Research Dossier

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The following materials are enclosed in this research dossier:

Dissertation Summary

Title: *Physical Quantities: Mereology and Dynamics*

Zee R. Perry

Physical quantities—things like length, mass, charge, and volume—are commonly represented in science and everyday practice with mathematical entities, like numbers and vectors. A satisfactory account of the physical world should give us an understanding of the underlying physical structure in virtue of which these mathematical representations are successful. In my dissertation, I defend a two-pronged account of quantity that analyzes this structure in terms of how that quantity traffics with the rest of the physical world. In the first half (Chapters 1 and 2), I argue that, for some quantities—which I call "properly extensive"—this structure is grounded in their relationship to the *parthood*. The second half (Chapters 3 and 4) concerns the relation between physical quantities and dynamics, and argues that all *other* quantities have their structure only derivatively, in virtue of their dynamical connections to properly extensive quantities according to the physical laws.

There is a commonly accepted distinction between *intensive* quantities (like density or temperature), for which the temperature, say, of a whole is, in general, not the "sum" of the temperatures of its parts, and *extensive* quantities which *are* additive in this way. In Chapter 1, I argue that there are more ways a quantity can impact what parts an object can have, or what those parts must be like, than what's captured by the intensive/extensive distinction, and introduce the notion of a *properly extensive* quantity. Quantities like mass and charge are extensive but not *properly* so, since they are "additive" but not "subtractive": *If* an object can be divided into massive parts, then its mass must be the "sum" of the masses of those parts. However, the converse is not necessarily true: A muon, for instance, has a greater mass than an electron but has *no* part as massive as that electron (since they are both fundamental particles). In contrast, length is *properly extensive*: A line's length is the "sum" of l_α and l_β if *and only if* it is divisible into two parts of length l_α and l_β respectively. Quantities like length, volume, and temporal duration are, I argue, properly extensive.

Chapter 2 defends an account of these quantities according to which predicates like "shorter than" and "(not as long as, but) as long as a part of" are not just necessarily coextensive (as established in Chapter 1), they're expressions of the *same relation*. I call this the Mereological-Reductive (M-R) account of properly extensive quantities, and present the M-R account of volume in formal detail. The account defines the relations that constitute volume's quantitative structure in terms of mereological relations and the sharing of intrinsic volume properties. I give mereological definitions for volume ordering and summation relations as well as a schema for the many volume *ratio relations*, e.g.:

x is 17/5-times the volume of $y =_{df}$ x is composed of 3 non-overlapping parts, 2 of which have the same volume as y, and another part, "z", such that y is composed of 2 non-overlapping parts, all of which have the same volume as z.

I show that this definition schema extends to capture even *irrational* volume ratios, like "π-times the volume of". The M-R account's definitions necessarily satisfy all the formal features needed to justify representation with real numbers, and they do justice to the intuition that volume ordering, summation, and ratio relations are *intrinsic* to their relata. In contrast, I argue that competing theories of quantitative structure, like those defended by Field (1984) and Mundy (1987), cannot give a fully general account of volume metric relations without giving up intrinsicality.

Chapters 3 and 4 concern quantities which are not properly extensive, like mass, charge, temperature, density, etc. We cannot ground these quantities' structure in the physical makeup of their instances (as the M-R account in Chapter 2 does for properly extensive ones) because their quantitative structure is not reflected in the parthood structure of their instances: e.g., two massive point particles may stand in the "π-times as massive as", or the "twice as massive as" or any of countless other mass metric relations, despite both having no proper parts.

