What Everyone Should Say About Symmetries
(and how Humeans get to say it)

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Abstract

The laws of physics have an interesting internal explanatory structure. Some principles explain others; some constraints fall out of the dynamic equations, and others help determine them. This leads to interesting, and non-trivial, questions for metaphysicians of laws. What sort of explanation is this? Which principles are explananda, and which explanandum?

In a recent and insightful series of papers, Marc Lange (2007, 2009, 2011a, 2011b) has discussed these questions in detail, with a focus on the explanatory priority of symmetry principles and their associated conservation laws. Lange argues that symmetry principles are meta-laws: laws governing the laws. The symmetry principles explain the conservation laws by governing them, just as first-order laws explain first-order facts by governing them. He then claims that his metaphysical view of laws can neatly accommodate metalaws but his competitors, namely Humeans and dispositional essentialists, cannot (2009, 2011b).

While I agree with Lange that symmetry principles explain conservation laws, I hold that he is wrong on all other counts. Symmetry principles are not meta-laws: they are first-order generalizations. The explanation of conservation laws from symmetry principles is not a covering-law explanation: it has more in common with reductive explanations of higher-order laws from more fundamental principles. And these facts put him at a loss relative to his primary competitor, the Humean view: this correct account of the explanatory power of symmetry principles falls neatly out of Humeanism, but must be added in *post hoc* to Lange's view.

Introduction

Picture an equilateral triangle–a triangle with three sides of equal length. Now imagine a line extending from one vertex of the triangle to the opposite side, such that the line bisects the angle of the vertex and is perpendicular to the opposite side. Then, mentally flip the triangle along this line, so that the side to the left of the line is now to the right, and vice versa. If you've done everything right, the image you arrive at is indistinguishable from the one you started with. Equilateral triangles have a bilateral symmetry along this axis: transforming them by flipping them along this axis leaves all of their properties unchanged. Their structure is invariant under this reflection.

Symmetries are easiest to picture in geometric shapes. But the notion is much broader: a transformation of a mathematical object is a symmetry transformation just in case it leaves the structure of that object unchanged. Physical theories to have symmetries: transformations between solutions of the central equations of the theory which leave form of the equations of motion unchanged. So, for example, Newtonian gravitational dynamics is symmetric under spatial and temporal shifts, kinematic boosts, and rotations. Just as the bilateral symmetry of an equilateral triangle can expressed in terms of a transformation which leaves the structure of the triangle unchanged, so these symmetries can be expressed in terms of transformations which leave the system's equations of motion unchanged.

Take, for example, spatial shifts. The symmetry transformation of such a shift takes the location of all the objects in the system and permutes them from $x \to x + \epsilon$. Now consider two objects in our system. How does this transformation affect the force between them, and so their motion? Well, the force between them is determined by their distance, and given by Newton's Law of Universal Gravitation: $F_{G,1,2} = \frac{Gm_1 m_2}{(x_1 - x_2)^2}$. If we subject the system to the static shift transformation, the force between them becomes $F'_{G,1,2} = \frac{Gm_1 m_2}{(x_1+\epsilon)-(x_2+\epsilon)} = \frac{Gm_1 m_2}{[(x_1-x_2)+(\epsilon-\epsilon)]^2} = \frac{Gm_1 m_2}{(x_1-x_2)^2} = F_{G,1,2}$. That is, the force is unaffected by the transformation. Similar arguments show that the acceleration of the system is unaffected by the shift; the change is, in some sense, dynamically irrelevant.

Symmetry principles are statements of the symmetries of a physical theory: they tell us under which transformations the dynamics of theory is invariant. But their presence raises questions for in the metaphysics of laws of nature: are symmetry principles themselves laws of nature? Do the symmetry principles *constrain* the laws? Or are they just a result of the dynamics we contingently have right here in the actual world? Here, I'll put forward a Humean view of the metaphysical status of symmetries. On this view, the symmetries, like the laws, give us useful information about the behaviour of physical systems. This information tells us which differences matter to that behaviour: two systems which differ only by a property which varies under symmetry transformations (rather than one which is invariant) behave the same way. Humeans hold that laws are true, informative generalizations; here, I argue that symmetry principles are laws.

This view is directly opposed to the current leading–and only–view regarding the metaphysical status of symmetry principles. In a series of recent papers, Marc Lange (2007, 2009, 2011a, 2011b) has argued that symmetry principles are *metalaws*: higher-order laws of nature, which govern other laws rather than first order facts. Lange does not believe that Humeans can account for the higher-order status or explanatory power of symmetry principles. In this paper, I argue that Lange is wrong to claim that symmetry principles are higher-order laws. So Humeans are right to deny them higher-order status. But nonetheless, I argue that Humeans can account for the explanatory force of symmetry principles at least as well as Lange[1].

The paper is structured as follows. In §1 I provide some background on symmetry principles, their place in physical theories, and their relationship to conserved quantities. I attempt there to clearly explain what a symmetry principle is, and in what way symmetry principles are taken–with some controversy–to feature in explanations of the truth of other laws. In §2 I thoroughly review Lange's account and argue that its central claim, that symmetry principles are law-governing laws, is a mischaracterization. Then, in §3, I provide a Humean view that puts the symmetries in their proper place. Finally, I conclude by drawing conclusions within metaphysics of laws. If I'm right about the status of symmetry principles, then Humeans have a uniquely good explanation of their counterfactual stability and explanatory force. Lange, I claim, is wrong about the structure of symmetry principles and the type of explanation they provide, but his account does have the resources to explain symmetries as first-order principles. But other views in metaphysics of laws, including dispositional essentialists, necessitarians (like Armstrong (1997)), and proponents of *sui generis* laws like Maudlin (2009) seem to incapable of providing an account of the explanatory force of physical symmetries.

