Laws of Nature and Symmetries in Physics. Philosophical Implications

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Introduction

Scientific practice is tasked with the discovery of the laws of nature. Being the objects of discovery, not analysis, few scientists pause to think what it is to be such a law. Yet among philosophers of science, this question is fueling an unresolved debate. The philosophical views in the debate broadly divide between those who claim that laws are nothing more than generalizations that *supervene* upon physical features of the world (e.g. Lewis), and those who espouse the so-called *governance* view (e.g. Maudlin). Advocates of the latter position claim that physical features fail to completely account for the state of the world at any given time. They hold that *nomic* features do not simply supervene on the physical features but rather are distinct from physical features, *restricting* their properties and *guiding* their evolution.

There is an alleged equivalence between this debate and the discussion of properties being *categorical* or *dispositional*.

On the Lewisian view, the fact that the properties of matter are categorical means that the particular values of those properties at one point in spacetime do not imply anything about the values of those properties at other spacetime points. These properties are not "outward looking" – one cannot infer fundamental nomic connections from them. It may be the case that in a different world the same particle will behave differently. For example, the force between two charged particles could be the inverse of the distance cubed, rather than squared.

The view of properties being categorical is therefore most closely associated with the Humean position, a position that states that laws supervene on the *distribution* of space-time properties (mosaic of point-like, particle properties), rather than on properties themselves, making laws *contingent* on this distribution. The position is often referred to as contingentist[1].

Criticisms of two sorts have traditionally been directed at the Humean view. On the one hand, people have objected that Humean laws aren't really laws at all - laws are supposed govern the properties of matter, not supervene on them. Sometimes this is put in explanatory terms: laws explain the properties of matter, but the properties of matter don't explain the laws. On the other hand, people have objected to Lewis's particular notion of Humean Supervenience: that the laws supervene on a mosaic of local properties intrinsic to particular points of spacetime. One of the stronger arguments deals with the *non-separability of the quantum state*: one cannot construct the global state of a system, even a two particle system - by simply looking at the local states of the constituents of the system. We will look in some detail at these arguments further in the paper.

A slightly different objection has recently been raised by Kerry McKenzie. Mckenzie, while defending a modified version of Humeanism, raises an objection to Humean supervenience - in particular, the claim that properties of matter in the mosaic are categorical - drawn from quantum field theory. She claims that by focusing on classical theories, Humeans have overlooked the importance of symmetries in the formulation of QFTs. Once these symmetries are taken into account, she argues, it seems that the Humean commitment to categorical properties is untenable (McKenzie).

In this paper, I will try to demonstrate that the role of symmetries in

[1] I must mention here that the sense in which the word "Humean" is used in this discussion is distinct from David Hume's epistemology-based account. I use the word "Humean" in the sense that, I think, David Lewis attributed to it - a property is Humean if it is an intrinsic property of space and time. It is *categorical* in nature, which means that it implies *nothing* about properties elsewhere. It also means that the properties can be *swapped around* without affecting the way the world is elsewhere

modern physics is compatible with properties being categorical, and so is perfectly compatible with Humean Supervenience.

Looking at the opposite end of the spectrum for a moment, a property being dispositional *does* imply a particular kind of lawful behavior, in a different world a particle with the same property, on this view, would behave exactly the same way, as in this world. Dispositional properties are associated with the governance view of laws, the view that is also often referred to as *necessitarianism* about laws.

Dispositional properties imply that nomic connections between properties exist in some sense independently of the particular arrangement of those properties. Insisting on this requires adding elements to the metaphysical picture of the world in particular, nomic elements and second, invites questions about the modes of *governance* by which laws act upon matter. Faced with this problem, perhaps the most honest response comes from Tim Maudlin, who says that that laws should be considered simply as ontological primitives that require no further analysis or explanation (Maudlin). For him, this view is perfectly compatible with beliefs and expectations we place on laws - things like providing explanations, making predictions, and supporting counterfactuals. Even if this is so, he leaves open the question as to the exact mechanism by which they affect matter.

When I started the research on this project, I had a small bias in favor of the *governance* view as something that was more intuitively accessible to me personally. I have now changed my views substantially.

After summarizing the respective positions of the Humeans (associated with categorical properties) and advocates of a governance view of laws (associated with dispositional properties), the paper will proceed as follows. I start from the same point as McKenzie: symmetries play a central role in quantum field theory, and could be seen to present a challenge to treating properties of matter as categorical. Furthermore, I will accept her claim that the properties of matter and the laws that describe it can be seen as consequences of these symmetries (I expand on the relationship between symmetries and laws toward the end of the paper). However, contrary to McKenzie, I argue that these symmetries can be understood as supervening on the distribution of categorical properties in the same way that Humeans have traditionally viewed laws. Symmetries, just like laws, should be thought of as descriptive; the problem McKenzie sees for Humeanism is mistaken. Finally, I expand on the relationship between laws and symmetries, arguing that laws should be thought of as consequences of these symmetries. In this sense, symmetries are more fundamental than laws. I will suggest that laws should be viewed as summarizing the detailed temporal evolutions of physical systems, i.e. their temporal dynamics. Thus, although the summaries of physical behavior provided by the laws can be seen as consequences of more fundamental patterns in the Humean mosaic summarized by symmetries, the two play very different physical roles and provide very different information.

SUMMARY OF EXISTING VIEWS

Humean Account of Laws

The Humean account of laws is at its core a *regularity* account. While there is debate over whether Hume himself was a regularist about laws, this is of little importance to my purposes here. As such, I will refer to the *regularity* account of laws as Humean, as is often the case in literature[2].

Simple Regularity Account

The definition is captured in the following statement:

> "It is a law that F's are G's if and only if all F's are G's"

Doubtless the strongest objections to this view are that (1) not all regularities are laws (e.g. it is not a law that all gold spheres are less than a mile in diameter) and (2) not all laws are regularities. The second problem may merit a few examples to be made manifest.

> *Example 1*: Newton's 2nd law is, on the one hand, a law of nature, but also it is only strictly true in idealized situations. Thus it is not true that $F{=}ma$ describes a true regularity in the world (Of course, in a world where Newtonian mechanics was true, then F=ma holds exactly and universally. However, we do not live in such a world.).

[2]Some scholars ((Beauchamp and Rosenberg), p.119) believe that Hume was not a regularist in the sense that we are using the word here and that his skepticism about metaphysics was informed more by the lack of *epistemic access* to evidence about the existence of this or that property rather than about the absence of evidence, including the evidence for nomic properties, itself.

Example 2: Laws concerning events that are not repeated (and so cannot demonstrate regularities in any straightforward sense), like the period of inflationary expansion of the early universe.

Yet another objection to this account concerns the projectability of the laws. Such laws can only ever be confirmed by a finite number of observations of their instances — and so could only summarize a finite series of observations — but are typically taken to hold true for an infinite set of events. For example, no one has ever experimentally confirmed that Newton's law of gravitation holds between bodies of π kilograms and $\sqrt{2}$ kilograms — how could one ever experimentally confirm such a thing? However, the Newton's laws are thought to apply to such situations regardless. If the laws merely summarize patterns of physical behavior, what justifies us in projecting them to cases like this?

Perhaps, the most vulnerable aspect of the *simple regularity* theories is their lack of clarity with their account of counterfactual conditionals and as such in what sense the laws so stated can constrain the dynamic behavior of matter. According to this view, it is a law that if the mailman drops the morning newspaper on my neighbor's driveway Mr Tanaka has a cup of coffee, as this is what I have observed as far back in history as I can remember. I assume however, that regardless of how timely and consistent the mail delivery in Japan is, a single non-delivery will not change Mr Tanaka's coffee-drinking habit.

In a nutshell, the bedrock of this approach, the statement that matters of fact about the world are everything one needs to have in order to have the full account of laws without any further qualifications appears lacking in its ability to deal with many of the issues I just raised. As most of these issues are relevant for other Humean accounts of laws, I will present them in ensuing pages.

Best Systems Approach

Among many versions of the *Modified Regularity Account* of laws David Lewis provides the most thoroughly developed account. The view is often referred to as the *Best Systems* approach as Lewis used the notion of *systems* in his precise definition:

> "Take all deductive systems whose theorems are true. Some are simpler, better systematized than others. Some are stronger, more informative than others. These virtues compete: an uninformative system can be very simple, and unsystematized compendium of miscellaneous information can be very informative. The best system is the one that strikes as good a balance as truth will allow between simplicity and strength. How good a balance that is will depend on how kind nature is. A regularity is a law iff it is a theorem of the best system." (Lewis, "Chance and credence: Humean supervenience debugged"), p. 478.

Lewis, by his own admission, follows Ramsey's theory of lawhood first articulated in 1928. It appears that in the beginning he accepted Ramsey's definition of laws because Ramsey's formulation best suited his discussion of modality. Lewis famously assumes that all logically possible worlds exist as concrete but causally disconnected entities, and for his analysis he needed to make laws capable of supporting counterfactuals. I will speak in much detail about this later, but what I will claim now is that the *Best System* account of laws doesn't need to assume this plurality of worlds; for this discussion I will proceed on the basis that only one world exists.

A slightly more expanded version of the *Best System* account has *fitness* as an additional criterion for evaluating the *Best System*. I believe Lewis added this requirement in order to differentiate between the descriptions of past events and the lawful predictions of the future evolution of the system. The criteria needed for law-hood so stated are more precisely defined as follows:

- *simplicity* - the fewer independent assumptions the system has to make determines how simple it is
- *strength* - the measure of strength the informativeness of the axiom or its implications, and
- *fitness* - how accurately the system describes the actual history of the world.

The criteria as described can be traded off against each other: one can assign probabilities to events and sacrifice strength, possibly at great gains in fitness and simplicity.

