation looks like a promising candidate for the ground of the unity of the material world as a whole, it quickly leads to problems, and it does not offer a route to a general principle of unity capable of addressing by itself both the aggregation and the multiplicity problems. Indeed, the lesson is more general: the causal-interaction approach *re-*

[14] Leibniz, of course, rejected space&time as a metaphysical principle of unity.

[15] For a recent extended discussion of Kant's treatment of unity and causality, see (Watkins, 2005).

[16] Much of the *Principia* is consistent with non-extended point particles. Evident here is the tension between the geometrical and dynamical conceptions of body. See (Biener & Smeenk, 2012, esp. pp. 115–116).

[17] See the discussion of Newton's atomism in Section 5.3 below.

quires that we introduce entities that are the subjects of the causal interaction but which themselves are genuine unities in virtue of some other principle of unity.

5. Laws as a principle of unity

I turn now to what I will argue is the most promising approach to unity available in Newton's physics. Since this approach is the least familiar of the three, it is worth saying a little about it before explicitly addressing the issues at stake in this paper.[18]

5.1. A law-constitutive approach to parts and wholes, and to their properties

In the manuscript "De Grav," Newton (2004, pp. 12–39) is engaging with Descartes's accounts of space, body, and motion, arguing that they are inadequate for a science of bodies in motion, and offering alternative accounts suitable for this purpose. One of the problems Descartes faces is how to provide the bodies that are to serve as the subject-matter of his laws of nature.[19] I have argued elsewhere (Brading, 2012) that Newton explicitly invokes the laws as part of his solution to this problem. As we noted in Section 3, above, the conditions offered by Newton in the tentative account of bodies he offers in "De Grav" include the requirement that bodies move "in accord with certain laws" (see Newton, 2004, p. 28). This requirement that to *be* a body that is the subject-matter of physics *is*, in part, to move in accordance with the laws, remained in place as Newton worked on revisions to the *Principia* (see Brading, 2012). The philosophical claim is this: we don't *first* give an account of what it is to be a body, and *then* specify the laws that such bodies satisfy; rather, satisfaction of the laws is partly constitutive of *what it is* to be a body *at all*. I call this the law-constitutive approach to bodies.[20]

Moreover, as I argue in (Brading, 2011), the very same approach is available for composite systems and their component bodies. While Newton's first law (the so-called "inertial law") considers the behavior of a single body isolated from interaction with any other bodies, Newton's second and third laws enable a solution to the problem of interacting bodies, such that the composite system (isolated from interactions with any other bodies) satisfies the same inertial principle. From the perspective of the law-constitutive approach, part of what it is *to be* a composite system *is* to satisfy the three laws, and part of what it is *to be* a component body of such a system is also to satisfy the laws.[21] Once again, the philosophical claim is that we don't *first* give a metaphysical account of parts and wholes, and *then* specify the physical laws that such parts and wholes satisfy; rather, satisfaction of the laws is partly constitutive of *what it is* to be a part or to be a composite whole *at all*.

I will not argue directly for the account of simples, composites, parts and wholes being offered here, and nor will I elaborate the general approach in detail. The approach is available in Newton's work, and I will assume it to be *prima facie* viable. With this granted, at least for the sake of argument, my claim in this paper is that one reason the approach deserves our attention philosophically is because of the treatment of unity that it offers. I turn our attention to this in the next section. Before doing so, there is one further aspect of the law-constitutive approach that is worth noting for the purposes of what follows.

Descartes's laws of nature put the problem of collisions center-stage, and articulating successful laws for the collision of bodies was an important achievement of the seventeenth century. A complete solution might be seen as involving two aspects: (1) Identify the properties by which to characterize bodies such that empirically successful rules of collision can be formulated; (2) Account for these properties in terms of a more fundamental metaphysics. For example, properties such as "hardness" and "elasticity" emerged as crucial in articulating laws of collision (aspect (1)), and the Cartesian project demands the reduction of these dynamical properties to the geometrical properties of shape, size and motion (aspect (2)). However, there was a debate during the seventeenth century over whether (2) is necessary, or even makes sense.[22] An alternative is to allow the laws themselves to characterize the properties of bodies, without remainder. Thus, John Wallis wrote:

