

Fundamental Properties and the Laws of Nature

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Abstract

Fundamental properties and the laws of nature go hand in hand: mass and gravitation, charge and electromagnetism, spin and quantum mechanics. So, it is unsurprising that one's account of fundamental properties affects one's view of the laws of nature and vice versa. In this essay, I will survey a variety of recent attempts to provide a joint account of the fundamental properties and the laws of nature. Many of these accounts are new and unexplored. Some of them posit surprising entities, such as *counterfactuals*. Other accounts posit surprising laws of nature, such as instantaneous laws that constrain the initial configuration of particles. These exciting developments challenge our assumptions about our basic ontology and provide fertile ground for further exploration.

1. Metaphysical Overview of Properties and Laws

In this section, I will describe in broad outline what fundamental properties are, as well as some of the philosophical issues pertaining to fundamental properties that have been discussed recently in the literature. Then, I will do the same for the laws of nature.

1.1. PROPERTIES

Fundamental properties are the most basic properties of a world. In terms of the new, popular notion of grounding, fundamental properties are themselves ungrounded and they (at least partially) ground all of the other properties.¹

Lewis (1983) identifies the fundamental properties with privileged sets of actual and possible objects. According to physicalism, these fundamental properties are likely given by ideal physics (mass, charge, spin, etc.) If property dualists are right, then some mental properties may count as fundamental as well. Following Lewis (1983), many philosophers think the fundamental properties are *perfectly natural* – they carve nature at its joints. Many philosophers also think the bearers of fundamental properties form *natural kinds* – the fundamental property of negative unit charge is part of what makes the collection of all electrons a natural one.

Philosophers disagree about whether the fundamental properties are intrinsic or not, whether they are locally instantiated or not, and whether these properties are universals, tropes, or something else. Philosophers also disagree about whether fundamental properties are inherently modal or not. For instance, there may be fundamental, dispositional properties with essential causal or nomic roles (e.g. anything with negative charge necessarily attracts objects with positive charge). Some also hold that these causal or nomic roles are individuating (e.g. anything that attracts objects with positive charge has a negative charge). On the other hand, the fundamental properties may be non-modal or categorical² and individuated solely by quiddities – a kind of haecceity, or this-ness, for properties. And, of course, one may have a hybrid view that includes some dispositional, fundamental properties and some categorical, fundamental properties.

These features of fundamental properties lead to some very interesting issues. For instance, some fundamental properties can be co-instantiated (1 g mass and a charge of +1), but some cannot (1 g mass and 2 g mass).³ Also, if fundamental properties are determinables, they seem able to come in degrees (the property of mass can be instantiated in different amounts).⁴ On the other hand, if fundamental properties are determinates, they seem to form natural groups (the property of 2 kg seems ‘more like’ the property of 1 kg and ‘less like’ the property of charge of +1).

Finally, these properties can be instantiated independently of one another, as in the case of the masses of different objects, or dependently, as in the case of the spin of different, but entangled, objects. In the case of particles with entangled spins, the spin properties of one particle – for instance, *z*-spin-up – cannot be fully characterized independently of the spin properties of the other. In the case of quark color, Tim Maudlin (2007) argues that one cannot say whether or not two quarks have the same color independently of the connection between them. These correlations suggest that we may need to modify our picture of the fundamental ontology. Perhaps, as Schaffer (2010) argues, particles are not as fundamental as the whole cosmos. Or, perhaps, as Maudlin (2007) argues, electromagnetic properties are not best captured by universals, but by more abstract mathematical objects called fiber bundles and their connections. As he puts it, ‘in gauge theory the electromagnetic field or the gluon field turns out just to *be* the connection on a fiber bundle.’ I will have more to say about these issues below.

1.2. LAWS OF NATURE

Broadly, there are two ways to view the laws of nature: as governing or as systematizing. These two views give different answers to the central question of whether the laws depend on the objects and properties in the world or whether the objects and properties in the world depend on the laws.⁵

According to the governing approach, the laws of nature have nomological and productive force. The laws *metaphysically determine* what happens in the worlds that they govern. It is common to see governing laws given a metaphorical gloss. They are said to have ‘oomph’ or that they ‘push’ and ‘pull’ stuff around the universe. Note that whatever governing is, it is widely considered to be distinct from causation. While governing laws may ground or underwrite causation, it is typically the other entities – such as events, facts, or states of affairs – that are taken to be causes. Two of the most thorough and prominent accounts of governing are given by David Armstrong (1983) and Tim Maudlin (2007).