1 Physical Symmetries

In this section I'll offer some introductory remarks on the place of symmetries in physical theories, and their relationship to physical law. These remarks will be regrettably brief: there are ongoing and important debates about the nature and import of symmetries to physical laws. But here, I am focused on the metaphysics of laws, so I will provide enough background for readers to follow my arguments and point towards more thorough explorations by other authors. I will attempt to first (§1.1) briefly explain what physical symmetries are and how they related to physical laws (especially conservation laws), and then second (§1.2) review the leading accounts of their philosophical significance.

1.1 The Structure of Physical Symmetries

Recall the triangle from the introduction. It's symmetries are those transformation that leave its shape unchanged. The symmetries of physical models are similarly those transformations that leave relevant structure unchanged. But how should we think of these transformations–that is, what are they transformations *of*, exactly? And what is the relevant structure that they leave unchanged?

[1]Yudell (2013) argues that Humeans can accommodate Lange-style metalaws. Here I present a stronger case for the counterfactual resilience and explanatory power of symmetry principles on Humeanism and argue that Yudell and Lange are wrong to conflate the explanatory power of symmetries with their status as higher-order principles. I'll discuss Yudell's view in §**??**.

Different answers to these questions allow us to come up with a catalogue of symmetries. In answer to the first question, symmetries are transformations of the *variables* of a physical model. Those symmetries which are mathematically and physically interesting have an associated transformation function–some specifiable mapping from one set of variable values to another. So a physical law has some symmetry–say, a velocity boost symmetry–in virtue of a transformation of one of the variables mentioned in that law–in this case, the velocity variable.

Realizing this, we can catalogue the symmetries of a physical law by features of the transformation function and by features of the variables it transforms. For *global symmetries* the transformation function is universal and constant. So for example a global boost transformation changes the velocity of all components of the system by the same amount. A global shift symmetry changes the location of all components of the system by the same amount. *Local symmetries* can be characterized by an arbitrary function, one which may vary across space. So a local symmetry transformation of a field may change field values within some region, but leave the values outside of that region unchanged. The global symmetry is characterized by a function changing the variable in question–again, velocity is a good example–but which is constant with respect to all other variables, whereas a local symmetry is characterized by a function which changes a target variable but is not constant with respect to other variables.

We also categorize symmetries with respect to the nature of the variable that the characteristic transformation ranges over. *External symmetries* transform those variables which describe the extrinsic or relational features of the system. Typical such features are the locations, velocities, or spatial orientation of the system. These features depend not only on the intrinsic qualities of the objects in the system, but also on their relations to spacetime and to one another. *Internal symmetries* transform those variables which characterize what are often taken to be the intrinsic features of the components of the system. So charge permutation is an internal symmetry: if the charges of all components of a system have their sign reversed, the system behaves in other respects identically. Because this involves a change in the intrinsic features of the system's components, it is an internal symmetry.

So, in answer to the first question, symmetry transformations transform the variables that a physical law quantifies over. But in order for a transformation to be a symmetry, it must leave some relevant structure unchanged. What is that structure? In answer to this second question, we can again catalogue symmetries by which relevant structure the transformation leaves unchanged. Here, I will be principally concerned with dynamic symmetries: those which leave the structure of the equations of motion of a system unchanged.

A lack of clarity in answering these questions has lead to considerable confusion in philosophy of physics, especially as it relates to the epistemic relevance of symmetries and their place in symmetry-based arguments against superfluous structure in physics and metaphysics. So Dasgupta (2013) says that we should "think of a symmetry of a law as a transformation on physical systems that (at a minimum) preserves the truth of the law" (p. 838). As Dasgupta notes, this obviously too loose a notion, as any transformation on the space of solutions would then be a symmetry. By abstracting away from the fact that most physically interesting symmetries are transformations of *variables* that leave *the equations of motion* unchanged, Dasgupta's first-blush explication of symmetries is open to trivial counterexamples. Nonetheless, there is still an interesting question about which mathematical structures we should require to remain constant.

1.2 The Physical Significance of Symmetries

The symmetries of a physical theory are a set of transformations on the space of solutions to that theory. They are a function from solutions to solutions, such that some relevant mathematical structure is the same in any two symmetry-related models–in the cases I'll focus on, these transformations can be described by a function on the variables in which the theory is formulated, and take us from one solution to another which has the same equations of motion. An account of the physical significance of symmetries is an account of what these two symmetry-related models have in common.

Because the equations of motion of determine the behavior of the system, we can expect symmetry-related models to behave identically. If two physical situations are internally identical, but merely at different places or times, then they can be described by the same equations of motion and their internal dynamics are identical; similarly, if two physical situations are internally identical, but one is rotated relative to the other, or moving at a different velocity to another, they will behave identically.

This is the first thing to note about symmetry-related physical states. They are empirically indistinguishable. No experiment can distinguish a world from one related to it by a symmetry; no experiment *within* an isolated subsystem of the world can distinguish it from a symmetry-related subsystem (although external observers can tell the difference between, say, a system and its rotated counterpart). The relationship between different sorts of symmetries, taken as global tranformations of the state of the world, and the behavior of subsystems is discussed in Brading and Brown (2004), Greaves and Wallace (2014), Dasgupta (2016).

Many philosophers take symmetries to be a guide to connecting the structure of a physical theory to the structure of the world. On this view, two symmetry-related solutions to physical equations are simply different descriptions of the same situation. There are not two worlds, in one of which I am here, and in the other I am three feet to the left, with everything else similarly shifted. Instead, there is just this world, and two mathematical descriptions of it. The fact that those descriptions put the origin at different places doesn't indicate any difference between the worlds as the origin in our mathematical description didn't correspond to anything in the world anyway. The symmetries tell us what structure the world does *not* have. Here's Hilary Greaves and David Wallace expressing this view:

> “...there is widespread consensus that ‘two states of affairs related by a symmetry transformation are just the same state of affairs differently described’. That is, if two mathematical models of a physical theory are related by a symmetry transformation, then those models represent one and the same physical state of affairs.” (Greaves and Wallace, 2014)

But this view is not universally held; other think that we should take the mathematical structure of theories seriously, and hold that a distinct possible world corresponds to each model of our theory. Nonetheless, on this view symmetry-related models correspond to empirically indistinguishable worlds. These authors think that these emprical consequences exhaust the significance of symmetries–they have no further metaphysical implications. Here’s Gordon Belot expressing this view:

> “Objects related by a symmetry occupy identical roles in the pattern of relations described by their structure [...] We can assume that only appropriately qualitative relations are represented in our structures – so that objects related by symmetries will be qualitatively indistinguishable.” (Belot, 2003: 394)

> “ My view is that if one denies that the application of time translation (or any other symmetry) generates distinct physical possibilities, then one ought to prefer to the standard formulations of classical mechanics those in which the offending symmetry has been factored out.”(Belot, 2003: 401)

Belot here defends a certain realism about the mathematical structure which describes the physical state. The idea here is that, if we think that there are not two distinct possibilities which differ by a symmetry transformation, we should move to a mathematical representation which doesn’t have that redundant representational structure. If we can’t find such a representation, we’re stuck with the unfortunate consequence that there are distinct but indistinguishable possibilities. He goes on to show that there are ways of ‘quotient out’ symmetry related states, so that instead of having a statespace with multiple, distinct states related by a symmetry transformation, one instead has a simpler statespace with a more limited range of states.

Of course, if one takes Belot at his word, one needs to explain how two worlds can differ without differing qualitatively. One view, associated with Tim Maudlin (2013), holds that there are haecceitistic connections between spacetime points at different worlds. On this view, worlds related by a spatial shift are such that every object occupies a different spacetime point in each world despite the fact that all of their relative spatial relations are the same.

I’m suspicious of spacetime haecceitism, so my sympathies lie with the view that symmetry-related states are identical, and merely described differently. For symmetry-related subsystems, this means that qualitative properties and relations within the subsystem are the same, although their relations to objects outside of the subsystem may differ. However, I don't believe that this debate has bearing on the arguments I present below: my arguments go through provided at least that symmetry-related worlds and subsystems are empirically indistinguishable to those within them.

2 Langian Metalaws

How should metaphysicians of law regard symmetries? Symmetries constrain our physical theories and the structure of our statespaces. Laws of nature, at least in physics, are typically differential equations. Rather than a list of generalizations in a first-order extensional logic, we get a single differential equation and constraints on how its free parameters can be set. So in Lagrangian mechanics we get the Euler-Lagrange equation and a set of constraints on the Lagrangian. Some of these constraints are requirements that the Lagrangian be invariant under certain transformations (these are the symmetry principles), while others specify the kinetic and potential energy of the system (these are typically understood as force laws and boundary specification of, say, the number and masses of any particles in the system). Recognizing that some of these constraints are correctly regarded as law-like while others seem to be boundary or initial conditions requires metaphysicians of law to get into the weeds of philosophy of physics. Which parameters are which? And where do we put the symmetry constraints?

2.1 Lange on Symmetries

Lange (2007, 2009, 2011a, 2011b) follows Morrison (2005) in arguing that symmetry principles are laws of nature, and that, even more interestingly, they are laws which govern not first-order facts but the laws themselves. Symmetries are *metalaws*: laws of the laws.

Lange draws inspiration for this view from the writing of some physicists. Here's Einstein describing the meaning of the Lorentz transformation, which gives us the central symmetry of special relativity:

> "The content of the [special] relativity theory can . . . be summarized in one sentence: all natural laws must be so conditioned that they are covariant with respect to Lorentz transformations." (Einstein (1954), quoted in Lange (2011b))

Similarly, when providing a Lagrangian (or Hamiltonian) formulation of classical mechanics, we specify the theory's symmetry group–those symmetry transformations under which the Lagrangian (or Hamiltonian) must be invariant. Lange takes this 'must' seriously–for Lange, the symmetries constrain the laws with a form of natural necessity: one stronger than that of the first-order laws.

Here's Lange:

> "A law is 'symmetric' in a certain respect exactly when it remains unchanged under a certain transformation" [...] "Generalizing from one symmetry exhibited by one law, a 'symmetry principle' ascribes some symmetry to the laws as a whole." (2009: 105-106)

Lange points out that some "regularities" of the laws, like some regularities of fact, can be accidents rather than necessary. He thereby distinguishes between consequences of the laws that merely *happen* to hold and those which *must* hold. Lange calls the first 'byproducts' of the laws and the second 'metalaws'. For example, it is consequence of the laws that there is no inverse cubed force law: there could have been, but there isn't. This consequence is a mere byproduct. He then argues that the symmetry principles are not mere byproducts. It's not that there could have been a law violating Lorentz invariance, or violating the isometry of space, but there isn't: there *must not be* such a law. Had we ended up with different laws, they would have been Lorentz invariant, and they would have been symmetric under rotations, shifts, and boosts.

Having established that symmetries are regularities of the laws, but are not accidental regularities, Lange infers that they are metalaws[2]: "A given symmetry principle may be a meta-law (that is, a 'second-order law') governing the first-order laws–a requirement to which the laws that govern sub-nomic facts must adhere." (Lange, 2009: 107).

2.2 Lange on Laws

Having argued that symmetry principles are higher-order laws, Lange now faces the burden of showing that his view of laws delivers the correct result. This, I think, he does exceptionally well. Lange's view of first-order laws is based on their counterfactual resiliency; he's easily able to extend this view to higher order laws. According to Lange's view, L is a law if and only if L would be true if p were true, for any p logically compatible with L.