At first look, Lewis' account makes numerous useful accommodations ((Lewis, *Counterfactuals*), p.74). It differentiates true generalizations that are laws from accidental true generalizations on the basis of whether a generalization is an axiom or theorem of the best system. If it is, then it's lawlike.

The requirement of *simplicity* neatly deals with vacuous non-laws. Statements like "there are no gold spheres more than 10,000 miles in diameter" or "all checkered pandas weigh less than 5 lbs" are vacuous propositions that (i) cannot be derived from the axioms of the Best System, distinguishing them from vacuous laws, and (ii) cannot be added as axioms, since they would make the system less simple.

Strength (i.e. *informativeness* by another name) restricts us to pick the most informative systems. "Some will say either what will happen or what the chances will be when situations of a certain kind arise, whereas others will fall silent both about the outcomes and about the chances, . . . and further, some will *fit* the actual course of history better than the others" (Lewis, "Chance and credence: Humean supervenience debugged"), p.480.

Another advantage of the *best systems* approach is that it allows for the distinction between basic laws and derived laws: best systems would subsume less generalized statements under more general statements. Kepler's laws were absorbed under Newton's and, in turn, the laws of Newton under the laws of the quantum field theory capturing our sense that the latter are more general, more fundamental than the laws of Newtonian mechanics. Thus, the approach guards against the infinite proliferation of laws, as could be the case with the *simple regularity* account.

The progression from more specific to more general theories seems to reflect what has been happening in science at least since the time when Newton formulated the laws of mechanics. My interviews with present-day scientists, with the people who formally charge themselves with *scientific practice* gave me the sense that while the initial instinct of modern scientists is that laws *govern* phenomena that they try to observe, their use of the word was somewhat frivolous. Even upon some reflection, they could not see how their work would change if they accepted the Lewisian view. Strikingly, for many of them, the question never occurred as anything worth pondering.

Lastly, Lewis and his supporters believe that the *best systems* definition of laws has the advantage of providing a robust framework for the support of counterfactual conditionals by invoking the *many worlds* approach introduced by Lewis in his theory of counterfactuals. I must mention however that this perceived benefit is heavily contested by opposing *governance* views. I will talk more about this later in this section.

Criticism of HS and HS-based Account of Laws:

I group the criticism of the Lewisian account of laws into four main lines of attack:

- Problem 1. Subjectivity,
- Problem 2. Deficient metaphysics, i.e. an inability for the matters of fact about spacetime points to account for all there is in the world,
- Problem 3. Circularity,
- Problem 4. Questions about the sense in which dynamical behavior of matter is restricted under Lewis' definition, and questions about his account of causal and counterfactual claims tie in with this criticism.

Subjectivity in defining simplicity and strength

The argument regarding subjectivity goes something like this: *simplicity* and the *bestness* of a system implies interpretation by human agents. If this is so, the absence of humans implies that there are no laws. Somewhat more relevant to everyday science production, *strength* and *informativeness* appear to be specific to the person regarding them, as well as to the language in which the laws are formulated. The extent to which the predicates we use correspond (*green* and *blue* as opposed to *bleen* and *grue*) with *natural properties* with which fundamental science purportedly deals poses the question of whether scientists could be fooled by the tools that are available to them in their formulations of laws. Could such formulations be flawed purely on the basis of the perceived deficiencies of the available toolkit of predicates and mathematical formulae?

Loewer (Loewer, "Humean Supervenience"), addressing the question of how the language that we use affects the types of generalizations that we make offers the following example. Should we consider the statement 'all emerubies are gred' less lawful from the point of view of the simplicity/strength tradeoff, than to say that 'all emeralds are green' or 'all rubies are red'?

The issue is that different linguistic choices may appear *simpler* or more *natural* to us, but that possibly just reflects a bias of the language that we are used to. If one does not have a language-invariant way to compare simplicity and strength, then it seems one does not have an objective way to determine the best system as we can't objectively compare them. Since axioms and theorems of the *best* system are supposed to be the laws, it then seems like we don't have an objective way of determining the laws.

Similar arguments apply to determining the strength of the system. For Lewis, the strength of a law so formulated is measured by how informative it is about the world, i.e. by how many possibilities it excludes. The fewer possibilities left for the system, the more informative and stronger the deductive system is and the theorem that is entailed by it.

One can ask a more fine-tuned question - what if there is more than one best system? To which the response could be: if there is an agreement on the language and the systems do indeed come up as equal in their *simplicity* and *strength* measure, then there is no fact of the matter as to what are the true laws of nature.

My view is that even if we bite the bullet and accept that there is an element of subjectivity in the system we take to be the best system, this does not seem fatal or even seriously damaging to the Humean view. After all, there can be little doubt that the properties we deal with, things like mass, charge, accurately summarize an enormous amount of physical behavior. I do not see a potential element of subjectivity as a reason to reject these statements as lawlike.

Metaphysics

This objection argues that a full account of the contingent matters of fact about the world is not all there is, in particular it does not tell us about the modal facts. The modal facts are not determined by the contingent facts. If, for the sake of the argument, we assumed that the world was classical and there were no quantum phenomena of any kind, a world where the positions and velocities of elementary particles were all there was to know about the matters of fact - a single particle traveling inertially at 1 m/s could be in a world where it is a law that inertial bodies travel at constant speeds in straight lines, and equally possibly it could be a world where it is *not* (Roberts, Stanford, p.10)). In other words, in the classical world, the positions and the velocities of all elementary particles in the world could accord with different laws.

Tooley and Maudlin advance more elaborate and realistic examples. Tooley claims (Tooley, Stanford, p.10) that Minkowski space-time is compatible with GR but it also could be compatible with rivaling theory of gravitation. Similarly, Maudlin points out that even within general relativity, the Einstein field equations are compatible with the universe being either open and closed.

A possible response to the Maudlin case is that even if, once all the facts are in, it still doesn't follow from the laws that the universe is open or closed, the Humean could just say that the openness/closeness of the universe is an accidental feature of our universe: a consequence of a boundary condition rather than a lawlike regularity.

Circularity of Explanation

Maudlin advances that the view of laws as describers is not consistent with some other views we commonly hold, such as the view that one of the roles of laws is to *explain* physical phenomena. On this count, if the laws are entailed by phenomena, if *describing* phenomena in some mathematical form is all that the laws can do, how can they explain that by which they are entailed? For example, if the reason that Newton's law of gravitation is a law is because, among other things, it accurately summarizes the elliptical orbits of the planets in our solar system, how could it possibly also explain those elliptical orbits? Explanans on this view are the same as the explanandum.

The circularity objection is a serious one if one proceeds with the account of explanation based on deductive-nomological model. There are other accounts of explanation. Recent attempt was made by Barry Loewer: he distinguished between metaphysical explanation and scientific explanation. The Humean mosaic metaphysically explains why the laws are true, while the laws scientifically explain phenomena by showing that they are instances of a simple and informative regularity. Metaphysical and scientific explanations "commute" on this view.

Regardless of whether one is entirely convinced by these arguments, it appears that the circularity objection, however weighty, may not be fatal to Lewis. I will press on with what I believe are more substantial criticisms.

Counterfactual conditionals and causality

Perhaps one of the most widely attacked elements of any *regularity* theory, and Lewis' subsequent improvement of *simple* regularity theories, is their central claim - that causes can be explained in terms of counterfactuals. These arguments allow the advocates of the *governance* view to expand upon the 'faulty metaphysics' charge from a different logical vantage point. Beauchamp and Rosenberg (Beauchamp and Rosenberg), and Maudlin present their case as follows.

If, per Lewis, the histories of the world exhaust all there is to know about the world, then the laws do not restrict the *possibilities* of the evolution of space-time points, in effect, being the most general descriptions of the *actual paths* that all space-time points take. So if any two worlds shared the exact same history given the same initial conditions, they would share the same set of laws. Yet "if laws restricted possibilities, as well as actualities, this conclusion would not hold; for then two different sets of laws might both be consistent with the same history of actual events."(Beauchamp and Rosenberg).

If, for example, I throw a ball in the air, its acceleration will be the force exerted on it through earth's gravity and the friction of the air divided by its mass. Lewis claims that in his account (as opposed to *simple* regularity account) F=ma is *independent* of me throwing the ball, otherwise the proposition could fall under *accidental generalization*. Any world where F=ma holds thus is the world similar to my world. Lewis posits that accepting small violations of the law poses less of a challenge to my world than re-writing lawful propositions every time there is small divergence with the matters of fact.

Regardless of one's views on the virtues of Lewis' account over other *regularity* accounts on the basis of its support for counterfactuals it is easy to lose focus on the important claim by Humeans - that there is no need for any *third factor* to account for causality, as Tim Maudlin insists. There is an antecedent set of qualities of spacetime and there is a consequent set of spacetime qualities that are counterfactually dependent on the antecedents and there is a set of laws that describe the evolution of these spacetime points. That is the full account of causality. Full stop.

In posing the challenge, Maudlin's example appears to be best designed to strip the issue down to its most essential arguments so I will re-introduce it here in some detail (Maudlin). The world is described as a simple grid (in this case, a 3x3 grid) with discrete points of matter distributed over some space. A point of matter is either present inside a chessboard-like cell (let's call it cell X), or it is not. And the rule governing the presence or the absence of the point of matter in a particular slot at any given *discrete* point in time is this: if any of the three or more of the adjacent cells at the discrete point in time immediately preceding t0 had matter present in them, the cell in question is endowed with matter presence at t0; however if any fewer than three of the adjacent cells had matter in them at t-1 the cell in question will have no matter in it at t0. We are asked to determine if a particular cell at t-1 could be considered as *causing* the state of box X at t0. This, of course, is a simplified version of the Conway *Game of Life* modified in such a way that the rules of the game are purely deterministic and there is no real life intuition that can guide or clutter our judgement.