Chapter 3 takes this point further. Not only is the parthood not *sufficient* to ground mass's metric structure, but, I argue, any account on which mass's additivity is *not* dependent on (or otherwise determined by) the *dynamics of massive bodies* commits itself to a pervasive explanatory failure. In particular, taking mass's additivity to be *independent* of dynamics commits you to widespread unexplained correlations between the mass properties instantiated by composite bodies and the dynamic behavior of those bodies. For instance, mass additivity explains why a body composed of two particles weighing 2g and 3g, respectively, *instantiates* the property 5g. And the dynamical laws can explain why that same composite body *behaves* roughly like a 5g *simple* particle. But (if additivity is fundamental) these two explanations will have almost *no* overlap, leaving us no means to explain their correspondence. The second half of the chapter extends this explanatory worry, arguing that the very same considerations apply to aspects of mass's *quantitative structure*, namely mass summation structure (in virtue of which one mass property is said to be the "sum" of two others). This gives rise to a new and powerful worry for certain popular accounts of the fundamental structure of physical quantities—most notably the view defended by Mundy (1987) and Eddon (2013).

Chapter 4 argues that the best chance for a viable account of non-properly extensive quantities ('non-' takes wide scope) requires a hierarchical picture—i.e. one where we define one quantity's structure in terms of some *other* quantity, whose structure is taken as given. Specifically, I defend an account which grounds the structure of non-properly extensive quantities in their dynamical connections to the properly extensive ones, as established by the physical laws. Here the difference between cases where, e.g., a pair of point particles stand in "π-times as massive as" and one where they stand in "twice as massive as" is determined by the degree of difference in the accelerations they undergo when impressed by forces of the same strength. I outline some ways this can be done (contra arguments from, e.g., McKinsey et al. (1953) who say classical mass *cannot* be defined in this way), and show how the difficulty of this task varies for different accounts of the metaphysics of dynamical laws.

Statement of Future Research

Zee R. Perry

My primary research interests fall within the metaphysics of physical science. Of these, there are two distinct, but closely related threads, the first concerning the metaphysics of physical quantities, and the second concerning the questions about the nature of spacetime and laws of nature. In addition, I have an active side interest in the ontology of art. My dissertation, "Physical Quantities: Mereology and Dynamics", defended in August 2016, primarily concerned with the first of these projects, though there are also significant overlaps with the second as well. Currently, a key portion of Chapter 1, "Properly Extensive Quantities", of the dissertation has been published (2015, *Philosophy of Science*)..

Two additional articles, consisting of material originally presented in the dissertation are currently under review. The account of quantity I present over the course of the dissertation, which uses the distinction coined in Chapter 1 to construct the two-part, hierarchical theory of quantitative structure developed and defended in Chapters 2 and 4, is well-suited to a book-length treatment. I plan to produce and submit, sometime in the upcoming year, a book proposal incorporating and expanding on the work done in the dissertation.

Spacetime and Dynamical Law

I am interested in issues concerning fundamentality and its role in privileging certain kinds of spacetime structures. I am also concerned with the nature of dynamic physical laws, and how we should understand their modal properties, the physical properties and notions to which they appeal, and the claim that they "govern" the physical world.

I, along with my co-author, Harjit Bhogal, are also working on a follow-up to our "What the Humean Should Say About Entanglement" (Forthcoming), which is to be titled **"Humean Nomic Essentialism"**. The view we defend in the first paper, two-state Humeanism, involves a variant of the best systems account of lawhood. On this variant the system that best describes a Humean mosaic may contain, in addition to true generalizations, the postulation of new, non-fundamental, physical ontology. It's widely thought that something could not possibly be an electron, or anything with (non-zero) charge, if it ignores all electric fields. The generalization of this intuition is a key motivating thought behind the view known as "Nomic Essentialism", according to which physical things have their nomic roles essentially. Some, like Ellis (1999), have argued that the core principles of the Humean worldview are inconsistent with this sort of picture, and so no Humean theory of laws could vindicate this intuition without giving up Humean supervenience. We show that this is mistaken, as two-state Humeanism satisfies a principle very much in the nomic essentialist spirit. We argue that this principle captures what's attractive about this intuition in a way that's consistent with Humean supervenience.