According to the systematizing approach, the laws merely summarize the events, properties, or trajectories of a world. The laws supervene on, or (stronger) are *metaphysically determined by* what happens in the world that they systematize. For arguments that supervenience is the wrong notion, see Jonathan Schaffer (2009). The laws do not produce one state of the world from another – rather, the laws are a concise way of *summarizing* relations between those states of the world. Even though these laws are generally taken to have a metaphysically objective existence,⁶ they are posited for epistemic reasons. Laws that systematize help us to understand the world, but have no role in producing the world. The most prominent systematizing account is David Lewis’s (1983), (1994) ‘Best System Analysis’ which subsequently has been developed in a variety of different ways.

2. Categorical Properties and Laws

Suppose the fundamental properties are *categorical*. Categorical properties are non-modal. They do not have, e.g., essential dispositions or causal roles. On this view, fundamental properties can be freely recombined. One fundamental property’s instantiation does not have any implications for the instantiation of other fundamental properties.⁷ If mass is instantiated in one location, that

has no bearing on whether or not mass or charge, etc. is instantiated somewhere else. Categorical properties are championed by Humeans who take seriously Hume's dictum that there are no necessary connections between distinct existences.⁸ There are two issues from modern physics that pose problems for categorical properties that deserve a careful treatment. The first comes from gauge theory in chromodynamics and the second, from quantum entanglement.

Tim Maudlin (2007) argues that some properties of chromodynamics cannot be fully characterized independently of one another. He offers the following analogy: does a 'North' pointing arrow in China point in the same direction as a 'North' pointing arrow in the United States? This question can only be answered once we bring the two arrows together to compare them. But, bringing them together is path-dependent. If we bring them together along the equator, say, we get the result that they do point in the same direction. However, if we bring them together along longitudinal lines, to the North Pole, they will point in opposite directions. The same path-dependence applies to the 'standard model' properties of fundamental physics. This suggests that fundamental properties may not be freely recombinable and may indeed have necessary connections to one another. According to Maudlin (2007):

we should note that adopting the metaphysics of fiber bundles invalidates a set of modal intuitions that have been wielded by David Lewis under the rubric of the Principle of Recombination. According to Lewis, Hume taught us that the existence of any item puts no metaphysical constraints on what can exist adjacent to it in space. This invites a cut-and-paste approach to generating metaphysical possibilities: any object could in principle be *duplicated* elsewhere, immediately adjacent to the duplicate of any other item (or another duplicate of itself). [...] Duplication is supposed to be a metaphysically pure internal relation between items. But from the point of view of fiber bundle theory, it makes no sense to 'copy' the state of one region of space-time elsewhere even in the same space-time, much less in a disjoint space-time. There is no metaphysical copying relation such as the Principle of Recombination presupposes.

Next, there is entanglement, a situation in which the properties of two distant particles are correlated. If one particle is measured to have '*z*-spin-up', its entangled partner will be measured to have '*z*-spin-down'. These correlations cannot be reproduced by local, intrinsic properties of the particles, and the effect is generally taken to show that quantum mechanics is 'non-local' in four-dimensional spacetime. Some philosophers, such as Alyssa Ney (2010), think entanglement is best understood in terms of the intrinsic/extrinsic distinction. Yet, it is unclear whether we should think of spin – assuming it is a fundamental property – as intrinsic or extrinsic. Let's take the intuitive characterization of 'intrinsic' given by David Lewis (1986), 'We distinguish intrinsic properties, which things have in virtue of the way they themselves are, from extrinsic properties, which they have in virtue of their relations or lack of relations to other things.' On the most straightforward reading, one particle would seem to have its spin extrinsically, because it has its spin at least partly in virtue of another particle's spin. But, if we take entangled spin as a fundamental property of *two* (or more) particles, it is arguable that the two particle system has its entangled spin intrinsically – i.e. nothing outside of the two particles is required to fully characterize their spin properties.⁹ If we take *systems*, rather than individual particles, as instantiating fundamental, entangled properties, perhaps this can still count as a categorical picture. While there are necessary connections between distinct *particles*, there are not necessary connections between distinct *systems* of particles. The maximal system of particles may include all the particles in the universe, in which case, Jonathan Schaffer's (2010) monist picture may be best-suited to the fundamental ontology. Schaffer (2010) argues that if we think of entanglement properties as extrinsic properties of individual particles, then 'duplicating the intrinsic properties of the particles, along with the spatiotemporal relations between the particles, does not metaphysically suffice to duplicate the cosmos and its contents. The intrinsic correlational properties of entangled wholes

would not be duplicated.’ He argues instead for a monistic fundamental ontology, according to which all fundamental properties (including spin) are properties of the whole cosmos.