> "m is a law if and only if in any context, $p \mathrel{\Box\!\!\rightarrow} m$ holds for any p that is logically consistent with all of the n's (taken together) where it is a law that n (that is to say, for any p that is logically consistent with the first-order laws)." (Lange, 2009: 20)

This is the first blush version of Lange's view; astute readers will note that it is circular, in that it assumes that there is some set of laws n in its definition

[2]Lange sometimes hedges about whether the symmetry principles are in fact metalaws in his sense; he seems instead interested in showing what would be required of a metaphysical view of laws in order for the symmetry principles to be explanatorily prior to the laws: 'I am not trying to argue that there actually are meta-laws; that is for science to investigate. My aim is to understand what difference it would make whether a symmetry principle is a meta-law or a byproduct of the laws–especially what difference it would make to the symmetry principle's explanatory power. The difference between a regularity among the laws that merely obtains and one that obtains as a meta-law is a difference for which any metaphysical analysis of natural law should account' (Lange, 2007: 460). Contra Lange, I hold that symmetry principles are not metalaws, but are not byproducts either and can be be explanatory.

of law. Lange later gives a longer, noncircular version of this principle. The differences matter only a bit: in the longer version, a crucial distinction is between 'nomic' and 'sub-nomic' facts, where the sub-nomic facts are all those which are not about which generalizations are laws or nomically necessary. Laws, on Lange's developed view, form the largest non-maximal set of 'sub-nomically stable' facts, where a fact is subnomically stable just in case it would still have held even if any sub-nomic fact were different[3].

What, then, are metalaws? According to Lange, meta-laws are those statements which are *nomically* stable: they would have held even if any facts, *sub-nomic or not* had been different. That is, they are truths that would have held even had the laws been different. According to Lange:

> [A] closed set of truths that are nomic or sub-nomic qualifies as "nomically stable" exactly when (whatever the conversational context) the set's members would all still have held (indeed, none of their negations might have held) under every nomic or sub-nomic supposition logically consistent with the set–however many such suppositions are nested. (Lange, 2009:114)

Lange argues that the symmetry principles would have held even had the other laws not held, including the conservation laws. The general derivation of conservation laws from symmetry principles through Noether's theorem depends on the fact that the laws have a Lagrangian formulation. Lange argues that had the laws not been Lagrangian, they still would have been invariant under the Galilean symmetry group (the converse Noether theorem also requires a Lagrangian formulation of the laws. One wonders whether a context emphasizing the converse Noether's theorem would lead us to different counterfactual intuitions). He concludes from this that "The symmetry principle has greater modal force than the conservation law and so can explain it, but the conservation law lacks the symmetry principle's modal force and so cannot explain it."

So Lange's view is as follows: (a) the symmetry principles are *nomically* stable. (b) The symmetry principles explain the conservation laws by governing them, that is, the explanation of the conservation laws from the symmetry principles is an example of a *covering law* explanation. (c) The modal force, or counterfactual robustness, of these generalizations tells us which is the metalaw.

2.3 Contra Lange

Here I aim to present arguments against (b): I will argue that symmetry principles are not properly thought of as higher-order. Instead, they are generalizations about the first-order facts.

[3]Here is the longer definition: "Consider a nonempty set G of sub-nomic truths containing every sub-nomic logical consequence of its members. G possesses sub-nomic stability if and only if for each member m of G (and in every conversational context), $\neg(p \mathrel{\Box\!\!\rightarrow} \neg m), \neg(q \mathrel{\Box\!\!\rightarrow} (p \mathrel{\Box\!\!\rightarrow} \neg m)), \neg(r \mathrel{\Box\!\!\rightarrow} (q \mathrel{\Box\!\!\rightarrow} (p \mathrel{\Box\!\!\rightarrow} \neg m)))$, ... for any sub-nomic claims p, q, r, . . . where Γp is logically consistent, Γq is logically consistent, Γr is logically consistent,. . . ."

Lange claims that symmetry principles are laws governing other laws. They explain features of the first order laws by necessitating or determining them in the way laws necessitate or determine first-order facts. This requires them to have nomic content–in order to govern or determine the first-order facts they must be *about* laws rather than first-order facts. Discussions of symmetry principles by physicists (like the Einstein quote in §2.1) and textbook presentations of symmetry principles as constraints on the mathematical formulation of Lagrangian theories can give us the impression that the symmetry principles are primarily constraints on the laws or their formulation. But this is misleading. The symmetry principles are not primarily about laws, but instead are about the first-order facts themselves; they do not explain features of law by governing them but instead by providing information about and constraints on the first-order facts that the laws govern.

Recall from §1.2 that explaining the significance of symmetries involves saying what symmetry-related models have in common. There are two principal views here: on one view, the two symmetry-related models are distinct, but empirically or qualitatively indistinguishable, possibilities. On this view, the symmetries tell us the limits of our empirical discernment. On the second view, symmetry-related states are qualitatively identical. They represent the same situation or possibility. On this view, the symmetries tell us what structure–present in our mathematically formulated theory–is lacking in the world.

On either view, symmetry principles provide a constraint on first-order facts. They either tell us what systems are empirically indistinguishable, or what systems are qualitatively identical. These constraints are not nomic constraints necessitated by natural law, but instead are epistemic or metaphysical depending on the account of symmetries we favor. On the first view, the symmetries relate empirically indistinguishable states, and so are an epistemic constraint on the law: we often know that we are unable to distinguish symmetry-related situations before we know more specifically what the laws are–for example, Galileo's Ship and Einstein's Elevator were employed assumptions about indistinguishable states to identify symmetry-related situations before the formulation of laws bearing those symmetries. On the second view, symmetries relate qualitatively identical states, and so metaphyically constrain the laws provided that–as most philosophers hold–the first-order laws depend on qualitative properties and external relations. These first-order facts about what structure the world has leads to constraints on the laws: our dynamics cannot make distinctions without a difference. By focussing on these constraints, we can make the mistake of thinking the symmetries are primarily about the laws. They are not.

Lange's view may also be inspired by the fact that we should have confidence that the symmetries will hold of future theories because they have held of past theories. This at first brush makes them appear to be inductively discovered higher-order laws, generalizations governing a succession of observed first-order theories[4]. How else could we discover these generalizations about

[4]Importantly, Lange does not explicitly endorse this claim about our empirical access to the symmetries; rather, it's motivated by his connection between the idea that symmetry principles are

the laws? But this too is a mistake. If this is what the symmetries are, and this is how we learn them, our knowledge of them should be taken to be quite suspect. Sure, all of the theories we've looked at obey these principles. But unfortunately, we're also quite confident that they're false theories. So we cannot count them as instances in an inductive argument. Recognizing this makes it hard to see our access to they symmetries as an example of induction by enumeration of instances.