This is what Maudlin claims: if *four* of the adjacent cells had matter in them it is impossible to say that *any three* of them were the cause of the matter presence at cell X at t0, as the rules initially stipulate. And that any different set of the three (out of four) adjacent cells are "alternative and distinct" causes of the same effect." (Maudlin), p.153.

In my view, the problem with Maudlin's argument is that there is no problem with Humeanism as challenged by Maudlin. Some pages later, he concedes that, all said and done, the rule (law) governing the transitions did not have to be unified under a simple rule posited earlier. If the identification of a *single and direct* cause was required, on the Humean account, there could be 512 different *transitions* rules (based on 512 different possible arrangements of cells in a 3x3 grid) between the state of cells at t-1 and the presence of matter in cell X at t0, and therefore the *pro* causation argument wins.

What Maudlin, Rosenberg, and their followers really claim, I think, is that Lewisian account of counterfactuals through its *fitness* requirement makes laws moulded to fit all available facts that are subsumed under general theories. And in that sense it is a fudge - all one has to do is to simply adjust the truth conditions (e.g. make a claim statistical rather than deterministic) and you have a law. So what's the problem?

For Maudlin, it is a lot more instructive and intuitive to introduce the *third factor* to account for causality that in his case is the *governance* component of laws, of which more in the next section.

Summary of Lewisian position

Here is a quick recapitulation of Lewis' account. Laws hold by virtue of providing true summaries of contingent matters of fact. Identical world histories — that is, identical distributions of properties in the Humean base — entail identical laws. Generalizations become laws iff they are axioms or theorems of the best systems, otherwise are deemed accidental. The system is considered best if has the best balance of simplicity, strength, and fitness, bearing in mind the issue of linguistic dependence mentioned above. Simplicity requirement ensures that the more specialized laws are subsumed under more general ones. The qualification of strength and fitness ensures that spurious laws are not generated.

Thus, the fact that there are no uranium spheres sized one mile in diameter is a law on account of the fact that the best system will certainly include quantum mechanics in its axioms, and one can then derive as a theorem that spheres of uranium become unstable and decay at sizes far smaller than one mile in diameter. Similarly, there is nothing about gold nuclei that allows one to derive the instability of gold spheres one mile in diameter from quantum mechanics, so this statement is not a law.

The attractive feature of the Lewisian position is that it does not appeal to modal arguments or to 'modality-supplying entities (e.g. universals or God)' (John W. Carroll, Stanford Encyclopedia of Philosophy) therefore avoiding discussions on the nature of such entities. Additionally, one doesn't need the mysterious metaphysics that comes with the governance view of laws.

Finally, per Lewis, laws support counterfactuals, and regularities that don't support counterfactuals are not genuine laws. There are no possible worlds where the counterfactual "if I had more uranium, I could build a sphere one mile in diameter" is true that are closer to the actual world than are the possible worlds where that counterfactual is false. On the other hand, there are many worlds where "if I had more gold, I could build a sphere one mile in diameter" is true that are closer to our world than one in which it is false.

Case for Necessitarianism

To the governance view advocates, of whom Armstrong, Dretske, and Tooley are credited with the most developed account, and Tim Maudlin, in my view, providing the most compelling modern argument, the matters of fact do not really tell us anything about the *nature* of the nomic facts. They simply instruct us how best to generalize over events, past and present. In that sense they are a useful guide to formulating regularities that do not have the right to be called laws.

Formulation

To correct the perceived deficiency they claim that it is a law that F's are G's if and only if F-ness necessitates G-ness. One of the more articulated supporters of necessitation, Armstrong, introduced the notion of *universals*, in the sense that a property of *being something* entails certain commitments that constrain *possibilities* of the carrier of that property, a *particular* in specific ways. In other words, general properties (Fness = being a massive object, Gness = traveling at the speed of light) of things enter into a relationship of necessitation (necessarily impossible, in this case) instantiated by particulars (e.g. electrons) to which general properties (F and G) are attributed. And that relationship of necessitation is a law.

So stated, two worlds that have the *exact same histories*, may have *different sets of laws* that govern them, as the examples of Tooley and Maudlin earlier suggested.

Benefits

The advantages of this approach are immediate. We now have the clear demarkation between accidental regularities and laws. The law *becomes* the necessity, as opposed to *accounting for* a necessity (van Fraassen). Being distinct from the matters of fact reduces the perceived logical circularity of *explanation* of observed regularities (explanans and explanandum being one and the same). Laws become the bedrock for inference and induction having an immediate appeal as prediction tools.

Philosophical primitives

And how are we to treat them ontologically? Maudlin's suggestion is to consider them philosophical and ontological primitives. Neither Maudlin, nor other supporters of *governance* present a mechanism through which laws affect matters of fact? Which, of course, invites criticism by Humeans.

Van Fraassen's criticism

Tied with the presentation of "enriched metaphysics" (Maudlin) is van Fraassen's counter-argument. He poses the twin problems of *inference* and *identification*. It must be mentioned here that originally van Fraassen directed his criticism against Armstrong. Armstrong's view is essentially a recasting of the governance view in terms of relations between universals. He posits that universals stand in the relationship of necessitation to each other and those relationships bind the particulars to behave a certain way.

How is it possible then, van Fraassen asks, to turn a claim about a relationship between universals, which is supposed to hold independently of the properties of particulars (e.g. it does not supervene on them), into a claim about necessary connections between particulars? What kind of relation is it that holds between the universals? Van Fraassen calls this the identification problem. Having specified the relationship between universals, and how it binds particulars, one then also must answer the question, 'in virtue of what does this relationship hold?' That is the inference problem.

In other words, the *lawmaking relation* needs to be specified (identification problem) and once done, it needs to be said in virtue of what it holds (inference problem). In a later paper Armstrong argues that the relation of necessitation is that of *causation*, inviting further criticism by Lewis who claims that in that case Armstrong's theory gives up most of its bite in favor of Humean supervenience as causation can be explained in terms of counterfactuals. The two problems Van Fraassen raises for Armstrong's view are, in a sense, just the general problem that faces all governance views of laws: how do the abstract laws 'govern' the physical particulars?

On balance

By adding "enriched metaphysics" to the philosophical toolkit and to some, subjectively, being more intuitively palpable, the governance approach appears to be convenient. But the philosophical questions that it leaves open are hefty and cannot be ignored even at the benefit of such a gain.

I would like to establish now what I believe the two views agree on. Both groups contend that laws must be formulated as propositions, and that they are claims on nature. Both appear to agree that categorical statements, like "neutrinos exist" do not qualify to be a law. On both views, mere logical necessities are not laws (e.g. $A \rightarrow A$ is not a law). Lastly, both schools agree that true laws are defined on all spacetime and are not local, even though for Humeans inferring global patterns from local properties is a slightly more involved process.

Recasting core disagreement

It appears that historically the argument focuses on whether the Humean account of causation that is framed solely in terms of counterfactuals (i.e. without a resort to laws as anything other than patterns in the arrangements of point-particles) can be tenable. If something other than the matters of fact *must* be required to determine causal claims, then laws are recruited to be good candidates for such a role. It appears that Maudlin does not positively settle the score. He does, however, demonstrate that nomic commitments can make the argument for causality much *simpler* and *easier* to make sense of.

But all of these arguments, of course, have been presented, examples and counter-examples provided numerous times over the last quarter-century, ever since Lewis presented his neo-Humean case. As the controversy persists, new approaches must be found to look at the problem.

This is what I believe to be most essential point. The iron-clad corollary of Lewis' statement that two worlds that have the same distribution of (categorical) properties have the same laws can only be that Lewisian laws do not restrict *possibilities* of the evolution of properties, they can only restrict *actualities*.

My argument will start with a discussion of what it means for the system to be in a particular state, that is what it means to be a matter of fact, per Lewis. I will analyze in some detail what it means to be a spacetime property and will look at what makes a property of the "mosaic" *categorical* in the Humean sense.

Lewis's Metaphysics and Properties

Spatio-temporalism

In order to shortcut the interpretation of the Lewisian position I will afford myself another long quote from Lewis:

> "Humean Supervenience is yet another speculative addition to the thesis that truth supervenes on being. It says that in a world like ours, the fundamental relations are exactly the spatiotemporal relations; distance relations, both space like and timelike, and perhaps also occupancy relations between point-sized things and spacetime points. And it says that in a world like ours, the fundamental properties are local qualities: perfectly natural intrinsic properties of points, or of point-sized occupants of points. Therefore it says that all else supervenes on the spatiotemporal arrangement of local qualities throughout all of history, past and present and future." ((Lewis, "Chance and credence: Humean supervenience debugged"), p.474)

All fundamental *properties* are "properties of points or point-size occupants of points" (Loewer) and the only fundamental *relations* are *spatiotemporal* relations. All else is *contingent* on the distribution of spatiotemporal properties, and all else is *entailed* by spatiotemporal relations.

Combinatorialism

This view makes Lewis an adherent of *spatiotemporalism*, i.e. the view that the only fundamental relations are spatiotemporal ones.

Lewis endowed his properties with certain characteristics that he believed ensure his contingentism about laws. As his whole theory is ultimately rooted in and proceeds from his theories on modality, it is important for us to establish whether positing only spatiotemporal relations as Lewis does, is sufficient for achieving the aims of the Humean Supervenience. So we will begin our discussion with the assumption that spatiotemporalism in its strict formulation mentioned above is the correct system of representation for the world. We will keep an eye on the compatibility of Lewis's characterizations with the *categorical* nature of these properties. More specifically, we will also try to ensure that the *mosaic* of properties as presented by Lewis allows us to support *modal combinatorialism* - a view that essentially allows for any local property at one point in the Humean mosaic to co-exist with any other local property at any other point. So spatiotemporal properties existing, say, here, entail no *commitment* whatsoever to what these or other properties *necessarily have to be* anywhere else. This is what is meant by the word *categorical* as it applies to properties. As a corollary to this, one way to think about categorical properties is to say that establishing the absence of *necessary connections* can only mean that categorical properties can be arranged in *arbitrary* patterns, that they can be *swapped around* at an arbitrary point in spacetime without changing the way the world is elsewhere.