"Does Physics Motivate a Dynamic theory of Quantity", an article expanding on material from my dissertation's Chapter 4, argues for accounts of mass on which its quantitative structure (the properties of mass we represent with mathematics) is grounded in the structure of *other quantities*—viz. spatiotemporal quantities like length or acceleration. I argue in favor of a specific type of such view, theories for which the dependence of mass on other quantities is established via the dynamical laws. For instance, in classical Newtonian mechanics, such a dynamic account of mass says all it is for A and B to stand in a particular mass ratio relation (like "4.8-times as massive as") is for the laws to dictate/predict that they behave in certain ways, where the differences between their behavior can be directly correlated with other quantitative relations—the way that, e.g., $\vec{F} = m\vec{a}$ says that the ratio of relative *acceleration* of two objects under the same force is the inverse of their mass ratio. I argue, specifically, that dynamic accounts of mass in terms of length and temporal duration are philosophically fruitful, since they offer an elegant solution to the problem of under-populated worlds, a pervasive puzzle in the metaphysics of quantity. There's also good *physical* reason to adopt such an account of mass. I argue that the way the dynamical laws handle certain possible worlds where the quantitative facts differ (where, that is, the quantitative structure of mass, length, and/or temporal duration is different than it actually is) strongly suggests that (1) mass is dependent, for its structure, on length and temporal duration, and (2) this dependence obtains in virtue of the dynamical laws being what they are.

I am also working on a paper, titled **"There's Nothing in the Rulebook That Says a Dog Can't Play Basketball"**, that considers two ways we might make sense of the claim that the laws "govern" the physical world. On the "pushy" conception, governing laws are responsible for "producing" or "bringing about" the temporal evolution of the physical state. On the "constraining" conception, laws govern by putting limits on the possible evolution of the physical state. I consider how well each conception deals with the objections commonly raised against governing accounts of laws, and discuss how these conceptions of governing make a difference to our account of lawhood and of the role of laws in the physical world. For instance, only the constraining conception of law understands those aberrant physical scenarios for which Newtonian particle mechanics fails to have a unique solution—cases like "space-invaders" or the Norton dome—as cases of *indeterminism* in the theory; fewer constraints mean more possible evolutions. On the pushy conception, unless there are probabilistic laws that govern stochastically, the lack of a unique solution means that the dynamical laws are unable to evolve the physical state.

There's a standalone paper that I've spun-off of this governing project, which tries to answer some of the metaphysical questions that arise once we recognize the distinction in that paper.. According to a pushy conception of governing, the laws govern events by *evolving* the physical state through time. This gives rise to an account of laws which clearly captures the role laws play in explanating what actually happens. However, pushy accounts of governing laws must also accomodate the *modal* roles played by laws, like grounding counterfactuals and the notions of nomological possibility and necessity, which is significantly less straightforward. For this kind of anti-Humean, laws of nature are not universally generalized propositions or anything of the like. As such, it makes no sense to ask at which possible worlds the laws are *true*. Nor can nomological possibility be had by taking the class of worlds where the same anti-Humean entity, the "pushy governing law", *obtains*. If governing laws occupy their own ontological category, then there's nothing *logically impossible* about Newtonian laws of nature "governing" worlds populated by nothing but spin-1/2 particles. In this paper, tentatively titled **"Governing Laws and Nomological Modality"**, I explore the positions available to the pushy-governing theorist. I argue that there are at least two attractive options, on which nomologically possibility is a matter of the laws both obtaining and *being able to* actually evolve the physical state of a world. Some options are distinguished by how they qualify the "able to actually evolve the physical state" condition—e.g., able to evolve for some non-zero duration, or able to evolve infinitely. Likewise, we might strengthen the condition by adding a *uniqueness* requirement, excluding from nomological possibility states that have *multiple* evolutions consistent with that world's deterministic laws.

The Metaphysics of Quantity

I am also actively working on papers that make contributions to the metaphysics of quantity beyond what falls within the scope of the dissertation.