Of course, it's a mistake to think of our older theories, like Newtonian gravitation or Maxwellian electrodynamics, as strictly speaking false. Instead, these theories are good approximations in certain scale and energy regimes. Recognizing this also allows us to see how the presence of symmetries in past theories leads us to require them of future theories. As I'll discuss in §**??**, the presence of symmetries in these successful but false past theories shows that we have quite a lot of empirical evidence that the true laws are invariant under these symmetry transformation. So, when we construct future theories, we need to capture the successes of those false theories of the past; doing so requires us to find the same symmetries in our future theory, or show how they arise from that theory in the energy and scale regime of the earlier theory. Hence, these symmetries act as a constraint on theory construction. This is the sense in which the symmetry principles are an epistemic constraint.

The view that symmetry principles are primarily about first-order facts, and thereby give rise to constraints on the laws, also finds support amongst physicists; here's physicist Eugene Wigner agreeing with this sentiment:

> "The geometric principles of invariance, though they give a structure to the laws of nature, are formulated in terms of the events themselves." (Wigner, 1967)

So, rather than being higher-order principles to which the laws must adhere, the symmetry principles are generalizations about the first-order facts of the world. They are justified because they encode information about the structure of spacetime (in the case of global external symmetries, those we've been focussing on thus far) or the property structure of the world (as, for example, the charge conjugation symmetry of classical electrodynamics does). This information provides us with some important empirical information: in addition to giving us quite general information about what properties and relations are (and aren't) instantiated in the world, symmetry principles tell us when two isolated subsystems will behave in the same way, despite having different connections to the rest of the world (there's some debate on the connection between different sorts of symmetries and empirically indistinguishable worlds and subsystems. See Brading and Brown (2004) and Greaves and Wallace (2014)).

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meta-laws rather than byproducts to the distinction between laws and accidental regularities. In the latter case, we learn the laws by generalizing from the the first order facts; analogously, if the symmetries were meta-laws, we should expect to learn them by generalizing from first-order laws. However, the claim that if meta-laws bear the relation to first-order laws that first-order laws bear to sub-nomic facts then meta-laws should be discovered through induction on laws is defended in Yudell (2013).

If symmetry principles are first-order generalizations, then they are not about the laws at all. Rather, physical theories are required to obey symmetry constraints because symmetry constraints are first-order facts which are known to be true. When we look beyond our current physics and consider possible new theories, we expect them to obey the symmetries of our old theory (and, plausibly, new symmetries we've discovered experimentally, as was the case with Lorentz invariance and special relativity) not because we've inductively discovered these symmetry principles by looking at old, false theories, but because these symmetries encode some of the most general empirical information we have about the world. We hold onto the symmetries because, though we take our old theories to be false in some detail, we conservatively retain our credence in these broader principles and because, due to their success in the experiments supporting the old theory, they have strong empirical support.

If the symmetry principles are first-order generalizations, then they cannot explain the conservation laws as part of a covering-law explanation. So Lange's view about the relationship between conservation laws and symmetry principles fails. Note that this does not mean that the symmetry principles can't explain the conservation laws in some other way. I haven't here argued against Lange's claim that the symmetry principles have a "greater modal force" than other laws, I've only shown that that force doesn't come from their governing those laws from a higher level. So it's plausible that Lange's view still delivers an explanation of conservation laws from symmetry principles in terms of their modal forcefulness, and that his view also finds the symmetry principles to be more counterfactually robust than other laws.

But I am suspicious that Lange can provide a satisfying *explanation* of this "greater modal force" if symmetry principles aren't taken to be higher order laws: while Lange is able to show that any set of statements which is "nomically robust" (i.e. a candidate for meta-lawhood) will be a subset of the (sub-nomically robust) laws, he doesn't provide any reason for believing the symmetry principles occupy this space. Rather, he simply presents the relevant counterfactuals and claims that they are intuitively true. This may just be my Humean sympathies at work, but I find an explanation which appeals to counterfactuals with antecedents so far removed from our experience without giving us any understanding of how we come to know them highly suspicious, whether or not I share the intuitive verdicts Lange provides. This argument may seem unfair–Lange isn't aiming to show conclusively that symmetry principles are metalaws; rather, he argues that if they are explanatory they must be metalaws. My worry, though, is that Lange's view doesn't provide us with the tools to tell whether they are explanatory metalaws or mere byproducts. On his view this question shakes down to the question of which counterfactuals hold, but as these are metaphysically bedrock we have nothing to go on when evaluating them other than our intuitions. I'll attempt to show that the Humean can do better in §**??**.

Moreover, if Lange is wrong about the place of symmetry principles, then his arguments against other views of laws also fail. Lange's arguments (2009, 2011b) rest on the claim that symmetries are meta-laws, something he doesn't believe that dispositional essentials or Humeans can countenance. I am not convinced that Humeans *cannot* accommodate metalaws: for a meta-law friendly response to Lange (2011b) that I find convincing, see Friend (MS) or Yudell (2013). But though it is not incumbent on Humeans or dispositional essentialists to accommodate higher-order laws, all views of laws should recognize the fact that there is an explanatory structure within the laws of physics. In the next section I'll argue that Humeans have available to them a clean explanation of the counterfactual stability of symmetry principles and their explanatory status amongst the laws without ascribing some higher-order status to them. If I succeed, then together with the arguments of this section, the shoe will be moved to the other foot: rather than having an explanatory advantage over Humeanism, Lange's view seems to provide the wrong result, and does so with more unexplained metaphysical danglers. Meanwhile, the Humean view starts with fewer metaphysical posits and naturally results in a view better motivated by received views in the philosophy of physics.

3 Humean Maxilaws

I've argued that symmetry principles are not metalaws. But I think Lange is correct to think that some physical principles–some of our laws–may be more counterfactually robust than others, and that some physical principles may explain others. I think that there's a strong case to be made that symmetry principles are among these, and that views of metaphysics of law should explain these facts. Here I'll show how I think Humeans secure the counter-nomic counterfactual robustness of the symmetries (§3.1) and an explanatory asymmetry within the laws (§3.2), without claiming that the symmetry principles are metalaws, or that this explanation is a covering-law explanation.