As Lewis is probably the most read and cited advocate of a metaphysics based on spatiotemporal connections between categorical properties, at least for now, I will continue to shape my discussion by reference to his views, as opposed to the broader literature on the subject. At the risk of being repetitive, first, I will now look at what specific *attributes* Lewis endows his properties with. I will then examine whether the properties so defined by Lewis confine them to the categorical realm that Lewis would like them to.

Local, Intrinsic, Fundamental, Natural Properties

For Lewis, the properties included in the Humean mosaic are *local*, *intrinsic*, *fundamental*, and *natural*, with grades attributed to their *natural-ness*.

I intentionally used the word *features* here, as there is a concern that using the word *properties* may be incorrect from the point of view of scientific terminology (see detailed discussion by Ned Hall). The controversy is exemplified thus: according the Lewis's original formulation, a mass of 1 kg and a mass of 2 kg are two distinct properties, so having one places no constraints on possessing the other, which, of course, is nonsense. The same controversy can be restated in describing spatial relations: a distance between A and B of 1 meter, combined with a distance between B and C of 2 meters puts the *constraint* on the distance between A and C of a maximum of 3 meters. According to Lewis, spatiotemporal relations between two points should be devoid of any constraints on relationships between any other points.

This is but one reason we might be dissatisfied with Lewis's categorical properties. Later I will present another, more serious one coming directly from contemporary physics.

I will now look in some detail at every characteristic that Lewisian metaphysics directs for the spacetime properties to have.

What does it mean for the property to be *fundamental* or *natural*? What does it mean for the property to be *intrinsic*? In what sense does requiring *locality* of properties differ from requiring that they be intrinsic? ((Loewer and Schaffer), p.112) If *locality* and *instrinsicality*, as we will show below require for properties to be point-like, how does this accord with the fact that some of them are necessarily vector-valued (such as the values of electromagnetic field for different space-time points), as vectors have a direction? I will address these questions in order.

For Lewis the only *fundamental* properties are *natural* properties, and the only *natural* properties are *physical* properties.

I will not argue for or against Lewis's version of physicalism (for I agree with most of what he says), even though some authors find it question-begging on the basis that Lewis's all-out commitment to physics could be viewed as an "abdication of philosophical responsibility" ((Hall), p.36). The argument here is that physics may, after all, be wrong in its taxonomy of properties. What if the relevant properties that we should be concerned about are the kinds that are advanced by *vitalism* or some other theory that is less well-regarded than those advocated by fundamental physics? This isn't a concern I'm going to consider going forward; I mention it here simply for the sake of completeness. I will steer the discussion towards physics at all times without questioning its dominance over all other sciences for the purpose of this discussion.

Per Lewis, a physical property is a property that is instantiated in nature. So, for example, since there is no such thing as a checkered panda weighing 5 lbs in the world, i.e. it is not *instantiated* in nature, the property of *being a checkered panda weighing 5 lbs* would not be a physical property. A more involved question is what it should mean for the property to be *natural*? The best way to address this question is to examine the role that naturalness is assigned in Lewis's philosophical framework. In other words, we need to define the *purpose* that naturalness should serve.

Lewis presents his most elaborate view on this issue in his "New Work for a Theory of Universals" (1983) further detailed in his 1986 work "On the Plurality of Worlds". We already know that the over-arching role he assigns to properties is to form the subvenient basis for all other truths in a given world. And in so doing he defines natural properties as the ones that are perfectly *similar* between perfect duplicates.

> …two things are duplicates iff (1) they have exactly the same perfectly natural properties, and (2) their parts can be put into correspondence in such a way that corresponding parts have exactly the same perfectly natural properties, and stand in the same perfectly natural relations (Lewis, *On the Plurality of Worlds*), p.61.

If there is a difference between objects, then one or more of the natural properties are different. Faced with this definition, one could argue that the objects that we commonly think of have infinitely many properties, making the determination of similarity or difference between objects a practically impossible task, as the objects would have infinitely many properties that are the same, and infinitely many properties that are different. And if this is so, the discussion will necessarily veer towards establishing the degrees of similarity, rather than focusing on the task at hand, the definition of natural properties.

To defend Lewis's concept of *perfect duplicates* one might, perhaps, prefer an easier solution (at least on the face of it) and talk about elementary particles. So the two particles would be the same if they have the same properties of, say, being a certain mass, a certain charge, and a certain spin. In order to be natural, these properties would then be required to hold regardless of what other properties there could be in the spatiotemporal environment of these objects (particles).

Notably, at least on some interpretations, Lewis assigns yet another role to naturalness that is related to how rational agents (human beings) come up with predicates about objects, the role that is related to the theory of meaning (Weatherson, "The Role of Naturalness in Lewis ' s Theory of Meaning

Naturalness in Lewis ' s Philosophy"). And the only propositions we are concerned with here are the ones that human agents formulate with respect to physical laws, which, per Lewis, only admit to natural properties. According to him, the use of natural properties in law formulations is supposed to add simplicity and parsimony.

The idea is that perfectly natural properties lend themselves to projection by rational human agents whereas less natural properties are less suitable for this purpose. In the famed example, it is supposed to be easier to project *green-ness* than than *grue-someness*.

The claim is contentious however, as, by way of a counter-example, projecting an indisputable natural property of being an electron with a fundamental property of having a charge -e does not appear to be any easier to project than a property of, say, being green, which, conceivably, is less *natural* in a sense that, at least intuitively, it easily lends itself to manipulation or change. The property of being green, for example, can be completely altered with nothing more than a change in the ambient light around the object with none of the properties of the object itself (that, remember, until now had the property of *being green*) being affected. In this sense *greenness* is less suitable for the purpose of establishing similarity between objects or for the formulation of a physical law.

Here is another way to look at the same problem: consider two worlds: one - in which a chair is red, and another - in which the chair is green. We want to say these two worlds are different, because the two chairs are (arguably) not the same chair — thus by changing the "greenness" of the chair we changed the worlds, establishing "green" as being a natural property. On the other hand, being "green" seems to depend on the energy of the photons that present the chair in question in the specific light, so including it in the formulations of scientific laws is not maximally simple or parsimonious, making " being green" not natural per the latter criterion.

So it seems that the naturalness defined through the notion of duplicates can disagree with naturalness as defined through projectibility by humans. And that, in turn, potentially gives rise to the discussion on the *degrees of naturalness* for the kinds of properties that end up being natural on one or the other formulation. My preference is to tie naturalness to the role that properties play in laws. Here is a version suggested by Ned Hall that does the job well:

> Property F counts as more natural than property G just in case some predicate expressing F can be defined, in terms of predicates expressing perfectly natural properties, more simply than can any predicate expressing G (Hall), p.35.

So stated, the property *green* would count as less natural than the property *charge*, for example, as *green* could be further broken down into constituents of photon spectra, energy states and quantum numbers of individual photons etc., in addition to being the kind of predicate that is more reflective of the epistemic quality of an object rather than its natural state (seeing green in infrared light yields a different color, for example), whereas *charge* is determinate for any observer, as well as irreducible. And so *natural* properties are more like *charge* and *mass* than properties like *being a table* or *being a certain color*.

The views about *naturalness* tie closely with the concepts of *intrinsicness* for Lewis. Let us remember that the natural property is required to hold the same regardless of any other properties that may have spatiotemporal relationship with it. In this sense, it is the *naturalness* of the property that is constitutive to making Lewisian properties categorical, as the requirement posed above is nothing but the description of the property being non-modal.

For Lewis, the natural properties that are shared between the two perfect duplicates are also *intrinsic*. With some simplification, this means that the property characterizes the particular object, and nothing else. It does not imply anything else about any other property at the same spacetime location or elsewhere. At least on the initial sounding, there appears to be a certain redundancy in this definition: all perfectly natural properties can come out as intrinsic, but the converse is not necessarily true. It may be intrinsic for the apple to be green but being green is not a natural property, as previously discussed.

Once again, the question can be simplified by talking about point-particles, and so reduced being natural would be almost equivalent to being intrinsic. For composite objects, there is a worry of circularity: how does one know if the two things are perfect duplicates without first defining what natural or intrinsic properties are? At the same time how does one know what those properties are without first assuming objects to be duplicates?

The way out of the riddle seems to be the acceptance of the view that if the objects have *parts* and that there exist *spatiotemporal* relations between them that could be determined as being the same, in turn resulting in the ability to establish if things are duplicates. So, in other words, not only must the objects share natural/intrinsic properties, these properties must stand in identical spatiotemporal relations if two objects are duplicates.

Next in line is the issue of *locality* of Lewisian properties. Aside from the less controversial examples of masses and charges, there is a debated question of whether vector-value magnitudes fit within Lewis's definitions. Lewis addresses the issue as potentially problematic but does not offer a satisfactory solution. He simply alludes to vector-valued properties qualifying for HS compatibility without being specific on how exactly this should be done.

Here is the gist of the problem.

Consider vector-valued magnitudes for electric or magnetic fields. At each space-time point these magnitudes have a specific direction. Being *intrinsic* or *local* to a space-time point seems to imply that we should not be able to assign a *direction* to a magnitude possessed by that point. *Intrinsicness* seems to imply that whatever it is that characterizes the occupant of the space-time point should be, well, point-like. So how does one account for vector valued properties of fields? Here is a solution offered by Weatherson.

> Call local supervenience the following thesis. For any length ϵ greater than 0, there is a length d less than ϵ with the following feature. All the facts about the world supervene on intrinsic features of objects and regions with diameter at most d , plus facts about the spatiotemporal arrangement of these objects and regions. This will mean that we can include all local qualities in the subvenient base, without assuming that these are intrinsic qualities of points. [This way] we'll also be able to include vector-valued magnitudes in the subvenient base without assuming that these are intrinsic properties of points (Loewer and Schaffer), p.114.