Another option advocated by Alyssa Ney (2010) and others is to take the particles themselves to emerge from a more fundamental wavefunction in a high-dimensional space. Then, spin is an intrinsic, local property of the wavefunction. For an excellent discussion of entanglement, see Alyssa Ney (2013). David Albert (2013) and Alyssa Ney (2012) go on to argue that fundamental entanglement properties imply that our physical space has roughly 3×10^{80} dimensions. Thus, an active area of research is to explicate how a space of such high dimensionality would seem to have only three dimensions to beings like us. This metaphysical picture can preserve categorical properties, but these properties are not of particles in three dimensions, but of the wave function – an extremely high-dimensional object.¹⁰

In this section, I will present a variety of different accounts of the laws of nature that all take the fundamental properties to be categorical.

2.1. CATEGORICAL PROPERTIES AND LAWS THAT SYSTEMATIZE

Consider the actual distribution of fundamental, categorical properties, past, present, and future. Then, take this distribution, which is often referred to as the ‘Humean mosaic’, as metaphysically fundamental.¹¹ It is not determined by anything else. More specifically, it is not because of any laws of nature that the properties are distributed in the particular way that they are. Given these assumptions, how should we think of the laws of nature, if, indeed, there are any laws on such a picture?

One popular view is that the laws of nature supervene on, or (stronger) are grounded by, the Humean mosaic. This view is called the ‘Humean Best System’, according to which laws are statements that summarize the distribution of categorical properties.

Traditionally, following David Lewis (1983) and (1994), the summary is taken to be the set of axioms of the system that best balances simplicity, informativeness, and fit when written in terms that reference only the perfectly natural, categorical properties.¹² Laws are simpler when the sentences are fewer and shorter. Laws are more informative when they summarize more of the distribution of categorical properties. And laws fit better when the probabilities assigned to sequences of property distributions are higher (closer to one). It is reasonable to think that these virtues ‘trade off’. For instance, gains in simplicity may result in a loss of informativeness. Thus, the best system is the one that strikes the best balance between simplicity, informativeness, and fit. Best system laws describe, but do not metaphysically determine, the evolution of the universe.

Lewis’s ‘Best System’ has been developed in more detail by a variety of authors. Not everyone is happy to posit a privileged set of perfectly natural, categorical properties, as Lewis (1983) does. Notably, Barry Loewer (2007) defends a view in which the laws are the axioms of the system that best balances simplicity, informativeness, and fit in terms that reference the properties that scientists find most useful. On this view, the fundamental properties and the laws are determined together, in a single, ‘package deal.’¹³

Though there are many objections to Lewisian best systems (and at least as many replies), I will present the three that I take to be most pressing in the recent literature.

The first objection is that best system laws cannot support all of the counterfactuals that we think laws ought to support. It is generally accepted that laws play an important role in evaluating counterfactuals – statements about what *would* be the case – *were* something to happen. To see the problem, consider a world with a single, massive particle at rest. This particle’s behavior is consistent with a wide range of different laws (Newtonian, general relativistic, etc.). Nevertheless, according to a Humean best system, that world’s laws – balancing simplicity,

informativeness, and fit – would merely state that all particles remain at rest. Thus, on a standard account of law-derived counterfactuals,¹⁴ if a second massive particle *were* present, both would remain at rest. Intuitively, however, it is true (in some conversational contexts) that if a second massive particle were present, the particles would accelerate toward one another. But, in order for the standard account of counterfactuals to yield this result, a law of gravitation would have to be true of that world. An account of the laws can accommodate these counterfactuals only if it countenances worlds whose distributions of properties match, yet whose laws of nature differ (or if it offers a different theory of counterfactuals).

This objection has been pressed by a variety of authors. For instance, John Carroll (1994) argues these thought experiments constitute counterexamples to the Humean view. Tim Maudlin (2007) argues that in practice, physicists think of possible worlds as models of, or possible solutions to, the laws of nature. Thus, different laws of nature often yield, as models, worlds that nevertheless match in their distribution of fundamental properties – something the Humean best system does not countenance. This suggests that the Humean best system is an impoverished way to view the laws of nature. Helen Beebe (2000) argues that these thought experiments beg the question against the Humean because they presuppose that worlds can differ even when they match in every matter of categorical fact. Susan Schneider (2007) argues that intuitions about these thought experiments ought to be taken seriously, but that it is still an open question whether the Humean view is strongest overall, despite this disadvantage. Heather Demarest (2015) argues that it is a strong reason against pairing categorical properties with a best system account of laws.