> I have this to adde ... you tell meeyt ye Society in their present disquisitions have rather an Eye to the Physical causes of Motion, & the Principles thereof, than ye Mathematical Rules of it. It is this, That ye Hypothesis I sent, is indeed of ye Physical Laws of Motion, but Mathematically demonstrated. (Letter to Oldenburg, 5 Dec 1668)

According to Wallis, once we have the correct rules of collision, there is no further metaphysical task: we are done. As Jalobeanu (2011) has pointed out, William Neile disagreed:

> I wish Dr. Wren would explain his principles a little more fully but he is against finding a reason for the experiments of motion (for ought I see) and says that the appearances carry reason enough in themselves as being the law of nature. I think it is the Law of nature that they should appear but not without some causes. (Neile to Oldenburg, 18 Dec 1668)

He went on:

> I think a body cant be made hard without motion in its particles that is with out a spring and the more motion it has the more spring it has ... I think all bodies are like fire only a masse of particles variously moving and sometimes resting ... (Jalobeanu (2011).)

Neile is arguing that we have to give an account of whatever properties appear in the rules of collision (such as springiness) in the terms of a prior theory of matter (in this case, a Cartesian matter theory).

The law-constitutive approach favors Wallis and Wren over Neile. The claim is that the quantities appearing in the laws, such as hardness, springiness, and quantity of motion, require no further metaphysical treatment: a *complete* characterization of these quantities can, in principle, be given by the laws. In other words, there is no further question about the "nature" of motion (for example) beyond that which is answered by appeal to the laws of nature. It is important to bear this in mind in what follows because it cuts off the possibility of traditional philosophical moves before they arise; in particular, no question of whether motion "inheres" in bodies can arise (the law-constitutive approach prevents an inherence metaphysics), and therefore no question can arise about whether there is something (motion) which "transfers" from one body to another.

---

[18] This section summarizes material from (Brading, 2011 and 2012).

[19] See for example (Garber, 1992, pp. 175–181).

[20] There are two versions of the law-constitutive approach: on the weak version, laws are necessary but not sufficient for the constitution of bodies; on the strong version, the laws are both necessary and sufficient. I argue that Newton explicitly adopts the weak version with respect to bodies (Brading, 2011). While the version adopted affects the details of the account given here of unity, it does not affect the general proposal, and I will not go into the details here.

[21] For the details of this account I refer the reader to (Brading, 2011).

[22] See (Jalobeanu, 2011) and (Brading, 2011, p. 139).

The debate over collisions is part of a more general philosophical trend that is prominent in Newton's work: Newton gradually transformed a series of metaphysical questions into empirical questions,[23] and this has profound philosophical ramifications.

We can summarize the law-constitutive approach as follows: bodies (systems, and their parts) are that which satisfy the laws, and the properties of bodies are characterized by their implicit definition in the statement of the laws.

5.2. A law-constitutive principle of unity

Returning to the topic of this paper, if one adopts the law-constitutive approach then the laws provide a principle of unity, or so I claim.[24]

Let us begin with the simplest idealized case and build up our understanding from there, step by step. For the case of "simple bodies" free from interactions, Newton's first law requires that such bodies conserve their state; in particular, their quantity and direction of motion. From the law-constitutive perspective, the conservation of quantity and direction of motion can be understood as the metaphysical ground of the unity of the individual entity:[25] the laws are constitutive of the entities that serve as their subject-matter, and these entities are genuine unities – each body is *one* – in virtue of conserving its quantity and direction of motion. I contend that this is a genuine candidate for a principle of unity. Conservation of total quantity and direction of motion is necessary and sufficient for the entity satisfying the laws to be a genuine unity. Moreover, on the law-constitutive approach to bodies there is no further question about "in virtue of what" a body satisfies the laws, since the laws themselves constitute the bodies that are their subject-matter. Therefore the necessary and sufficient condition for a genuine unity is also a principle of unity.

The approach extends to composite systems. The role of Newton's second law is to determine how our lone body of the first law will change its state under the influence of external forces. Such forces arise through the interaction of bodies among themselves. The role of the third law is to determine the behaviour of interacting bodies, behaviour that must be consistent with the first law continuing to hold for the collection of interacting bodies taken as a whole. From the law-constitutive perspective, such a collection of interacting bodies forms a composite whole *in virtue of* conserving its total quantity of motion and its overall direction of motion (the direction of motion of the center of mass of the collection). Thus, conservation of quantity and direction of motion can be understood as a principle of unity for a composite system, when that system as a whole is free from external interactions. Indeed, the approach as expounded thus far makes no distinction between simple and composite systems.

