August 14, 2021

What Breathes Fire into the Equations*

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Since the 17th century one of the main goals of physics has been the discovery of the fundamental constituents of physical reality and the fundamental laws of nature that describe them. Fundamental laws are the nomological engines that underlie all lawful regularities, causation, and explanations not only in physics and but also in the special sciences and macroscopic phenomena generally. Proposals have included Newton's laws of classical mechanics and gravitation, Maxwell's electromagnetic field equations, Boltzmann's statistical mechanics, Schrodinger's and Dirac's equations, the principles of the standard model of quantum fields and particles, and the equations of General Relativity. Some physicists dream of a final theory – what Steven Weinberg calls 'the Theory of Everything" (TOE) - that unifies general relativity and quantum mechanics and specifies laws that cover all physical entities from the smallest to the largest.

While physicists have been busy proposing, elaborating, and testing systems of laws scientifically minded philosophers have engaged in discussions and disputes about the metaphysics of laws. The metaphysical question is "in virtue of what does a generalization or an

equation express a law?" Or as Steven Hawking more colorfully phrased it "What breaths fire into the equations?" In this paper I hope to contribute to the discussion of this question. But first, a review of the current state of play bout the metaphysics of laws.

The idea that there are laws that govern the motions of material bodies and that it is the job of physicists to find them became prominent in the 16th and 17th centuries. Laws were then thought of either as mathematical descriptions of how God directly governs the motions of material bodies or as instruments used by God to govern their motions.[1] In subsequent centuries the view that laws involve the Deity faded away although the metaphor of governing remained. This raises the question of the metaphysics of laws. If not God, what makes a regularity or equation a law? Contemporary philosophy is dominated by two approaches to answering this question that I will call Necessitarian and Humean.[2] The first holds that reality includes at its most fundamental level a kind of necessity in virtue of which laws are able to play their roles in explanation, confirmation, counterfactuals and causation. In contrast, Humean accounts deny the need for fundamental necessity and say that laws are regularities that possess some other feature which enables them to play their roles.

[1] See Harrison (2019) for a god discussion of the early history of the concept of law of nature. Descartes was the key figure in promoting the idea that there are laws that govern the motions of bodies.

[2] "Governing" because the account originated in the 17th century with the idea that laws are the principles by which God governs the motions of bodies (see Harrison). "Humean" because Hume was the philosopher who first clearly rejected necessary connections and the governing account. There are also dispositionalist and neo-Aristotelian accounts; Cartwright (1999), Mumford (1998). These like governing views understand nomological modality as a fundamental feature of reality although they tend to deflate the significance of laws in favor of the dispositions and capacities of entities and systems. These views are not the focus of the current paper.

There are two main varieties of necessitarian accounts- governing views and powers views- that are accompanied by different views about the natures of fundamental properties.[3] On governing accounts laws are items over and above the properties they govern while on powers views law are regularities that result from the activities of powers that inhere in properties.

Talk of governing echoes the concept's 17th century theological birth but few of its present defenders make an overt appeal to theology to explicate it.[4] Rather, they understand laws to be features of reality that govern events by necessitating regularities among them.[5] Some go further by connecting their accounts of laws with metaphysical views about time. On this approach a dynamical law governs by taking an event or the state of a system (or the entire universe) at a time (or on a Cauchy surface) and evolving it to states at subsequent times thus forging connections between the earlier and later states.[6]

Talk of powers harkens back to pre-17th century Aristotelian science with its explanations in terms of capacities and dispositions. According to powers accounts fundamental properties are dispositions that bestow on their instances the power to bring about subsequent events. Laws are regularities that result from the exercise of these powers. For example, on this view

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[3] Marc Lange has developed a third view in between these two according to which counterfactuals are fundamental and laws are expressed by propositions that possess a kind of counterfactual stability. See Lange (20xx) and Loewer (20xx) for a critique.

[4] For a discussion of the theological origin of the concept of laws of nature see Harrison (2xxx)
Two philosophers who do make the connection between theology and governing explicit but for different reasons are John Foster (2005) and Nancy Cartwright (2004). Foster in *The Divine Law Maker* argues that God's will is required to make sense of the governing role of laws and Cartwright in "No God No Laws" appeals the connection between laws and theology in her argument that there are no laws of nature and for a return to a more Aristotelian account of science.

[5] This type of account of laws was developed by Armstrong, Dretske and Tooley in the 1980s and more recently by Maudlin.

[6] Governing suggests a growing block account of time's passage. Tim Maudlin (2007) proposes an account that only requires that time has an intrinsic direction but that by itself does not presuppose a growing block metaphysics of time. The connection between views of laws and views of time is discussed in Loewer (2012).

gravitational mass is a property that has the power to produce an attractive force on other bodies that makes them accelerate and the gravitational law describe the resulting regularity. Since these regularities hold in virtue of the natures of the properties they connect, they are metaphysically necessary although which powers and so which laws are instantiated is contingent. Most versions of powers views also seem to involve a direction of time since the exercise of a power is temporally directed.[7]

Humean accounts of laws are so named because Hume is known as "the greater denier" of necessary connections.[8] The way I use the term Humean views don't claim that there are no truths concerning natural necessities, laws, causation, counterfactuals and other natural modalities but only that they are not metaphysically fundamental.[9] On Humean accounts such truths hold in virtue of laws not the other way around. Humeans consider governing to be a misleading metaphor that remains from the theological origin of the concept of laws and fundamental powers to be a relic of medieval metaphysics. Instead, they construe fundamental laws to be truths that express scientifically significant regularities and patterns among instantiations of fundamental properties and quantities that are themselves individuated

[7] Since an object may be subject to a number of different powers these accounts need to be supplemented with laws that specify how powers compose.