3.1 Humean Laws and Counterfactuals

The modern received Humean view of laws is the Best System Account (BSA), which has its roots in the writing of David Lewis:

> I take a suitable system to be one that has the virtues we aspire to in our own theory-building, and that has them to the greatest extent possible given the way the world is. It must be entirely true; it must be closed under strict implication; it must be as simple in axiomatisation as it can be without sacrificing too much information content; and it must have as much information content as it can have without sacrificing too much simplicity. A law is any regularity that earns inclusion in the ideal system. (Or, in case of ties, in every ideal system.) (Lewis, 1983: 367).

The orthodox understanding of the BSA holds that laws are those generalizations which best combine simplicity and informativeness, where these are taken to weigh against one another. Of course, not every follower of Lewis is orthodox: Loewer (2007), Hicks (2017), and Jaag and Loew (MS) think that rather than focussing on simplicity we should flesh out "the virtues we aspire to in our own theory-building;" Callendar and Cohen (2009, 2010) develop a version of the BSA without Lewis's notion of perfectly natural properties (unmentioned in this quote, but the focus of the paper it derives from). But, I think, these distinctions–while important additions to the Humean corpus–aren't required to help us understand the relationship between symmetry principles and other laws of physics. And, I believe, what I have to say about the Humean view will work even if something else is plugged in to Lewis's simplicity slot. So without, I hope, losing any Humean support, I'll focus on the BSA as the view that the laws are axioms of that system which best combines simplicity and informativeness.

Before discussing the place of counterfactuals for a proponent of the BSA, let's briefly look at the advantages of the view. The BSA comes equipped with a ready explanation of our interest in laws. We are interested in believing truths; the laws are statements which (A) we can learn (because they're simple) and (B) are such that, if we use them as axioms of our reasoning, we will infer lots of truths. This understanding of our interest in laws isn't restricted to philosophers. Physicists, too, see this as a good explication of our reason for seeking laws. Here's Eugene Wigner:

> The world is very complicated and it is clearly impossible for the human mind to understand it completely. Man has therefore devised an artifice which permits the complicated nature of the world to be blamed on something which is called accidental and thus permits him to abstract a domain in which simple laws can be found. The complications are called initial conditions; the domain of regularities, laws of nature. (Wigner 1967)

Laws are widely taken to play a variety of roles in scientific reasoning and human practice, including, but not limited to, grounding counterfactuals, underwriting predictions, explaining the behavior of physical systems, and providing a basis for causation. On the orthodox Lewisian view, the laws are counterfactually robust almost by stipulation: Lewis's semantics for counterfactuals builds the laws into the 'closeness' relation, where a counterfactual is defined to be true if its consequent is true in all of the closest worlds where its antecedent is true. Since worlds which obey the same laws (nearly enough) are defined to be closer than worlds which don't, the laws are counterfactually robust by stipulation (Lewis 1981, XXXX).

Philosophical explanations should aspire to more than stipulation, and the Humean can do more to connect laws to counterfactuals than merely stipulate. So the question here is, why do we hold any facts fixed while evaluating counterfactuals? Nonhumeans have an easy, if unsatisfying answer to this question: we hold those facts fixed where are, because of their nature, necessary. Humeans, on the other hand, start by giving pragmatic arguments that we should use the laws when reasoning: doing so allows us to believe many more truths than we otherwise would. Then, we argue that this practice leads us to treat the laws as necessary or counterfactually robust, so that, as Hume says, ''twil appear in the end, that the necessary connexion depends on the inference, instead of the inference's depending on the necessary connexion' (Hume, Treatise, I. III, §VI).

We primarily use counterfactuals in practical reasoning, both in deciding what we will do and in deciding how to assign praise and blame with respect to the actions of others. When considering what we will do, we are required to suspend judgement about which action we will perform. We then attempt to determine what will occur as an outcome of each of our available actions. Although the structure of deliberation requires us to suspend judgement about which action we will perform, it does not require us to suspend judgement about anything else; so in determining what will happen, we use our best inferential principles to determine what will happen on each of our action alternatives. If the Humean is correct, these are the laws–not because they are backed by any metaphysical relation, but because they are useful in allowing us to infer truths.

If we do this–take these laws as axioms of inference–we'll have quite a number of beliefs purely in virtue of reasoning on the basis of the laws. Some of these beliefs will be consciously endorsed; others (possibly infinitely many others) will be purely dispositional beliefs–things we believe not because we are actively thinking about them, but because we would endorse them if we were asked or if they were relevant to a decision situation.

Now consider the Ramsey test for counterfactuals (Ramsey 1929): according to the Ramsey test, we should endorse a counterfactual just in case, were we to add the antecedent to our stock of beliefs, and change our belief set as little as possible, we would come to believe the consequent. I don't think that the Ramsey test is an adequate philosophical account of counterfactuals, or even all there is to say concerning our knowledge of counterfactual truth. But I do think that any successful account of counterfactuals needs to show that the Ramsey test is *truth-conducive*: that is, it's at least a reliable way of evaluating counterfactuals, and by employing it we can come to know which counterfactuals are true (at least in most situations, and provided we start with mostly true beliefs).