In the strongest version of this principle of unity, conservation of quantity and direction of motion is necessary and sufficient for the system, be it simple or composite, to form a unity. Notice that this principle of unity is not about the physical glue that binds a composite system together. For this, in the Newtonian picture, we need the specific forces that appear on the left-hand side of Newton's second laws of motion. Rather, according to the law-constitutive approach to unity, satisfaction of the conservation law is necessary and sufficient for unity, independent of any claim about forces. Moreover, notice that no claim is being made about causal interaction: the very same principle applies to simples as to composites, and in neither case is causal interaction playing any role.

One might wonder what the grounds are for claiming that our composite systems are indeed composite. For this, we need an account of parts, as well as of wholes, and the law-constitutive approach also provides such an account. Indeed, the fact that the law-constitutive approach extends to the interacting parts of a composite system is crucial to the superiority of the approach in offering a principle of unity. However, there are additional complexities for the case of parts, so we will take it slowly.

First, we noted above that by means of his third law Newton provides a rule which determines the outcome of two body collisions and interactions, such that the motion of the component bodies after the collision (say) is determined uniquely and quantifiably. This is the means by which we extend the law-constitutive approach to the *component bodies* of a composite system: Newton's laws give necessary conditions for something to *be* a part of a composite system, and sufficient conditions for those parts to be determinate. As such, the law-constitutive approach delivers a principle of unity for the *parts* of composite systems: given a system, those (candidate) parts which satisfy the laws (including the second and third laws) are themselves genuine unities, and therefore (genuine) parts.

Second, notice that this account of parts is more complex than the account of wholes (be they simple or composite) because we are no longer treating systems (be they simples or composites) that are *isolated* from external interactions. The parts of our composite system are interacting with one another, and this means that the force laws are relevant. It is important to see how this works, and how it is different from the causal-interaction approach.

Recall the problems that we ran into for the causal-interaction approach when considering the Earth-Moon two-body system. One problem was that while the gravitational force was used to glue together parts (the Earth and the Moon) into a composite whole, the gravitational force itself couldn't provide us with the Earth and the Moon as the prior unities to be glued together: the approach had to take the simples as *given* or as otherwise grounded. On the law-constitutive approach, by contrast, the Earth and the Moon are genuine parts of the Earth-Moon system because they satisfy the laws (Newton's laws of motion with the gravitational force on the left-hand side of the second law). They are thus genuine unities. Moreover, the composite is a genuine whole because the system as a whole conserves its total quantity of motion (recall that we are assuming a world containing no other bodies). The law-constitutive approach delivers *both* the simples (the parts) and the composite (the whole).

Thus, the law-constitutive approach to unity seems to succeed where the causal-interaction approach failed. But we must take one further level of complexity into account before we declare victory. The Earth-Moon system is a special case because the two parts—the Earth and the Moon—are spatially separated. While they remain spatially separated, the gravitational force in conjunction with Newton's three laws of motion enables the law-constitutive approach to distinguish the Earth-Moon system into genuine parts: the Earth and the Moon. However, were the Earth and Moon to come together spatially, the behavior of the Earth and the Moon would no longer be accounted for by the gravitational force in conjunction with the three laws of motion alone. This is because the gravitational interaction alone does not render bodies impenetrable, and this is what we need for bodies to touch and not overlap spatially. (The gravitational force law runs into problems if two bodies are located at the same spatial point because the strength of the interaction goes *inversely* with the square of the distance.) The gravitational force alone cannot account for why a rock on the surface of the Earth does not pass through the surface and con-

[23] This a theme familiar from the work of Howard Stein, George Smith, and Bill Harper, and developed most recently in (Biener & Smeenk, 2012), (Murray, Harper & Wilson, 2011), and (Janiak, 2008). See also the references in these papers.

[24] The roots of this approach in Newton's work, and the case for it, are made in detail in (Brading, 2011).

[25] Notice one important implication: it cannot be that the very same bodies could satisfy different sets of laws; we will return to this point below (see Section 5.5).

tinue to move towards the center of the Earth. Thus, given only the gravitational force and the three laws of motion, no "part" of the Earth is a genuine part according to the law-constitutive approach. From the point of view of Newton's gravitational force and in the absence of any other forces, the Earth and the Moon must be treated as simples.