Let's assume for now that this is a valid solution to the vector valued properties problem. In a few pages we will be considering further objections to Lewis's requirement that all facts supervene on local contingent facts — the most significant of which comes from the non-separability of quantum states.

The above discussion is a very cursory introduction to Lewisian metaphysics, of course, and is only meant as a way to ring-fence a further discussion on whether properties so defined can be considered categorical or whether they imply dispositional commitments in some sense. As such, the kinds of properties I will be dealing with are things like mass, charge, spin, vector-valued magnitudes of EM fields and the like.

Categorical Nature of Lewisian Properties Examined

Lewisian contingentism about the laws is commonly assumed to pivot on the notion of spacetime point-like properties being *categorical*, as I mentioned earlier. And outside of Lewisian notions of intrinsicness, locality, fundamentality that we just discussed there appears to be much less clarity as to to the synthetic definitions for the categorical. Phrased another way, what kinds of relations between properties are supposed to violate their categorical nature?

Let's start with what we think we agree on. The over-arching motivation for the properties to be categorical is, of course, for them to be able to fit the bill of HS. And in so being, the properties at certain spacetime points, as we have said before, entail no commitments to properties at other spacetime points, otherwise the properties are said to be dispositional.

Even though many different versions of the discussion are on offer, the canonical debate in literature is somewhat binary in dividing the properties into *categorical* and *dispositional*. In this paper I will not be concerned with things like the hypothetical dispositions of keys to open certain locks or dispositions of glasses to break. Much literature is dedicated to dispositionalism using these garden-variety examples. All of high complexity examples reduce to more fundamental relationships such as the ones analyzed by fundamental physics. And when the examples are pared down to the level of fundamental properties, things like mass and charge, it is perhaps prudent to avoid running to the classes of examples together.

As such, Armstrong defines categorical properties as properties that are “self contained” and “don’t look outward to interactions” (Armstrong). There are other variations on the same topic. I prefer Loewer’s definition that states that “their instantiation has no metaphysical implications concerning the instantiation of fundamental properties elsewhere and elsewhen.” (Loewer, “Humean Supervenience”), p.177. It is Loewer’s definition that I will use going forward.

We will also assume going forward that the kinds of relations that falsify the categorical nature of a property may range from commitments to *other magnitudes* for the same spacetime point (i.e. that a single property can’t have two magnitudes of the same property at the same spacetime point), or commitments to properties or magnitudes at other spacetime points, occupied or unoccupied, or commitments to the structure of spacetime itself, or the commitments to the *structure and the form of laws* that a property may be a feature of.

My goal in this section is to set the stage for further discussion on whether Lewisian properties that I narrowed down to things like mass, charge, spin, field vector-valued magnitudes, scalar potentials and the like - things that are the subject of study of fundamental physics - are categorical on this definition[3].

Starting with a simple example, let’s introduce a particle with a certain mass and a certain charge located at some spacetime point. It would appear

[3] I will claim that this is far from a foregone conclusion. I will suggest however that the binary philosophical associations along the lines: categorialism about properties -> contingentism about laws on the basis of HS, on the one hand, vs: dispositionalism about properties -> necessitarianism about laws, on the other, is wrong

that this is exactly the kind of an example that advocates of the classical version of HS would be most willing to accept and exactly a kind of a particle that is endowed with all the requisite Lewisian properties: point-like, fundamental, natural etc. It does not seem to imply anything about the distribution of masses and charges elsewhere in the universe. It may abide by some laws that are descriptive of its behavior, such as the law of universal gravity or a Coulomb law, or it may abide by other laws if it were to exist in a world different from ours. For all we know, it could be the only particle existing in the universe.

Let's introduce another elementary particle located at a different space-time point. The first thing we want to do is to measure the distance between these two particles. And immediately we stumble upon a problem.

Problem 1.

Assume that these particles exist in a world like ours, and that the spacetime they exist in is a non-Euclidian space. In order to derive the distance between them requires us to integrate the space-time *metric* over the shortest *path* between them. That commits us to the *assumption* that there are *paths*, or as a minimum, *other* points in addition to the two that we are concerned about. The very fact that we have to assume something about the structure of the spacetime in order to establish something as trivial as the distance seems, at least superficially, to violate Lewis's *no commitment to other space-time points* basis.

Problem 2

The classical representations of physics where an arbitrarily large number of properties can be measured with arbitrary precision hit a famous stumbling block with quantum mechanical phenomena.

A particle having position X is not supposed to entail anything about its having any other properties, if HS is correct. But the uncertainty relations tell us that "having definite position X" is sufficient for determining that it does not have the property of "having definite momentum P".

In addition, the problem is that the majority of states in QM are non-separable. That is, the joint state of particles 1 and 2 is not just the (local) state of particle 1 + the (local) state of particle 2. So the state of the system isn't just a sum of the local properties of its constituents. While the the problem occurs long before talking about Bell-type non-locality, Lewis himself brought the example non-locality as troubling for his system[4].

While being familiar with the problem, Lewis's answer to the puzzle, at least initially, was to question the philosophical foundations of QM, rather than to address the issue of quantum non-locality that seemingly violates the *no commitment* clause required of *categorical* properties.

In the end, I think, Lewis concedes that he does not have an answer but he does not want for this theory to be viewed as accounting for classical phenomena only, as it surely will result in its quick demise. On his own admission, he is not trying to defend reactionary physics allowing by implication for further work on the seeming incompatibility of quantum mechanics with local categorical properties necessary for his version of HS. He mentions

[4]The shorthand version of the problem is this. The entanglement of particles where a *state* of a pair or a group of particles can only be defined simultaneously commits particle x's spin uniquely based on the spin of the entangled particle_commits_ and *constrains* entangled particle y. Surely, the properties involved are quantum properties and no classical properties are known to behave in such a way. But equally importantly, Lewisian representation of the world should be able to accommodate quantum phenomena. Most certainly, the problem cannot be ignored

this in his 1986 work, and then again returns to the same point in 1994:

> The point of defending Humean Supervenience is not to support reactionary physics, but rather to resist philosophical arguments that there are more things in heaven and earth than physics has dreamt of. Therefore if I defend the philosophical tenability of Humean Supervenience, that defence can doubtless be adapted to whatever better supervenience thesis may emerge from better physics (Lewis, "Chance and credence: Humean supervenience debugged"), p.474.

Loewer, in defense of Lewis, later suggested that Bohmian interpretation of QM could serve as the necessary fix for Lewis, perhaps providing a solution. More specifically, one way of addressing the problem is to say that there are categorical properties in higher dimensional space. Since ultimately the objection to categorical properties that I will consider does not trade on the non-separability of quantum states, I will not pursue that proposed solution here. As we re-examine the Lagrangian formulation of classical physics and recent advances of QFTs it appears that certain properties of spacetime and matter not only require implicit commitments to the structure of spacetime, but very specific commitments to the existence of other particles, very specific interactions between them, and the very structure of the lawful formulations.

Canonical Debate Re-Examined. Symmetries

To briefly summarize the preceding chapters is to say that the traditional discussion about laws is binary. With some grievous oversimplification, the opposing views can be reduced to two fairly rigid conceptual associations:

1. categorical properties -> laws as generalizations -> HS; on the one side of the divide, and
2. dispositional properties -> *guidance* laws -> enriched metaphysics, on the other.

While the thrust of the mainstream debate seems to continue to focus on the relative theoretical and practical merits of *supervenience* vs *guidance* as outlined above, the contention that the very framework is severely wanting, although not yet well represented in philosophical literature, is not new. Kerry McKenzie of UCSD pivots her case on the overall incompatibility of the philosophical arguments commonly used with the way modern physics presents the formulations of laws.

Specifically, her charge is that the mathematical form of laws of QM and particle physics structurally *entails* certain kinds of *interactions* of the physical objects that are integral to these laws. Oftentimes, the *interactions* themselves that are described by laws *define* the properties of objects of lawful formulations, particles included. She contests that the structure of the laws presented by QM, such as the

$$\langle (n, \pi^+)|H_s|(p, \pi^-)\rangle$$

((McKenzie), p.8) cannot be tortured into the first-order logical form (for all x, xF then xG) that philosophers are so wont to use. And if this is so, the claim about the categorical nature of properties that have been defined in terms of the relationship they bear to laws expressed in this logical form should be re-examined.

She believes that such a re-examination reveals an incompatibility between the definition of what it means to be a categorical property and the form of laws presented by present-day physics. Furthermore, she believes this incompatability is metaphysically important, rather than being a simple lamentation of a philosopher trying to encourage scientific relevance of an abstract philosophical discourse.

I will take it for granted for now that her concerns are valid, and cannot be resolved through mathematical and logical transformations. This may sound irresponsible. After all, why shouldn't we try to argue and attempt to do just what she finds troublesome - that is, to make exhaustive efforts to find mathematical and logical conformity where she sees none? It appears that aside from the potential futility of such attempts she offers a far superior solution based on the alleged methodological importance of physical symmetries.

Some may argue that recasting the discussion by introducing entities that are sufficiently similar to laws is a simple change in terminology, and therefore is not conceptually additive. But I don't think so. I will attempt to demonstrate in this section that McKenzie's view finds strong validation from many vantage points in philosophy and physics.

To begin, I will be content with keeping an open mind about the possibility of relaxing the frame of reference for the discussion out of the rigid confines of traditional theoretical associations, as McKenzie suggests. If I am successful in my arguments, it will be clear that symmetries are well-defined entities that are not only different from laws in their mathematical structure, not only have fundamental methodological significance but also are in possession of so many useful features as to make them appear custom-made to fill in explanatory voids left by the traditional canonical debate.