The second objection is that the best system does not always yield probabilities that are credence-guiding. It seems that our credences, or degrees of belief, ought to track the lawful, objective chances in the world. For example, if a die has a chance of $\frac{1}{6}$ of landing two-up, then someone who knows the chance ought to have a credence of $\frac{1}{6}$ that it will land two-up. David Lewis (1980) codifies this as the *Principal Principle*: one's reasonable initial credence in p ought to be equal to the chance of p , assuming one has no inadmissible information (e.g., from the future). Unfortunately, this plausible principle is not compatible with a Humean best system account of laws. The incompatibility is known as the 'big bad bug' of Humean supervenience. The conflict arises from the fact that knowledge of best system chances – which is really just knowledge of the lawful systematization of the Humean mosaic – amounts to a kind of knowledge of the future. This implies that in certain cases, even when one knows the best system chances (and nothing else about the outcome of future events), one ought to have credences that differ from those chances. For instance, suppose a world contains only one, chancy die (and myself, a non-interacting observer). The die will be rolled six times and the best system laws give it a chance of $\frac{1}{6}$ of landing two-up. Then, if I know these facts, and if I observe the die to land non-two-up five times, I ought to be certain that the remaining roll will land two-up (otherwise, the best system would not have said the chance of two-up is $\frac{1}{6}$). But, this means that while the chance is only $\frac{1}{6}$, I ought *not* set my credence to $\frac{1}{6}$, but rather to 1.¹⁵ It is generally conceded that on a Humean best system of chance, one must modify either the Principal Principle¹⁶ or the account of chance,¹⁷ neither of which is a particularly attractive option.

Another objection that has been developed recently is that laws that merely systematize are not truly explanatory. Grant that the laws have predictive utility, indeed, the laws may be indispensable for scientific theorizing. But, they do not explain why things are the way they are – a feature that is typically taken as a hallmark of laws of nature. Of course, it is uncontroversial that best system laws do not explain in the sense of metaphysical grounding or production – rather, it is the mosaic of fundamental properties that metaphysically grounds (or perhaps merely subvenes) the laws. And, it is uncontroversial that the best system laws scientifically

explain – in the sense that one can use these laws to make predictions. Thus, the debate is really a debate about what counts as *genuine explanation*. Marc Lange (2012) presses this objection and Barry Loewer (2012) and Michael Hicks and Peter van Elswyk (2015) respond to it.¹⁸

2.2. CATEGORICAL PROPERTIES AND HIGH-LEVEL LAWS THAT SYSTEMATIZE

Fundamental, categorical properties may be enough to ground not only basic laws of nature, found in physics, but also higher level laws of nature, such as the laws of chemistry, biology, and even economics. David Albert (2000) and Barry Loewer (2008), (2007), argue that two statements which describe the initial state of the universe also deserve the status of lawhood because they, in conjunction with the basic dynamic laws of nature, are powerful enough to yield all of the special science laws. More specifically, one statement is that the universe began in a state of comparatively low entropy. The second statement is a uniform probability measure over the initial (low-entropy) distribution of categorical properties. These posits are non-dynamical, because they constrain only the initial state of the universe – they say nothing about how the state evolves over time. Thus, their theoretical, predictive utility (after all, if they are right, the two statements help to yield all of the generalizations one could ever want) outweighs the counter-intuitiveness of believing in ‘static’ laws of nature.¹⁹

2.3. CATEGORICAL PROPERTIES AND LAWS THAT GOVERN

Categorical properties need not pair with a systematizing, Humean theory of laws. David Armstrong (1983), for instance, develops a view according to which fundamental, categorical properties contingently enter into ‘necessitation relations’. Consider a world in which a property *F* is related by necessitation to *G*. In that world, *F* necessitates *G* and if an object, *x*, is *F*, then *x* is likewise *G*. These necessitation relations are themselves contingent, so there are worlds in which the properties *F* and *G* are not so related. Whichever necessitation relations happen to hold in a world are the laws of that world. There is a large literature of objections and replies to such a view. The most serious objection is from David Lewis (1983) who wonders why such laws ‘necessitate’ – it cannot be merely from the fact we call them ‘necessitation relations.’ Bas van Fraassen (1989) calls this the *problem of inference*: why can we infer from the fact that *F* and *G* are related by necessitation that all *F*s are *G*?²⁰