In **"Are Physical Constants Quantities?"** I consider two ways of understanding the nature of fundamental physical constants—like the gravitational constant, G, or Planck's constant. On the "world-property" picture, these constants are magnitudes of a physical quantity instantiated by the world as a whole. On the "special-kind-of-law" picture, dynamical laws are relations between physical quantities, and what physical constants do is characterize the *nature* of these relations, though they are not, themselves, quantities. The world-property view is, prima facie, more attractive since it can make sense of the idea that change in the values of physical constants (whether over time or from place to place) is nomologically possible. However, I argue, the special-kind-of-law picture makes up for these difficulties with its simplicity. That is, we can ground physical constants in a very clear and simple way on the special kind of law picture. The world-property view, on the other hand, requires positing a new physical quantity (and all the structure that goes with it) for each such constant, and, I argue, may well also require positing quantities for (what we'd intuitively call) "*merely possible* constants".

My "Properly Extensive Quantities" (2015) introduces the notion of a "properly extensive" quantity (like length, volume, or temporal duration), and distinguish them from "merely additive quantities" (like mass and charge), which are extensive but not properly so. It is sometimes said of mass (or of extensive quantities in general) that it is the "measure" of a physical system's "*extent*". In **"Extension, Zero magnitudes, and the Problem of Quantitative Resemblance"**, I argue that *properly extensive* quantities are better suited to "measure of the extent" of a physical system than the broader category of "extensive" quantities. Two important issues in the metaphysics of quantity depend, I argue, on which quantities are "measures of extent": The first concerns *quantitative resemblance*. It's generally thought that the notion of "exact similarity", understood in terms of shared natural properties, cannot account for a 3m rod being more similar a 2m rod than it is to a 45m rod (since none of them share any natural length properties except "has a length"). I argue, however, that we can give an elegant theory of quantitative resemblance, in the case of properly extensive quantities, in terms of exact similarity, but only if these quantities are the measure of a system's "extent". This account depends on the second issue, which concerns so-called "zero magnitudes". Should we interpret the terms '0m' (zero meters of length) or '0kg' as denoting a *lack* of length/mass? Or, are they merely another way of *having* length/mass, on par with any of that quantity's other magnitudes? The notion of extent, I argue, offers a clear answer: *zero extent* is a lack, while other zero magnitudes are not.

One of the papers I've started outlining most recently concerns a *specific* quantitative property and how it should be understood in relation to a particular space-time structure. It is framed around the tension between two claims: (1) In 1879, A. A. Michelson measured the speed of light to within 99% accuracy; and, (2) Strictly speaking, there is no speed of light (in special relativity). In this article, provocatively titled **"There's No Speed of Light, so What the Heck did Michelson Measure?"**, I resolve this tension and explain how the specific value assigned to light (i.e. 299,792km/s) should be understood, if not as a speed. While the tension between (1) and (2) is obvious, their plausibility is somewhat controversial. Many physicists and philosophers of physics reject (2). The first part of the paper resolves this confusion by diagnosing it as stemming from commitment to a "Strong Co-ordinate Abstraction Principle" (or "Strong CAP") according to which agreement between *all* different equivalent co-ordinate representations (of a given sort) about some physical claim entails that this claim is a physically real part of the system represented. Strong CAP is *prima facie* plausible, but, I argue, this plausibility evaporates in the face of some blatant counterexamples—e.g., all the different Cartesian co-ordinatizations of a Euclidean space will all agree that "there exists some point which is the origin point" (despite disagreeing about which point it is). I argue that the problems with Strong CAP are pervasive. That is, there's no plausible weakening of CAP that could *rule out* its problem cases *and* retain the speed of light. The ascription of a speed to light is, despite its constancy across different inertial frames, an artifact of our co-ordinate system and not reflective of the physical world. Once it's established that, strictly speaking, there is no speed of light. Then the claim that Michelson measured the speed of light with upwards of 99% accuracy becomes appropriately mysterious. What could he have been measuring, if not the speed of light? Surely not something purely conventional. The remainder of the paper outlines what part of the world the value 299,792km/s corresponds to. Put roughly, the number represents an *a posteriori* relationship between our independently-chosen units for temporal duration and spatial distance. Special relativity privileges a ratio relationship between values of the two quantities which, under previous space-time theories, were incommensurable. The value obtained by Michelson is the measure of this ratio relation.

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