McKenzie argues that the laws of modern physics, in particular of quantum field theory, cannot support a commitment to categorical properties. Her argument turns on the role that symmetries play in these laws.

In more detail, she begins by claiming that symmetries are commonly thought of as more fundamental than laws in quantum field theory on account of the fact that 'for a given matter content ... the symmetry associated with a fundamental law does in fact suffice to determine it uniquely (McKenzie), p. 12.

She bases this on the fact that there is a sense in which the existence of a symmetry can be seen to fix the laws of a quantum field theory, as I will discuss in more detail in what follows. The presence of these symmetries in the Humean base, however, means that one cannot 'swap properties around' at will: there are constraints on the relationships that properties in the supervenience base can have with one another. For instance, if one discovers that all of the properties of the Humean base are invariant under a Charge-Parity-Time Reversal (CPT) symmetry, this means that the presence of a particle of, for a example, an electron of mass m at spacetime point X entails that all other electrons, and all other positrons, at different spacetime points must also have mass m.

McKenzie concludes that this means that the properties in the Humean base must be dispositional — they must be 'outward looking' — in order to be consistent with the role that symmetries play in quantum field theory: "when we try to repeat the debate in the context of laws that bear more similarity to the fundamental laws of physics (QFT), we can no longer claim that the fundamental kind properties are 'free of nomic implications' and as such categorical in character" (McKenzie), p.15.

While I agree with her emphasis on the importance of symmetries, her argument warrants more scrutiny. In particular:

1. The methodological importance of symmetries should be discussed in more detail, in order to justify her claims about their role in modern quantum field theory.
2. The role that symmetries play in restricting properties, and in particular whether this means that categorical properties are somehow untenable, needs to be considered more critically.
3. The nomological role of symmetries needs to be addressed in more detail, i.e. whether there is really a hierarchical relationship between laws and symmetries.

In order to illuminate the above points I will aim, wherever appropriate, to link symmetries with examples that purport to demonstrate that it is impossible to maintain the notion of categorical properties as defined and discussed in the previous chapter. Getting ahead of the logical flow of this paper I will here introduce my speculation that symmetries should be viewed as accidents in the arrangement of fields. And that, I will argue, makes a version of HS modified in a way not undermining HS foundations a relevant and valid theory of lawhood compatible with the kind of metaphysics that is entailed by symmetries.

Symmetries and Lagrangians

For the symmetry to be present, objects and their dynamics must be *invariant under certain transformations*. In addition to spacetime and gauge symmetries, my discussion will cover symmetries less frequently addressed in the philosophical literature, such as permutation symmetry. So in basic terms, a symmetry is any transformation that can be performed on a system while its physics remains invariant.

A brief historical expose may be informative. It was pointed out by K. Brading and E. Castellani ((Brading and Castellani, “Symmetries and Invariances in Classical Physics”), p.1347) that while principles of invariance were viewed as secondary to dynamical laws, work of Einstein marked the reversal of the trend:

> It is now natural for us to derive the laws of nature and to test their validity by means of the laws of invariance, rather than to derive the laws of invariance from what we believe to be the laws of nature (Quote)

All declarative statements of this sort ring hollow without concrete examples. Philosophical discussion on this topic sometimes proceeds at such a level of abstraction that it can easily lose sight of the connection between the philosophical debates and the physics that makes them interesting in the first place. In order to ensure the ensuing philosophical discussion is well-grounded, I will offer a brief technical sketch of some relevant roles that symmetries play in physics before moving on to discuss their philosophical significance.

Noether’s Theorem

A particularly powerful way to describe a physical system is by means of a Lagrangian. A Lagrangian takes in various field configurations and outputs a number at each point in space-time. Integrating the Lagrangian over both space and time gives the *action* for that particular field configuration. Suppose that we have a scalar field that at each point in space and time takes on a real number. Furthermore, suppose that we define the Lagrangian as follows:

$$\mathcal{L} = \frac{1}{2}\left(\frac{d\phi}{dt}\right)^2 - \frac{1}{2}\left(\frac{d\phi}{dx}\right)^2 - \frac{1}{2}m^2\phi^2$$

In this simple example we assume for the time being that the universe is one-dimensional. Suppose that the field takes on the value $\phi = 0$ everywhere in space and for every moment in time. Then $\mathcal{L} = 0$ always and everywhere. The action then is also zero. If instead $\phi(x)$ takes on the value $\phi(x) = e^{-x^2-t^2}$ (in other words, it's a bump at $x = 0$ that starts out really small, grows until $t = 0$ and then decreases in size), the action would be

$$S = \int dtdx\mathcal{L} = \int_{-\infty}^{\infty} e^{-t^2}dt \int_{-\infty}^{\infty} e^{-x^2}dx = \pi$$

The values can be any number, large or small. The central principle of the Lagrangian framework is the idea of the so called *principal of least action.* It states that the field configurations that are actually seen in nature are the ones that minimize action. Described this way, the Lagrangian, together with the principal of least action, selects out the possibilities in the universe.

Since the introduction of the Lagrangian formulation in physics it has been noticed that many of the observed Lagrangians had a high degree of symmetry in a sense I mentioned above.

Consider the following Lagrangian that is designed to dictate the physics of two different fields ϕ and ψ:

$$\mathcal{L} = \frac{1}{2}\left(\frac{d\phi}{dx}\right)^2 - \frac{1}{2}\left(\frac{d\phi}{dt}\right)^2 - \frac{1}{2}m^2\phi^2 + \frac{1}{2}\left(\frac{d\psi}{dx}\right)^2 - \frac{1}{2}\left(\frac{d\psi}{dt}\right)^2 - \frac{1}{2}m^2\psi^2$$

Notice that this Lagrangian treats the two fields identically. At first it might be thought that there is simply a symmetry interchanging the two fields. In other words, at first there seems to be only a discrete symmetry.

Upon further reflection, however, we acquire additional insight. We perform the transformation that not only interchanges the two fields, but actually mixes them:

$$\begin{aligned}\phi &\to \phi' = \phi\cos\theta + \psi\sin\theta \\ \psi &\to \psi' = -\phi\sin\theta + \psi\cos\theta\end{aligned}$$

Here θ is a number that does not vary in space or time (as a result this is what is called a global symmetry). Let's check to see what happens when we plug in these new fields ϕ' and ψ' into the Lagrangian.

$$\begin{aligned}\phi'^2 &= (\phi\cos\theta + \psi\sin\theta)^2 = \phi^2\cos^2\theta + \psi^2\sin^2\theta + 2\phi\psi\cos\theta\sin\theta \\ \psi'^2 &= (-\phi\sin\theta + \psi\cos\theta)^2 = \phi^2\sin^2\theta + \psi^2\cos^2\theta - 2\phi\psi\cos\theta\sin\theta\end{aligned}$$

When we add them together and multiply by $\frac{1}{2}m^2$ we find

$$\frac{1}{2}m^2\phi'^2 + \frac{1}{2}m^2\psi'^2 = \frac{1}{2}m^2\phi^2 + \frac{1}{2}m^2\psi^2$$

In other words, the last two terms of our Lagrangian are completely invariant under this more general symmetry. In fact, this transformation also leaves the first two terms unchanged and so it is a symmetry of the full Lagrangian. This is much more interesting because it's a continuous symmetry (i.e. the number θ above can be any number between 0 and 2π). Noether's theorem tells us that there must be some conserved charge associated with this symmetry. In this case that charge comes out to be:

$$Q = \int dx \left(\phi\frac{d\psi}{dt} - \psi\frac{d\phi}{dt}\right)$$

To see that the charge is in fact conserved, we need to write down the equations of motion for this Lagrangian and go through the mathematical steps of the Noether's theorem to obtain

$$\frac{dQ}{dt} = 0$$

This is the power of Noether's theorem: she proved conclusively that there is a conserved quantity associated with every continuous symmetry of a physical system.

The methodological importance of symmetries for practicing physicists is frequently remarked upon. Noether's theorem offers insight into why this is the case. Furthermore, it suggests that symmetries reveal something deep about nature: symmetries themselves seem to have important metaphysical implications.

The first two symmetries presented are not directly relevant to our discussion. I include them here in order to set up the stage for their mathematical structure.

SO(2), SO(3)

What kind of symmetry did we find above? To define it more specifically, we find that it can be presented in the form of a matrix equation such that the transformation is contained within the matrix:

$$\begin{pmatrix} \phi \\ \psi \end{pmatrix} \rightarrow \begin{pmatrix} \phi' \\ \psi' \end{pmatrix} \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \phi \\ \psi \end{pmatrix}$$

It turns out that its transpose is also its inverse:

$$\begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}^T \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

Matrices that satisfy this property that $O^T O = I$ are called orthogonal matrices. There are two separate kinds of orthogonal matrices, the ones that have a determinant of +1 and the ones that have a determinant of -1. The full set of these matrices is called O(2) - O stands for orthogonal - while the part of O(2) that has a determinant of +1 is called the special orthogonal group, SO(2). The symmetry of our Lagrangian above is therefore nothing but an SO(2). Interestingly, this is also the symmetry of rotations in two dimensions, but the appearance of SO(2) here is completely unrelated to actual physical rotations - it's an internal symmetry[5]

U(1), SU(2)

U(1) is a slightly different symmetry, although it reduces to SO(2) through applying Euler's famed equation ($e^{i\theta} = \cos\theta + i\sin\theta$).

Instead of having two real fields as in our first example, consider a single complex valued field ϕ. As a Lagrangian must be real-valued, we write:

$$\mathcal{L} = \frac{d\phi^*}{dt}\frac{d\phi}{dt} - \frac{d\phi^*}{dx}\frac{d\phi}{dx} - m^2\phi^*\phi$$

Notice that if we multiply ϕ it by an overall phase, $e^{i\theta}$, the above Lagrangian does not change. In other words, we have found a continuous symmetry. The set of all phases is referred to as U(1).