More recently, Tim Maudlin (2007) advances a similar view, according to which fundamental properties are *governed* by laws of nature. While Maudlin does not accept that the fundamental properties are purely categorical,²¹ he does not take them to have essential dispositions or causal roles either. Thus, Maudlin’s view is most similar to Armstrong’s view. Maudlin takes the laws of nature to be fundamental. And, the laws take one state of the world and produce the next via the fundamental relation of governance. Since the laws of nature, the properties, and the relation of governance are all fundamental bits of ontology, Maudlin offers no analysis of them. Consequently, one of the strongest objections to this view is that it does not clarify the notion of lawhood or illuminate what it is for a law of nature to govern.

2.4. CATEGORICAL PROPERTIES AND SYMMETRIC LAWS

Since categorical properties do not have modal features, the behavior of the objects that instantiate them can differ radically from world to world. In some worlds, like charges repel, in others they attract, and in still others, they explode/disappear/etc. The only way to identify a categorical property across different possible worlds is via its ‘quiddity’ – a haecceity for properties. Jonathan Schaffer (2005) has argued that these quiddities allow for symmetric laws in a way that

properties defined by their structural roles do not.²² A symmetric law is one in which two (or more) different properties play the same structural roles. If a property's identity were reducible to its structural roles, then it would be impossible for two different properties to play the same role. Only if properties have identities over and above their structural roles – as categorical properties do with their quiddities – are symmetric laws possible.

3. *Dispositional Properties and Laws*

In this section, I will present a variety of different views of the laws of nature, each of which takes the fundamental properties to be dispositional.

3.1. DISPOSITIONAL PROPERTIES

Recently, there has been a resurgence of interest in fundamental properties that are dispositional – properties that are connected (e.g., via causation) to the behavior of the objects that instantiate them.²³ While fundamental dispositional properties are not reducible to categorical bases, they may yet be analyzed in terms of counterfactuals or something else. There are many objections to counterfactual analyses of non-fundamental, dispositional properties, and there are good reasons to think these objections carry over to fundamental dispositional properties. Some philosophers, such as Alexander Bird (2007), maintain that there is not a reductive analysis, but a necessary bi-conditional relating fundamental dispositional properties and counterfactuals. Barbara Vetter (2014) offers a novel characterization of the connection between dispositional properties and modality. On Vetter's account, dispositional properties are individuated solely by their manifestations – dispositions pick out easy possibilities, rather than counterfactual conditionals.

One of the new and exciting questions is how fundamental, dispositional properties relate to the laws of nature. In this section, I will discuss different accounts of the laws of nature, assuming that the fundamental properties are dispositional.

3.2. DISPOSITIONAL PROPERTIES AND NO LAWS

Nancy Cartwright (1983) takes the fundamental properties to be causal. She argues that the fact that these fundamental properties can interact with one another in a variety of ways precludes the existence of true and explanatory fundamental laws of nature. This is because the laws are typically formulated as involving only a single property, and so are, at best, *ceteris paribus* laws. Stephen Mumford (1998) goes further. He accepts that laws govern essentially and argues that since dispositional properties determine the evolution of the world, there is no need for governing laws. Governing laws would introduce causal overdetermination in a world that already includes fundamental powers. Therefore, there are no laws at all.

3.3. DISPOSITIONAL PROPERTIES AND BEST SYSTEM LAWS

However, there are reasons to think that the laws of nature are indispensable to the practice of physics. Thus, if there are both fundamental, dispositional properties and laws of nature, what is the best account of those laws? Heather Demarest (2015) argues that dispositional properties and a modified best system account of laws go well together. On this view, the laws of nature are the axioms that best systematize all of the possible distributions of the actual, fundamental, dispositional properties (where 'best' is the same as it is for the categorical best system). Demarest argues that if one accepts a best system account of the laws, then one ought to take the fundamental properties as dispositional – doing so avoids several objections that plague the categorical best system account. And conversely, that if one accepts fundamental, dispositional

properties, then one ought to think the laws systematize the possible distributions of those properties.

3.4. DISPOSITIONAL PROPERTIES AND NECESSARY LAWS

Many who accept fundamental dispositional properties also defend necessitarianism about the laws – the idea that the laws of nature are metaphysically necessary.²⁴ Suppose that the fundamental properties are essentially dispositional – necessarily, anything with the dispositional property of negative charge is disposed to attract positive charges and repel negative charges. Suppose further that dispositional properties are individuated by their dispositions – necessarily, anything that attracts positive charge and repels negative charge has the dispositional property of negative charge. Then, if we assume there are no alien (i.e., non-actual) fundamental properties, every possible world is going to contain only actual fundamental, dispositional properties (though in different amounts and in different arrangements). It seems plausible that such worlds, which exhibit no difference in the kinds of properties and possible behaviors, would not differ in their laws of nature either.