While this highlights complexities down the road for the law-constitutive approach in identifying what the *actual* unities are given the *actual* force laws, the point I wish to emphasize is that the philosophical solution to the problem of unity offered by the law-constitutive approach is independent of the specifics of the force laws. The proposal is that, whatever the laws turn out to be, they will deliver parts and wholes along the lines just described for the gravitational case.[26] In this way, the law-constitutive approach provides a philosophical account of the unity of simples, composites, and their parts: both the aggregation and the multiplicity problems are solved.

5.3. Newton and the transformation of atomism into an empirical question

We are being offered a principle of unity that applies across the board to simple things, composite systems, and component parts of those systems. Thus, the law-constitutive approach succeeds where the space-time and causal-interaction approaches most conspicuously fail: we have a principle of unity for simples, enabling us to solve the multiplicity problem. This means that we are not driven to add a further principle of unity for the simples (in order to avoid the infinitely divided or infinitely divisible plenum), by appeal to atomism, for example, or by positing non-extended points as our "fundamental" simples out of which extended bodies are made. Indeed, if we adopt the law-constitutive approach, the very question of whether there are simples (i.e. bodies that satisfy the first law and that do not themselves have parts) or whether it's division all the way down becomes an empirical matter. As we have seen, the law-constitutive approach provides a principle of unity that is not hierarchical: any body that satisfies Newton's first law (for example) is a genuine unity, regardless of whether it is a simple or a composite. Thus, for there to be genuine unities we do not need to posit "fundamental" simple unities, such as atoms. We no longer need atomism in order to address the multiplicity problem. Therefore, as philosophers, we can if we wish be neutral about whether there are any such "fundamental" simples, and leave the issue as an open empirical question.

I think that this is a helpful perspective on Newton's atomism. Despite the problems that it faces, there is no doubt that the atomist "solution" to the multiplicity problem is present in Newton's work. Newton argues for atomism in his earliest unpublished writings (see McGuire and Tamny, 1983, p. 341 and surrounding pages), beginning with a homogeneous "first matter" which is divisible into parts. The problem is how such a division into parts is possible (the multiplicity problem), and the solution that Newton argues for is atoms and the vacuum. Newton's atomism is present from this earliest work through to his mature published work. In the *Principia*, Newton's "Rules for the study of natural philosophy" contain reference to "the least parts of bodies" (Newton, 1999), and Query 31 of the *Opticks* asserts the thesis of atomism as "probable" (Newton, 1979, p. 400).

However, it also clear that Newton's approach to matter theory evolved significantly during his lifetime. The argument of Biener and Smeenk (2012) is important in this regard. Biener and Smeenk discuss two conceptions of matter that run through much of Newton's physics ("geometrical" and "dynamical" conceptions), showing how priority gradually shifts from the former to the latter, even though Newton saw no conflict between the two until very late. The geometrical conception of matter is familiar from Descartes, and it relates "quantity of matter" to the volume of space that a body occupies. This view is found in "De Grav", where (as we saw earlier) Newton presents an account of bodies as shapes impressed in space, and for our purposes the crucial point to note is that it makes claims about the nature of matter prior to specifying the laws. According to the dynamical conception, on the other hand, quantity of matter is characterized by the way a body interacts with other bodies, which is in turn characterized by the laws governing the behavior of bodies (and in particular the response of a body to impressed force). This is consistent with a law-constitutive approach. While the geometrical conception is prominent in "De Grav," the dynamical conception is also present: whenever Newton characterizes bodies in "De Grav," he includes the requirement that to be a body is to move in accord with certain laws. In the *Principia*, the geometrical conception appears in Definition 1 but, as Biener and Smeenk argue, the dynamical conception does most of the work in the arguments of the *Principia*. Moreover, Biener and Smeenk argue that when a tension between the two conceptions began to make itself felt, during Newton's correspondence with Cotes prior to publication of the second edition of the *Principia*, the dynamical conception triumphed.