Consider now two different complex fields ψ_1 and ψ_2. Organize them into a vector as we did before

[5] One can of course go one step further and perform similar permutations with 3x3 orthogonal matrices that define SO(3) symmetry. The idea is exactly the same: the resultant Lagrangians reduces to the original Lagrangians.

$$\Psi = \begin{pmatrix} \psi_1 \\ \psi_2 \end{pmatrix}$$

and consider the Lagrangian:

$$\mathcal{L} = \frac{1}{2}\frac{d\Psi^\dagger}{dt}\frac{d\Psi}{dt} - \frac{1}{2}\frac{d\Psi^\dagger}{dx}\frac{d\Psi}{dx} - \frac{1}{2}m^2\Psi^\dagger\Phi$$

Now consider mixing the two fields up. However, instead of just allowing a mixing between the two fields, suppose that we allow ourselves to take some of the real part of ψ_1 and put it into the imaginary part of ψ_2. The Lagrangian then becomes:

$$\mathcal{L} = \frac{1}{2}\frac{d\Psi^\dagger}{dt}\mathcal{M}^\dagger\mathcal{M}\frac{d\Psi}{dt} - \frac{1}{2}\frac{d\Psi^\dagger}{dx}\mathcal{M}^\dagger\mathcal{M}\frac{d\Psi}{dx} - \frac{1}{2}m^2\Psi^\dagger\mathcal{M}^\dagger\mathcal{M}\Phi$$

Note that if we choose the matrix $\mathcal{M}$ such that its Hermitian conjugate is also its inverse, this reduces to the original Lagrangian. The set of matrices that satisfy this are called unitary matrices[6] If we pick the ones that have a unit magnitude, we get the group SU(2). One can generalize this and talk about SU(3) and beyond.

Representations

The way we talked about symmetries previously amounted to writing down a Lagrangian and then seeing what symmetries it has. Suppose we took the opposite route. In particular, suppose that we postulate that a system has an SU(2) symmetry and then try to write down a Lagrangian that possesses this symmetry. The first thing we would require is a set of objects that can transform under this symmetry. In the above examples this was usually a

[6]Unitary matrices must have a determinant that has a unit magnitude (instead of just +1 or -1, there are now many values for this since the determinant can be complex)

vector of fields (for SU(2) we called it Ψ). The question now is whether there are other ways of doing it. In fact there are other ways, but this will require a brief detour into the topic of group representations.

The way we thought about the SU(2) transformations above was in terms of 2x2 matrices. It is trivial to make this particular picture more abstract and just say that we have these *things* (to use a non-technical term for now) called *transformations*. Even though we previously used 2x2 matrices, we are not bound to use them inextricably. Instead, we can avail ourselves of 3x3, 4x4, 5x5 and higher dimensional matrices. Noting further that the 2x2 and 3x3 matrices are unitary, we find a close correspondence among them. They can be thought of as representing the same transformation. As a result we call the first of them a two dimensional representation of an element of SU(2) while the second one is a three dimensional representation of the same element of SU(2)[7]

$$\begin{pmatrix} 1 & -i\alpha/2 \\ i\alpha/2 & 1 \end{pmatrix} \to \begin{pmatrix} 1 & -i\alpha/\sqrt{2} & 0 \\ i\alpha/\sqrt{2} & 1 & -i\alpha/\sqrt{2} \\ 0 & i\alpha/\sqrt{2} & 1 \end{pmatrix}$$

Since an SU(2) symmetry then can be represented by either 2x2 matrices or 3x3 matrices, we then can let the transformation operators act on either two complex fields or three complex fields, depending on which representation we decide to work with.

With this sketch of group representation theory in hand, we can now demonstrate the power of the "symmetries first" approach to writing down

[7]Note that technically the second one is also an element of SU(3) since it is unitary and 3x3-dimensional. This is just a statement that SU(2) is a subgroup of SU(3). For the purpose of this example we simply assume that both of these matrices represent the exact same transformation belonging to SU(2)

Lagrangians that was mentioned above: the first task is to postulate the existence of some symmetry, say SU(2), and then to ask which mathematical *representations* exist for that particular group. In the case of SU(2) there are representations of dimension $1, 2, 3, 4, \ldots$ but other groups may have fewer or a higher number of representations. Suppose that we decided to work with a 7-dimensional representation of SU(2). We then would need to mathematically assume the parameters for 7 different complex fields that this symmetry can act on. Here is the most important argument - if you find 6 of these in nature, you can *predict* the existence of the 7th since the symmetry would naturally be incomplete without it. Notably, at this point, there is no agreement as to whether there are any particular reasons for why some representations are observed in nature and others are not. In other words, it is up to the model builder to decide which representation to use. The point I am trying to emphasize here is that from the methodological point of view postulating symmetries, rather than particular Lagrangians, has been a very powerful approach for theoretical physicists. This is, in large part, because the mere existence of a symmetry implies a number of things about the physical world — in particular, the relationships that certain physical quantities must bear to one another. This will be addressed in considerable detail shortly, but first I will turn to a famous example of such reasoning from the history of physics.

The eightfold way

This is precisely what happened with the *eightfold way.* This term was introduced by Murray Gell-Mann to describe his theory of organizing baryons and mesons into octets.

In the early 1960's it had been observed that certain mesons behaved almost identically so it was believed that there was some symmetry relating their observable properties. There were eight such particles and since SU(3) has an eight dimensional representation, it was thought that the symmetry in question might be an SU(3). Separately, a set of nine different particles to which the same principles could be applied also behaved almost identically. The SU(3) does not have a nine dimensional representation but it does have a 10 dimensional representation. Gell-Mann then postulated that perhaps there was another particle yet unobserved that could complete this decuplet. Two years later, in 1964, Omega-minus particle was discovered as predicted.

In other words, it is impossible to have SU(3) symmetry *realized in nature* without having the full set of tuplets present.

This prediction gave rise to the search for other representations. With the confirmed existence of the 10 particles that act similarly, and then another 8 that form the octet, the question was posed as to whether there should be particles corresponding to the other representations of SU(3) as well. In particular, SU(3) also has a three dimensional representation (the one we actually used when we first discussed SU(3)), the so-called fundamental, or *defining* representation. Even though at that point it was not yet observed in nature Gell-Mann postulated that it must exist. He called the triplet of particles entailed by the three dimensional representation of the symmetry *quarks.*

Indeed, Gell-Mann was correct: we now know that quarks transforming according to the fundamental representation of SU(3) do exist. Both historically and conceptually, this demonstrates the power of a "symmetries-first" approach: by simply postulating the existence of a particular symmetry in nature, one is thereby committed not only to the existence of new particles, but also to specific relationships between specific properties of those particles. The existence of symmetries therefore entails relationships between properties of fundamental particles.

Gauge Symmetry, Standard Model, Grand Unification

The advance of thinking in terms of symmetries led to the postulation of the quantum theory for electromagnetism [ˆ].

If instead of changing the phase of all the field values, as required by a *global symmetry*, we did so for each point in space and time twisting each value by a *different* phase amount postulating that the physics needs to remain unchanged, and making the symmetry a *local gauge symmetry*, a new object would need to be introduced into a Lagrangian to make it invariant under the symmetry transformation. Technically speaking, we defined the parameters for the *gauge field* for the corresponding symmetry[8]

[8] This is how it works mathematically.

Performing the transformation blindly yields:

$$\mathcal{L} \to \frac{d}{dt}\left(e^{-i\theta(t,x)}\psi^*\right)\frac{d}{dt}\left(e^{i\theta(t,x)\psi}\right) - \frac{d}{dx}\left(e^{-i\theta(t,x)\psi^*}\right)\frac{d}{dx}\left(e^{i\theta(t,x)}\psi\right) - \frac{1}{2}m^2\psi^* e^{-i\theta(t,x)}e^{i\theta(t,x)}\psi$$

Previously, when θ was just a constant, it passed straight through the derivatives and cancelled between the two factors. It still works like this in the last term, but the first two are problematic since the derivatives will also act on $\theta(t,x)$. The strategy is then to come up with a better kind of derivative, one that allows the exponential factor to pass straight through it even though it's not constant. A little calculation leads us to the invention of a new object:

$$D_\mu = \partial_\mu + iA_\mu$$

allowing us to write down the Lagrangian that is invariant under local transformations:

$$\mathcal{L} = (D_\mu\psi)^*(D^\mu\psi) - m^2\psi^*\psi$$

So far, this object $A\mu$ doesn't do anything interesting by itself because, as there are no derivatives of $A\mu$ inside the Lagrangian, so we don't yet understand its behavior. The technical term for the property is a non-dynamical field. Adding derivatives to the

The theory we have at the end is precisely the theory of electromagnetism, as the gauge field that we were required to add in order to make the Lagrangian invariant under transformations is nothing but the electromagnetic field. In this sense one can think of the photon as a *requirement* for obtaining a local U(1) gauge symmetry. Even though photons were discovered by physicists through many conceptually different processes, the success of parameterization of such an important object through symmetries is methodologically astounding.

Other symmetries, such as SU(2), lend themselves to the same logic. The process is much more involved, and the theory called the Yang-Mills theory was written to model the process. Importantly, the logic is very similar for all similar procedures. We start by writing down a theory that is invariant under global SU(2) symmetries just as we did earlier, subsequently promoting the transformation matrix to be a local function of space-time, and the invariance postulation requiring us to introduce new fields.