The strongest objection to necessitarianism is that it offers an impoverished view of possibility. Against the claim that the laws of nature are necessary, it certainly seems as though gravity could be stronger or weaker than it actually is. Indeed, scientists often make these kinds of counterfactual suppositions when they discuss, e.g. how much the constants of nature could vary before atomic structure would break down.²⁵ And, against the claim that there could be no alien fundamental properties, it certainly seems as though the actual fundamental properties do not exhaust the range of all possible fundamental properties. For replies to these objections, see Alastair Wilson (2013).

3.5. COUNTERFACTS AND LAW SENTENCES

Marc Lange (2009) has recently developed an exciting and altogether novel account of properties and laws. On Lange's account, the fundamental ontology includes *counterfactuals*. These counterfactuals are inherently modal – something very much akin to dispositional properties. Lange argues that counterfactuals ground counterfactual sentences, which, in turn, ground the laws. While the details of his view are a bit complicated, the basic idea is that some counterfactual sentences form stable sets. The laws of nature are given by the sentences that are true 'come what may.' More specifically, in any conversational context, and under any counterfactual antecedent (that does not directly contradict the purported laws), a law sentence is true. For instance, the following sentence is true in every conversational context: 'Were I to drop this pen, gravity would still hold.' On this view, at least some of the fundamental properties are modal (in a way that is very similar to dispositional properties), while the laws are the sentences that exhibit the counterfactual stability described above.²⁶

4. Conclusion

How should we think of the laws of nature, if the fundamental properties are categorical? How should we think of the laws of nature if the fundamental properties are dispositional? Conversely, how should we think of the fundamental properties if the laws of nature govern? And how should we think of the fundamental properties if the laws merely systematize? Furthermore, how are all of these questions affected by current physics? Fundamental properties and the laws of nature are both active areas of inquiry and their intersection provides fertile ground for future research.

Short Biography

Heather Demarest specializes in philosophy of science, metaphysics, and philosophy of physics. Her work focuses on metaphysical interpretations and implications of current theories in physics. She is an Assistant Professor at the University of Oklahoma. She received a BA in Physics and Philosophy from CU, Boulder; a BPhil in Philosophy from Oxford; and a PhD in Philosophy from Rutgers.

Notes

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¹ For more on the notion of grounding, see Jonathan Schaffer (2009), Karen Bennett (2011), and Kathrin Koslicki (2012). Kathrin Koslicki (2015) and Michael Della Rocca (2014) have given arguments that many notions of ground may not be able to do the important work that many assume they can do. Thanks to an anonymous referee for noting that it may be possible to formulate (at least some) of the relevant notions of dependence purely in terms of supervenience, as David Lewis (1994) argues. For arguments to the contrary, see Jonathan Schaffer (2009).

² Note that here I use 'categorical' in the Humean sense, to mean non-modal, and take it to be distinct from 'instantiated.'

³ This assumes the fundamental properties are determinates, rather than determinables. For more on necessary correlations between property instantiation, even among allegedly categorical properties, see Wilson (2010) and (2015).

⁴ For more on properties that admit of degree, see Jessica Wilson (2012), Maya Eddon (2013a) and (2013b), and Maya Eddon and Christopher J. G. Meacham (2013).

⁵ Historically, the central question has been whether the laws supervene on a 'Humean mosaic' – the actual distribution of categorical (non-modal) properties. But, this runs together two questions. First, are the fundamental properties purely categorical? And, second, do the laws entirely depend on the distribution of fundamental properties or does the distribution of fundamental properties depend (at least partly) on the laws? In this paper, I focus on the second question.

⁶ See, for instance, Barry Loewer (2007).

⁷ Depending on how one thinks determinables (mass) relate to their determinates (2 kg, 3 kg, and etc.), the instantiation of one fundamental property may restrict the instantiation of others after all, even if those properties are categorical. For a detailed discussion of this problem, see Jessica Wilson (2012).

⁸ For a criticism of Humeanism, generally, see Wilson (2010).

⁹ Thanks to an anonymous referee for suggesting this.