This triumph of the dynamical conception is philosophically significant with respect to the issues we are discussing here because it enables us to be neutral on whether or not there are atoms without running afoul of the problems of divisibility that led us to atomism in the first place: atomism becomes an *empirical* question, rather than one that must be settled *a priori* before physics can begin.[27]

5.4. Advantages of a law-constitutive approach to unity

The *prima facie* advantages of the law-constitutive approach are therefore clear. A single principle of unity solves the aggregation problem for the whole universe and also for sub-systems, and solves the multiplicity problem. This is unlike either of the other approaches arising from Newton's physics that we have considered here. Moreover, the law-constitutive approach makes atomism an empirical matter, in line with Newton's increasing thrust towards turning metaphysical questions into empirical questions.[28]

We have, by now, departed significantly from Newton's own position. For Newton, I think there is no question but that space&time, as emanations from God, provided the metaphysical ground of the unity of the world as a whole. However, I also insist that the law-constitutive approach to bodies is explicit in Newton's work, and offers a natural extension to a principle of unity for the universe as a whole and to its parts in the way I have outlined here. And we do not need both. Since the space&time approach is insufficient on its own to solve the aggregation and multiplicity problems, and the causal-interaction approach fares little better, we should see where the law-constitutive approach can take us.

5.5. The status of the laws

If the laws are to play this fundamental metaphysical role, grounding the unity of what there is, then we must address the metaphysical status of these laws. Newton cannot be our guide

[26] In order to complete our account of the nature of bodies, systems, and their parts, we will need the details of all the forces, but the form of the solution, and its philosophical viability or otherwise, is independent of the specific form that the force expressions take.

[27] See Section 5.1. above, for references on this theme of rendering metaphysical questions empirically tractable.

[28] Once again, see Section 5.1 above for references on this theme.

here: as I noted above, when it comes to unity it is clear that space&time play the fundamental role for him. Moreover, Newton's account of the status of laws is a matter of scholarly discussion. In this final section, I therefore consider the problem in the context of early modern philosophy more generally.

In his recent book on laws of nature in early modern philosophy, Walter Ott (2009) frames his discussion in terms of two possible models for the status of laws. On the "bottom up" model, laws "flow from" the natures of bodies (such that one could not have a world with the very same bodies but different laws of nature). On the "top down" model, laws are imposed on bodies, independent of their natures (so that the very same bodies could obey different laws). He then poses a dilemma. Either we adopt the "bottom up" approach, in which case the nature of bodies is what is responsible for their behavior and there is no ontological role for the laws.[29] Or we adopt the "top down" approach so that laws "genuinely govern" in the sense that the behavior of bodies does not follow from the nature of those bodies alone, but then the ontological status of this "governing" stands in need of clarification: whence the causal efficacy that goes beyond that of the bodies themselves?

Ott argues that Descartes implements a "top down" strategy. With God as the primary cause "Descartes turns, not to extension and its properties as secondary causes, but to laws." Thus, it is not the properties of bodies that are the secondary causes (the causes of the particular motions of particular bodies), but the laws. Moreover, these laws do not follow from the nature of bodies as extended things, but from the nature of God, specifically his immutability (see Descartes, 1991, Part II). Ott writes: "The laws of nature are derived, both epistemically and metaphysically, from God's nature alone," and "swing entirely free of the bodies whose behavior they prescribe" (Ott, 2009, p. 54). My purpose here is not to enter the debate over Descartes exegesis; I am quoting Ott on Descartes as an illustration of what Ott has in mind by the "top down" view, and because Descartes was an important source for Newton. The problem to be addressed is this: On such a top-down view, whence the causal efficacy of the laws? Are they efficient causes, as one might understand the power of bodies on the bottom-up approach, supplementing or replacing the efficient causation of body upon body according to their natures? Or is some other account more appropriate?

I do not propose to answer this question here from within the law-constitutive perspective, but rather to make three important points that pertain to any such answer. The first is that this approach is neither "top down" nor "bottom up," but represents a third option. In constituting the very bodies that are their subject-matter, the laws constitute the nature of those bodies, and their causal powers. Thus, neither are the laws rendered redundant by any law-independent natures of bodies, nor do they "swing free" of the bodies that they govern thereby rendering the dominion of laws over bodies mysterious.

This does not answer the question of the status of the laws, but that very observation brings me to my second point. A variety of possibilities remains available, and the law-constitutive approach itself is *neutral* among them. Adopting the law-constitutive approach will not decide for us among various possibilities for the status of laws. However (and this is the third point), the approach that you take to laws has immediate implications for the status of the entities that are the subject-matter of the laws: they can be no more metaphysically robust than the laws themselves. Thus, if the laws are mind-dependent regularities, then bodies inherit this mind-dependent status. If there is a variety of necessity associated with the laws, then this will transfer to the nature of bodies, and to their behavior in accordance with the laws, including their interactions among themselves.