And this is precisely how the Standard Model works. The standard model is a gauge theory where the gauge group is a product of three different parts:

$$G_{SM} = U(1) \times SU(2) \times SU(3)$$

Lagrangian, makes the field dynamical. There is a unique way of doing this in such a way that the object is invariant under U(1) transformations, invariant with respect to its second derivative of time, as well as Lorentz invariant. The end result is:

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + (D_\mu\psi)^*(D^\mu\psi) - m^2\psi^*\psi$$

Thus we defined the field strength:

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$

The finer details of the Standard Model are clearly outside of the scope of this research but the main idea is this: in order to make symmetries and their representations work, we have to make various symmetries local. And just like the U(1) case above, we are forced to introduce new fields, the so-called gauge fields. We need one such gauge field for the U(1) factor, three such fields for the SU(2) factor, and eight fields for the SU(3) factor because the groups are 1,3, and 8 dimensional, and we need one field for each free parameter to make the covariant derivatives work out properly. These fields are the photon field, A_μ, the weak bosons W_μ^+, W_μ^-, and Z_μ^0, and then the eight gluons A_μ^a. And finally, similar logic leads us to the mathematical prediction for the Higgs field, the boson for which was experimentally discovered to much fanfare in 2012 having been predicted mathematically 48 years prior in 1964.

And here is the final technical comment: where in the world do all the quantum numbers, magnitudes for masses and charges come from? They seem totally random. We find that if these numbers were anything different, even one of these numbers, we would get *anomalies*, sicknesses in the theory. The ways of our world that fixed values so rigidly should underscore the importance of the origins of these numbers.

One might guess that while the electron and the 'up' quark appear to be different particles, perhaps, they are somehow *related to each other* behind the epistemic veil. This is the idea of *grand unification*. It turns out that the group for the standard model, U(1) x SU(2) x SU(3) is actually a subgroup of a larger group called SU(5). Supposing for a moment that the universe respects this larger symmetry group and that for some reason much of this symmetry is hidden from us, there should be 24 different gauge bosons because SU(5) is 24-dimensional for reasons it having 24 independent parameters. Experimental physicists so far have observed only 12 of these, so the guess is that there are another 12 'hiding' from us. One reason we wouldn't have seen them is that they end up being much too heavy to have appeared in collider experiments.

To follow previously described logic, the relevant question then becomes what representations should be considered. It turns out that if we pick two different representations, those of dimensions 5 and 10, all of the original matter fields of the standard model fit perfectly! Rather than dealing with all of the seemingly random numbers presented to particle physicists, all that needs to be done is to postulate these two representations, and the standard model neatly follows from it.

Even more amazingly, SU(5) is itself a subgroup of a larger group called SO(10) in which all of the standard model representations of matter are neatly packaged into the simplest possible representation of SO(10), the so-called spinorial representation of dimension 16. Now, oddly enough the 16 dimensional representation contains 16 different fields instead of the 15 that we observed. This should serve as a predictor of the existence of yet another matter field. Computing its parameters from the perspective of the standard model symmetry group makes this field behave just like the missing right-handed neutrino suggested by some other symmetries. In other words, postulating the simplest possible representation of SO(10) not only yields all of the odd-looking numbers in the unified particles table that previously appeared random, but it also *predicts* the existence of another particle.

This is in some ways the most beautiful result in particle physics which many a physicists marvels at. Postulate the simplest realization of a symmetry and everything that we know automatically follows from it!

We now consider the implications that symmetries have for a theory of

Humean supervenience which relies on the existence of categorical properties in the Humean mosaic.

Categorical Properties Revisited

It is time now to take philosophical stock of my technical and historical excursions. Without asserting any ontological primacy for the symmetries at this point, a few things should be vividly clear. First, one can see why McKenzie takes there to be an incompatibility between the role symmetries play in quantum field theories and categorical properties. After all, the fact that many properties of particles are related to one another via symmetries implies that those properties are 'outward looking' — the existence of a property at spacetime point X can require the existence of a property at spacetime point Y, in order for the symmetry to hold. This should at least give pause to the advocate of a Humean base made up of categorical properties.

There is a sense in which McKenzie is right: Humeans have often talked about categorical properties as those which are not restricted in the relationships they can participate in with other properties: in the absence of any established law-like generalizations, if a property at spacetime point X is categorical, one cannot learn anything about any other property at a different spacetime point Y by looking only at X.

Traditionally, Humeans thought that such information could *only* be had once one had identified a set of law-like generalizations. What McKenzie points out is that symmetries can constrain properties, and allow us to extract information about properties at other spacetime points, even in the absence of any laws. So it seems as though certain traditional understandings of categorical properties in the Humean base may need to be revised, in light of the importance of symmetries in QFT. That said, I ultimately do not think that McKenzie is right that we must consider the properties of the Humean base to be dispositional.

The way for the Humean to preserve categorical properties in the face of McKenzie's objections about symmetries is to treat symmetries in the same way as one treats laws: as summaries of patterns of categorical properties in the Humean base. Like laws, they supervene on the distribution of categorical properties. Also like laws, the fact that we can make predictions about properties at spacetime point Y given properties at spacetime point X doesn't mean that those properties themselves have any fundamental modal connections. This solution, as well as the relationship between laws and symmetries, is discussed in the next section.

Symmetries, Supervenience and Laws

While the properties *here* can indeed very much imply a whole lot about the properties *elsewhere*, and this linkage being supported at the level symmetries rather than properties themselves, we are still quite far from being able to conclude that symmetries entail that properties are not categorical. In order to do so, it seems that McKenzie has to assume that symmetries are fundamental, somewhat like laws on the governance view. But even if symmetries are more fundamental than laws, in the sense that symmetries can entail laws, this doesn't mean that they need to be fundamental nomological entities: they can supervene on the Humean base just like Humean laws do..

Without opening a debate on structuralism, from the examples above it would be more reasonable to say that the relationship of symmetries to matter distribution could be that of *supervenience*, although the kind of supervenience that is most elegant and simple. I would advance a humble claim that symmetries should be viewed as structures that *summarize* certain properties of *base ontologies* with the latter being the distribution of matter fields.

Applying the same logic to the origin of symmetries, it may be a worthwhile suggestion to consider that symmetries came about as *accidents*, that they came about as a result of certain *arrangements* of relativistic quantum mechanical fields that could have turned out many different ways. The fields could have arranged themselves in such a way as to produce different symmetries that could have had different kinds of representations, and as a result, produced different laws summarizing the relationships that the field values have to one another.

We do not know of any reasons why the fields arranged themselves the way they did. We cannot pinpoint any *necessity* to their arrangement in a way that we observe it. And this is exactly why I think the idea of symmetries is compatible with the spirit of Humeanism. My advocacy is therefore that there are indeed 'no necessities in nature'.

The important claim this paper makes on behalf of symmetries is that, contrary to McKenzie's assertion, they do not entail that properties in the Humean base must be dispositional. Although it does appear at first glance that symmetries render properties 'outward-looking' in a way that seems dispositional, these symmetries can be seen as summarizing patterns in a categorical Humean base in exactly the same way that laws have always been seen to do, for Humeans. So while McKenzie's objection does illustrate that the threat of nomological connections in the base can arise even before one considers laws, ultimately it does not represent a serious threat to the Humean position.

And where do laws fit into any of this? Are we essentially advocating some version of Humeanism about laws? Perhaps, but with some important distinctions. The role that this previous discussion carves out for laws is much different from that of symmetries.

The first important distinction is this: laws, while themselves are *static*, deal with temporal *dynamics* of systems' evolutions while symmetries can be viewed as static mathematical structures that are simply reflective of the arrangements of fields. Symmetries can be viewed as statements that certain defined physical content, certain patterns in the distribution of properties of elementary fields (e.g. electromagnetic charge, isospin, etc.) will remain invariant as those fields change over time. By themselves, symmetries cannot say anything about the details of the temporal evolutions of those fields themselves, i.e. what actual changes do take place in a field state between time $t1$ and time $t2$.

On the other hand, laws, to reflect their dynamical nature, are often formulated as differential equations (or their equivalent integral formulations) that in most cases have in them a time derivative of the particular physical entity whose evolution they describe. Thus, even though laws can be derived from symmetries, they provide very different information about the physical quantities that they describe[9]. The Euler-Lagrange equations derived from the SM Lagrangian are a good example but any of the differential equations (or their integral formulations) that physics uses that account for or predict evolutions of physical systems are equally suitable.

If we agree on this, perhaps, the next relevant question is to establish the nature of the relationship between symmetries and laws. More work

[9] Even though most laws are viewed to describe the dynamical evolution of physical systems, it may not need to be the case. For example, some view the Past Hypothesis as a law (e.g. David Albert and Barry Loewer). This would be an instance of a non-dynamical law. The assertion is a matter of some controversy, however, and is beyond the scope of this paper.

likely needs to be conducted on the topic but the research by physicists Gross, Wilczek (Quote) and Politzer (Quote) does lead us to suggest that at the level of fundamental physics symmetries may be sufficient to specify relevant laws *uniquely for a given matter content.* In other words, laws can be formulated but for the values of the constants that figure in them - something that needs to be established experimentally.

Conclusions

To summarize, our working definition of laws is this: laws are mathematical formulations of dynamical evolutions of physical systems that are entailed by symmetries and their representations and can be uniquely fixed by them for a given matter distribution, and, perhaps, in some cases, for a given set of initial conditions (to take account of statistical laws, like the laws of thermodynamics).

So described, lawful formulations, like the Lagrangians, being the mathematical *generalizations* of dynamical evolution of observed physical phenomena, are a in some way a *convenient* way to track down the evolutions of physical systems. Being descriptive, they do not *guide* with the requisite need for metaphysical 'enrichment'. Therefore, they do indeed *supervene* on underlying reality. And being themselves entailed by symmetries that summarize and supervene on all relevant matter distribution properties the Lagrangian-laws maintain rigidity allowing them to *support counterfactuals*, just as Lewis would have preferred.

Thus, despite McKenzie's objections to categorical properties and the apparent problem raised by the role of symmetries in QFT, it appears that Lewis's intuition and Humean Supervenience in general remains safe after all.

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