¹⁰ Tim Maudlin (2013) and Valia Allori (2013) disagree with Albert and Ney and argue that the high-dimensional space required by quantum entanglement ought to be thought of as a mathematical abstraction. They tentatively argue that if the wavefunction of the universe does not change over time, then it can be thought of as a law of nature. They reject categorical properties.

¹¹ Note that some philosophers, such as Jonathan Schaffer (2010), think that the distribution of categorical properties is not metaphysically fundamental because it depends on the monist whole.

¹² For this section, we can take the perfectly natural properties to be fundamental, as Lewis (1983) does.

¹³ See also, Jonathan Cohen and Craig Callender (2009).

¹⁴ While there are a wide variety of counterfactual analyses, most agree that a counterfactual evaluated in a non-actual possible world must take the laws of that world into account.

¹⁵ For a good discussion, see Rachael Briggs (2009).

¹⁶ See, for instance, Ned Hall (1994) and Jenann Ismael (2008).

¹⁷ See, for instance, Frank Amtzenius and Ned Hall (2003).

¹⁸ See also, Tim Maudlin (2007) and Alexander Bird (2007).

¹⁹ For arguments that Humean special science laws ought to systematize non-fundamental properties, see Jonathan Cohen and Craig Callender (2009) and Markus Schrenk (2012).

²⁰ It is worth mentioning that vanFraassen argues that this objection, paired with the *problem of identification*, is a strong reason to reject metaphysically real laws altogether.

²¹ See discussion above.

- ²² For more on causal roles and quiddities, see John Hawthorne (2001).
- ²³ See, for instance, Nancy Cartwright (1999), Alexander Bird (2007), Jonathan Jacobs (2011), and Barbara Vetter (2014).
- ²⁴ See, for instance, Alexander Bird (2004).
- ²⁵ See, for instance, Jonathan Schaffer (2005).
- ²⁶ See Heather Demarest (2012) for arguments that context sensitivity and problems with nested counterfactuals prevent Lange's account from being successful.

References

- Albert, D. *Time and Chance*. Cambridge, MA: Harvard University Press, 2000.
- . *Wave Function Realism*. In (eds) A. Ney, D. Albert, *The Wave Function: Essays on the Metaphysics of Quantum Mechanics*, Oxford, UK: Oxford University Press, 2013.
- Allori, V. Primitive Ontology and the Structure of Fundamental Physical Theories, In (eds) A. Ney, D. Albert. *The Wave Function: Essays on the Metaphysics of Quantum Mechanics*. Oxford, UK: University Press, 2013.
- Armstrong, D. M. *What Is A Law Of Nature?*, Cambridge: Cambridge University Press, 1983.
- Arntzenius, F. Hall, N. On What we Know About Chance, *British Journal for the Philosophy of Science* 54 (2003): 171–179.
- Beebe, H. The Non-Governing Conception of Laws of Nature, *Philosophy and Phenomenological Research*: 61. (2000): 571–94.
- Bennett, K. Construction Area: No Hard Hat Required, *Philosophical Studies* 154. (1) 2011: 73–104.
- Bird, A. Strong Necessitarianism: The Nomological Identity of Possible Worlds, *Ratio* 17.3 (2004): 256–276.
- . *Nature's Metaphysics*, Oxford, UK: Oxford University Press, 2007.
- Briggs, R. The Anatomy of The Big Bad Bug, *Noûs* 93.3 (2009): 428–449.
- Carroll, J. *Laus of Nature*, Cambridge, UK: Cambridge University Press, 1994.
- Cartwright, N. *How the Laws of Physics Lie*, Oxford, UK: Oxford University Press, 1983.
- . *The Dappled World*, Cambridge, UK: Cambridge University Press, 1999.
- Cohen, J. Callender, C. A Better Best System Account of Lawhood, *Philosophical Studies* 145. (2009): 1–34.
- Della Rocca, M. Razing Structures to the Ground, *Analytic Philosophy* 55.3 (2014): 276–294.
- Demarest, H. Do Counterfactuals Ground the Laws? a Critique of Lange. *Philosophy of Science* 79. (2012): 333–344.
- . Powerful Properties, Powerless Laws, In J. Jacobs (ed.). *Putting Powers to Work: Causal Powers in Contemporary Metaphysics*, Oxford, UK: Oxford University Press, 2015.
- Eddon, M. Fundamental Properties of Fundamental Properties, *Oxford Studies in Metaphysics*, 8, Oxford, UK: Oxford University Press, 2013a.
- . Quantitative Properties, *Philosophy Compass* 87 (2013b): 633–645.
- Eddon, M. Meacham, C. J. G. No Work for a Theory of Universals, *Oxford Studies in Metaphysics*, Oxford, UK: Oxford University Press, 2013.
- Hall, N. Correcting the Guide to Objective Chance, *Mind* 412 (1994): 505–517.
- Hawthorne, J. Causal Structuralism, *Philosophical Perspectives* 15. 2001361–78.
- Hicks, M. T. van Elswyk, P. Humean Laws and Circular Explanation, *Philosophical Studies* 172. (2015): 433–443.
- Ismael, J. Raid! The Big, Bad Bug Dissolved, *Noûs* 42.2 (2008): 292–307.
- Jacobs, J. Powerful Qualities, Not Pure Powers, *The Monist* 1. (2011): 81–102.
- Koslicki, K. Varieties of Ontological Dependence, In F. C. Benjamin Schneider (ed.), *Metaphysical Grounding: Understanding the Structure of Reality*, Cambridge, UK: Cambridge University Press, 2012.
- . The Coarse-Grainedness of Grounding, *Oxford Studies in Metaphysics*, Oxford, UK: Oxford University Press, 2015.
- Lange, M. *Laws and Lawmakers*, Oxford, UK: Oxford University Press, 2009.
- . Grounding, Scientific Explanation, and Humean Laws, *Philosophical Studies* 164.1 2012: 255–261.
- Lewis, D. A Subjectivist's Guide to Objective Chance, in R. C. Jeffrey (ed.), *Studies in Inductive Logic and Probability*, 2, Berkeley: University of California Press, 1980. 263–93.
- . New Work for a Theory of Universals, *Australasian Journal of Philosophy* 61. 1983: 343–77.
- . *On the Plurality of Worlds*, Oxford, UK: Basil Blackwell, 1986.
- . Humean Supervenience Debugged, *Mind* 103. (1994): 473–90.
- Loewer, B. Laws and Natural Properties, *Philosophical Topics* 35.1, 2 (2007): 313–328.
- . Why There is Anything Except Physics, In J. Howhy J. Kallestrup (eds), *Being Reduced: New Essays on Reduction, Explanation and Causation*, Oxford, UK: Oxford University Press, 2008.
- . Two Accounts of Laws and Time, *Philosophical Studies* 160.1 (2012): 115–137.
- Maudlin, T. *The Metaphysics Within Physics*, New York: Oxford University Press, 2007.