There is much more to be said in developing the details of how this might go given any particular stand on the status of laws (or of bodies). Clearly, moreover, there are direct connections to one's account of causality. My purpose here has been to highlight the existence of this third approach to unity in Newton, and to begin the argument for its superiority over the other two, more familiar, approaches.

6. Conclusions

I have claimed that there are three candidates for principles of unity in Newton's physics: space&time; causal-interaction; and law-constitutive. The first two are familiar, and I have argued for the presence of the third in Newton's work elsewhere (see Brading, 2011). Here, my purpose has been to argue for the superiority of the law-constitutive approach in providing a principle of unity. This superiority lies in the ability of the law-constitutive approach to provide a single principle of unity that applies to simples, composites, and the universe as a whole. What is interesting, I think, is to re-consider the moves made by philosophers post-Newton in the light of all three possibilities, rather than just the first two. In particular, the themes discussed in this paper are prominent in Kant's writings on natural philosophy, where the problems of unity, and the roles of space and time and of causality, are transformed and explored. Does recognition of the law-constitutive approach open up moves that Kant might have made but didn't? And if so, what are the implications?

Acknowledgements

My thanks to Mary Domski, Michela Massimi, and Eric Schliesser for their comments on earlier drafts of this paper.

References

Biener, Z., & Smeenk, C. (2012). Cote'squeries: Newton's empiricism and conceptions of matter. In Janiak & Schliesser, pp. 105–137.
Brading, K. A. (2011). On composite systems: Descartes, Newton, and the law-constitutive approach. In D. Jalobeanu & P. Anstey, pp. 130–152.
Brading, K. A. (2012). Newton's law-constitutive approach to bodies: A response to Descartes. In Janiak & Schliesser, pp. 13–32.
Burtt, E. (1954). *The metaphysical foundations of modern science*. Anchor Books.
Descartes, R. (1991) Trans.. In V. R. Miller & R. P. Miller (Eds.), *Principles of Philosophy*. London: Kluwer Academic Publishers (First published 1644).
Garber, D. (1992). *Descartes' Metaphysical Physics*. Chicago, London: University of Chicago Press.
Holden, T. (2004). *The Architecture of Matter: Galileo to Kant*. Oxford: Oxford University Press.
Jalobeanu, D. (2011). The Cartesians of the Royal Society: The debate over collisions and the nature of body (1668–1670). In D. Jalobeanu & P. Anstey, pp. 103–129.
Jalobeanu, D., & Anstey, P. (Eds.). (2011). *Vanishing Matter and the Laws of Nature: Descartes and Beyond*. New York: Routledge.
Janiak, A. (2008). *Newton as Philosopher*. Cambridge: Cambridge University Press.
Janiak, A., & Schliesser, E. (Eds.). (2012). *Interpreting Newton: Critical essays*. Cambridge: Cambridge University Press.
Lennon, T. M. (2007). The Eleatic Descartes. *Journal of the History of Philosophy, 45*, 29–47.
Murray G., Harper W. & Wilson C. (2011). Huygens, Wren, Wallis and Newton on Rules of Impact and Reflection. In D. Jalobeanu & P. Anstey, pp. 153-193.
Newton, I. (2004). De Gravitatione. In A. Janiak (Ed.), *Philosophical Writings* (pp. 12–39). Cambridge: Cambridge University Press.
Normore, C. G. (2008). Descartes and The Metaphysics of Extension. In J. Broughton & J. Carriero (Eds.), *A Companion to Descartes* (pp. 271–287). Oxford: Blackwell Publishing.
Ott, W. (2009). *Causation and Laws of Nature In Early Modern Philosophy*. Oxford: Oxford University Press.
Rozemond, M. (2008). The Achilles Argument and the Nature of Matter in the Clarke Collins Correspondence. In T. M. Lennon & R. J. Stainton (Eds.), *The Achilles of Rationalist Psychology* (pp. 159–175). Springer.
Slowik, E. (2009). Newton's Metaphysics of Space. A "Tertium Quid" betwixt Substantivalism and Relationism, or merely A 'God of The (Rational Mechanical) Gaps'? *Perspectives on Science, 17*, 429–456.
Watkins, E. (2005). *Kant and the Metaphysics of Causality*. Cambridge: Cambridge University Press.

[29] An epistemic role might well remain, of course, in summarizing regularities.