If the Ramsey test is truth-conducive, then the best system laws are counterfactually robust. For suppose we took some generalization to be a law. Then–because the laws are those generalizations which are particularly useful for inferring truths–we would take it as an axiom in our reasoning, and have many beliefs on its basis. So removing it from our belief set would result in a large change in our beliefs, as we would also lose those beliefs (including dispositional beliefs, possibly infinitely many) that we have on its basis. Hence, removing the laws from our belief set would result in a less-than-minimal change. Recall that the Ramsey test asks us to add the antecedent of a counterfactual to our beliefs and change our beliefs as little as possible, and then see if the result includes the consequent. Since removing the laws will never be a minimal change, we will only do so if the antecedent of the counterfactual contradicts them. So, if the Ramsey test is truth-conducive, the members of the best system will be remain true under any counterfactual supposition with which they are logically compatible.[5]

The Humean then has a story to tell about why the laws are counterfactually robust: they're excellent principles for inference for truth-interested agents. Humeans give different justifications for using laws as tools of inference: Lewis (1983) follows Ramsey (1929) in holding that laws are axiomatizations of all truths, while Loew and Jaag (MS), and Dorst (forthcoming) argue that laws are useful because of their applicability to subsystems and Hicks (2017) holds that laws are principles which can be discovered empirically and evidentially supported. But what unifies these views is that they account for our reasoning about nonactual possibilities by extending a view about our reasoning concerning what we're really interested in, namely truth and action in the actual world.

To see whether the symmetry principles are *more* counterfactually robust than other laws, then, we just need to see whether they are suited to similarly occupy a privileged role in reasoning. Do we have beliefs because we reason using the symmetry principles? Are they the sorts of principles we can use to infer truths and discover empirically? The answer to all three questions clearly is yes.

I argued in §2.3 that the symmetry principles provide information about which actual situations behave the same way, and on what the property and relational structure of the world is. Because they have strong empirical support, and because we have dispositional beliefs on the basis of them, the symmetry principles are positioned to hold even in counterfactual situations where other laws do not. Their empirical support, and their function as a basis of reasoning, is plausibly prior to our empirical support for specific theories. Thought experiments illustrating symmetry principles, including Einstein's elevator and Galileo's ship, identify situations that our laws should treat the same way, and are used in the formulation of new systems of law. For the same reason we hold laws fixed when reasoning about non-actual situations, we should hold symmetry principles fixed when reasoning about non-actual situations with different laws–doing so is epistemically conservative and a natural extension of good epistemic practice for a truth-interested agent in the actual world.

[5]It's worth noting here that the Ramsey test provides no reason to expect "tiny miracles" of the sort Lewis advocated in Lewis (1981). So much the worse for tiny miracles, I say. Lewis introduced them in part to rule out certain backtracking counterfactuals, and allow for counterfactual future developments that wildly depart from actual future developments–a hard needle to thread if our measure of counterfactual "closeness" is similarity in matters of particular fact. But this way of getting to that goal is a cheap trick. The fact that we can affect the future and not the past should not be settled by the semantics of counterfactuals but by temporal asymmetries in the physical world–most probably, those of thermodynamics (see Albert (2001) and Loewer (2007) for this perspective). The basic idea is this: in many cases, the changes to the past will be hidden in the world's precise microstate, about which we have few or no beliefs, while changes to the future will manifest in the worlds macrostate. One of Lange's (2011b) arguments against Humean metalaws goes by way of these miracles–not a bad argument against an orthodox Humean, but I think we should dispense with the miracles and keep the Humeanism.

3.2 Symmetries and Conservation Laws

So we should take symmetry principles to be more counterfactually robust than the laws as a whole, and counternomically counterfactually stable. Should we also hold that symmetry principles explain some or all features of our laws? Here I'll of the best cases for symmetry-based explanation in contemporary physics: the connection between variational symmetries and conservation laws.

Emma Noether famously showed that for every variational symmetry of a Lagrangian, there is a corresponding conserved quantity. Many authors have taken this to show that the conservation law is *explained* by the conserved quantity, despite the fact that there is a converse Noether theorem, showing that for every conserved quantity there is a corresponding symmetry.

The question, then, is: given that they are interderivable, why do the symmetries explain the conservation laws, but not vice versa? The answer, I think, lies not in the general relationship between symmetry principles and conserved quantities, but instead in the metaphysics. What makes the symmetry principles true? What makes the conservation laws true? As Brading and Brown put this point: "[t]he imposition of a symmetry on a theory places a restriction on the possible form of the theory, and insofar as this restriction has empirical significance then so too does the symmetry itself. *This* is the proper place to look when analysing the empirical significance of a given Noether symmetry" (Brading and Brown (2003: 99), emphasis in original).

Let's consider a specific case: time translation symmetry. Time translation symmetry holds because there is not a preferred temporal origin: two states which differ only with respect to when they occur are qualitatively identical in all internal respects. Neither of them has a property the other doesn't. And this is made true by the structure of spacetime[6]. The Noether current associated with time translation symmetry is $Q = \frac{\delta L}{\delta \dot{q}}\dot{q} - L(q, \dot{q})$. This is the Legendre transform of $= T + U$, the total energy of the system. How do we get from time translation symmetry to the conservation of energy? We add to the symmetry, which describes the structure of spacetime, substantive assumptions about the dynamical formulation of the theory: that the theory *has* a Lagrangian, that its Lagrangian is related to the total energy of the system, and that its action obeys Hamilton's principle.

I've argued elsewhere (Hicks and Schaffer 2017) that the energy of the system is a nonfundamental property of the system: it's grounded in more fundamental properties, namely, the trajectory of the system through configuration space (giving its kinetic energy) and the connection between the fundamental quantitative properties in the system and forces between objects in it (giving its potential energy).

This means that the derivation of conservation laws from symmetries starts from something quite metaphysically fundamental–facts about spacetime–and adds a combination of defined quantities and contingent (from the perspective of the MSS) dynamic laws. This combination of boundary conditions and

[6] Or, for relationalists, by the structure of spatiotemporal relations.

less-fundamental quantities makes the derivation of conservation laws from symmetry principles look like a typical case of a less fundamental law being derived from a more fundamental law. So, from the perspective of the MSS, the conservation laws reduce to spacetime symmetries together with a specific set of dynamic laws.

It's worth taking a moment to draw out the comparison with an accepted case of inter-theoretic explanation. Thermodynamics is taken to be explained by statistical mechanics by (a) positing some more fundamental structure–collections of point particles and a dynamics over those particles, and (b) putting constraints on the possible states of that structure, both in the form of dynamic laws and apparently contingent restrictions on their initial state (the Past Hypothesis). Here, the more fundamental structure is the structure of spacetime and facts about the properties that reside on it, and the added constraints are the quite broad-but not necessary–restriction that the trajectories of particles through spacetime must have a Lagrangian description. These together provide an explanation of the conservation laws.