- . The Nature of the Quantum State, In A. Ney, D. Albert (eds), *The Wave Function: Essays on the Metaphysics of Quantum Mechanics*, Oxford, UK: Oxford University Press, 2013.
- Mumford, S. *Dispositions*, London, UK: Oxford University Press, 1998.
- Ney, A. Are There Fundamental, Intrinsic Properties?, In A. Hazlett (ed.), *New Waves in Metaphysics*, London, UK: Palgrave Macmillan, 2010.
- . Introduction. *The Wave Function: Essays on the Metaphysics of Quantum Mechanics*, Oxford, UK: Oxford University Press, 2013.
- . The Status of our Ordinary Three Dimensions in a Quantum Universe, *Nous* 46.3 (2012): 525–560.
- Schaffer, J. Quiddistic Knowledge, *Philosophical Studies* 123. (2005): 1–32.
- . On What Grounds What, In D. Chalmers, D. Manley R. Wasserman (eds), *Metametaphysics*, Oxford, UK: Oxford University Press, 2009.
- . Monism: The Priority of the Whole, *Philosophical Review* 119.1 (2010): 31–76.
- Schneider, S. What is the Significance of the Intuition That Laws Govern?, *Australasian Journal of Philosophy* 2. (2007): 307–324.
- Schrenk, M.. Properties for and of Better Best Systems, *unpublished*. 2012.
- van Fraassen B.. *Laws and Symmetry*, Oxford, UK: Clarendon Press, 1989.
- Vetter, B. Dispositions Without Conditionals, *Mind*. 2014.
- Wilson, A. Schaffer on Laws of Nature, *Philosophical Studies* 164.3 (2013): 653–667.
- Wilson, J. What Is Hume's Dictum, and Why Believe It?, *Philosophy and Phenomenological Research* 80.3 (2010): 595–637.
- . Fundamental Determinables, *Philosopher's Imprint* 12.4 (2012): 1–17.
- . Hume's Dictum and Metaphysical Modality: Lewis's Combinatorialism, In B., Loewer, J. Schaffer (eds), *The Blackwell Companion to David Lewis*, West Sussex, UK: Blackwell, 2015.