Why doesn't the derivation go in the other direction? Because spacetime, and location in spacetime, is more metaphysically fundamental than trajectories through spacetime and quantities defined over the configuration of particles in spacetime. The reason the conservation laws are explained by the symmetries is that the former describe things that are grounded in things described by the latter.

Of course, not everyone accepts this. For example, Brown (2005) argues that the structure of spacetime arises from the dynamics of our world, rather than vice versa. Not, I think, coincidentally, Brown and Holland see no explanatory asymmetry between symmetry principles and conservation laws: "We have now established a *correlation* between certain dynamical symmetries and certain conservation principles. Neither of these two kinds of thing is conceptually more fundamental than, or used to explain, the other. [...] After all, the real physics is in the Euler-Lagrange equations of motion for the fields, from which the existence of dynamical symmetries and conservation principles, if any, jointly spring." (Brown and Holland 2004: 10). On the view I defend here, if Brown is right about the relative fundamentality of dynamic principles and spacetime symmetries, Brown and Holland are also right about the explanatory relationship between symmetry principles and conservation laws. I take this to be an advantage to my view: what explains what, even amongst the laws of physics, turns on how the world is actually structured rather than on ungrounded counterfactuals (or inaccessible essences).

4 Conclusion

I conclude that the Humean view has an advantage in explaining the explanatory structure within the laws of physics. To recap: symmetry principles describe quite abstract features of the spatial, temporal, and quantitative structure of our world. These abstract features provide us with information about which parts of the world are qualitatively alike, and which are different. Because our laws only respond to qualitative features, symmetry principles provide quite strong constraints on the structure that the laws can take. But they provide these constraints because they are true, informative generalizations that we know when we are formulating our physical theories, not because they have a mysterious power to make the theories or laws develop one way rather than another.

The Humean view, if it succeeds for first-order laws, provides a link between the informativeness and simplicity of a set of generalizations and their modal resilience and explanatory power. This link arises because of the pragmatic utility of holding such generalizations fixed when reasoning and acting, and it naturally extends to symmetry principles, which are counterfactually robust and explanatory even amongst the laws[7]. So the Humean view is quite powerful: it not only gets right the nature of symmetry principles and their explanatory status within the laws, but it connects naturally to a philosophical explanation of why we, as agents mostly interested in finding out about the actual world, would be interested in this counterfactual stability.

Can other views of laws reap this success? I am not sure. But I do think they will face challenges. As Lange (2009) and French (2014: 251) note, dispositional essentialists are in quite a pickle: whether or not the symmetry principles are meta-laws, they do seem to be robust under counterfactual changes in the actual laws. But for the dispositional essentialist, the laws are metaphysically necessary. So it's not clear how these counterfactuals should be evaluated. Of course, things are not yet hopeless: perhaps a dispositional essentialist of the stripe of Demarest (2015), who holds that the essences pick out the objective property structure of the world but the laws are determined by a best systematization of these properties, can use a strategy like that defended here to show that there is an explanatory structure within the laws. Such a dispositional essentialist could appeal to the grounding-based explication in §3.2 to explain how some of these laws explain others, even if she could not easily show that some principles are more counterfactually robust than others.

Proponents of *sui generis* laws, like Maudlin (2007) are similarly out on a limb. If the laws are part of the ontological structure of the world, what should we make of their internal explanatory structure? And if the laws are really just one *sui generis* posit, it's hard to see how some of that entity's features could be more counterfactually robust than others. Plausibly, such a structure can be built in by hand. But it is more satisfying if it we are able to explain it from the scruples of our view.

Similarly, I think there is hope for Lange. For while I have argued that he is wrong to take the symmetries to be meta-laws, he still has the resources to make them more counterfactually robust, and so (on his view) more explanatory, than conservation principles and other dynamic laws. My chief complaint with this

[7]It's worth repeating here that I don't take this to be part of the *semantics* of counterfactuals. Rather, I think that, whatever the true semantics of counterfactuals, it must get this connection; otherwise we would not have good reason to employ them when making decisions about what to do in the actual world.

strategy is that it seems to build the explanatory structure in by hand: by stipulating that these counterfactuals are true and fundamental, we lose any ability to explain why these facts, rather than others, are the counterfactually robust ones. We thereby have a less satisfying philosophical explanation of the explanatory power of symmetries relative to the other laws. Perhaps, at the end of inquiry, the Humean view will not succeed and we will have to accept this shallower explanation. But I am not yet ready to give up.

Other parts of the internal structure of laws should also interest metaphysicians. Which features of the laws are stipulated or definition, and which describe the world? What is the status of idealizations? Given that our laws often come with a variety of free parameters, how do we tell which of these are nomically necessary and which boundary conditions? What is the metaphysics of physical quantities, or fibre bundles? Many of these questions have generated considerable interest within the philosophy of physics but too little amongst metaphysicians of law. Humeans, and other metaphysicians, are just beginning to discuss them–recently Humeans have tackled the metaphysics of the wavefunction (Miller (2014), Bhogal and Perry (2017)), the status of idealisation laws (Friend, MS), the metaphysics of fibre bundles (McKenzie 2014) and the distinction between constants of nature and boundary conditions (Hicks 2017, Jaag and Loew MS). I believe–and I am certainly biased–that Humeans have a leg-up here, as Hume's principle (no necessary connections between distinct existences) gives us a principled way to find concepts, notions, and kinds which are not fully distinct, but have some sort of internal structure. This means that as a more refined understanding of questions in philosophy of physics percolates through metaphysics, Humeans are able to provide an explanatory theory of the nuances of physical theories, while other views must be tailor-made to yield the right result. But my guess is also that there are more questions to ask, and that the more contact metaphysicians have with philosophy of physics, the more tools they will have to develop their views about laws.[8]

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