[8] Lewis (1986) p. ix. Lewis thought that he was a great denier of necessary connection but Hume an even greater denier. Some say that Hume didn't deny that there are necessary connections but claimed only that we have no impressions of them so causal relations are not knowable. Strawson (1989). For a discussion of the actual Hume's view of laws see Jacovides (2021)

[9] Humeans themselves divide into those who think that "it's a law that p" expresses a truth and those who deny this and instead hold it expresses an attitude toward "p" e.g. to use it in making predictions, explanations and so on. Craig Callender likens this division to the metaethical distinction between realism and projectivism in meta-ethics . and argues that it is difficult to see a real disagreement between the two kinds of views as long as one holds that there are aptness conditions for asserting "it's a law that p" and one is a minimalist about truth.. (Callender 2021)

independently of laws and causal relations. Humeans claim that such truths are capable of playing their roles in scientific explanations, etc. without any reliance on governing, powers or fundamental necessary connections.[10] The most prominent contemporary Humean account of laws is David Lewis' Humean Best System Account (BSA).[11] According to the BSA a proposition expresses a fundamental law in virtue of its place in a system that systematizes and unifies patterns among events.

On powers views physical entities are active in virtue of their properties and laws are regularities that derive from the activity of the powers they instantiate. In contrast, on governing and Humean views physical entities are by nature inert. Both latter views hold that fundamental properties and entities are individuated independently of laws and causal relations. They differ in that on governing accounts laws are features of reality that are over and above fundamental property instantiations that are responsible for nature's activity by governing it while on Humean views laws are not features of reality in addition to property instantiations but are propositions that summarize and systematize their distribution in space-time.[12] Unlike some governing and powers views the BSA is not committed to time possessing an intrinsic direction. Governing and Powers view are compatible with presentist and growing block accounts of time while the BSA requires an eternalist view since it presupposes that it makes sense to think of laws as systematizing the instantiations of fundamental properties

[10] Among recent proponents of Humean views are David Lewis, John Earman, Mike Hicks, Christian Loew and Barry Loewer.
[11] Lewis first discusses the account in Lewis (1973) and elaborates in Lewis (1986). He attributes the basic idea of the BSA to Mill and Ramsey. The BSA is further developed and defended in Loewer (1996) (2007)
[12] The idea that it is the nature of fundamental properties and entities to be metaphysically independent of laws is a descendent of the 17th century view that matter is inert and alterations in motion is due to governing laws that themselves derive from God. This view contrasted with the Aristotelian conception on which matter possesses intrinsic powers.

throughout the entirety of space-time. Motion is not metaphysically fundamental but is a consequence of the patterns of instantiations.[13]

In this paper I will describe an account of the metaphysics of fundamental laws and fundamental properties I call "the Package Deal Account (PDA)" that is a descendent of Lewis' BSA but differs from it in a number of significant ways. The most significant is that unlike Lewis' BSA, the PDA does not depend on the existence of the metaphysically elite fundamental properties/quantities that Lewis calls "perfectly natural" properties/quantities that are at the basis of his account. It replaces Lewis' account with an account on which fundamental properties and entities are not metaphysically prior to the laws but on which they and laws are co-equal elements of a package. The PDA earns its Humean credentials by maintaining that laws systematize the distribution of property instantiations and supervene on them. The PDA goes further than other philosophical accounts in explicating the notion of laws and fundamental properties in terms of the practice and aims of physics rather than relying on metaphysical presuppositions. It thus advances the increasingly popular project of naturalizing metaphysics. As we will see, it also supports an immanent or embedded rather than a transcendent metaphysics of physics. I begin by reviewing Lewis' account of perfectly natural properties and his Humean BSA of laws.

[13] For an excellent survey of views of the metaphysics of time see Zimmerman (2005)

David Lewis' Humean BSA

In "New Work for a Theory of Universals" Lewis announced that David Armstrong persuaded him that not all properties are equal. He says that reality includes a distinction between perfectly natural properties/relations[14] and the rest.

> "Formerly I had been persuaded by Goodman and others that all properties were equal: it was hopeless to try to distinguish 'natural' properties from gruesomely gerrymandered, disjunctive properties.
> Eventually I was persuaded, largely by D.M. Armstrong, that the distinction I had rejected was so commonsensical and so serviceable -indeed, was so often indispensable - that it was foolish to try to get on without it."

According to Lewis properties are sets of possible individuals. On this view while properties in general are abundant, perfectly natural properties are sparse and special.[15] They carve reality at its joints. He says that the distinction between perfectly natural properties and the others is either itself primitive or that it may be explained in terms of primitive notions of *universals* or *similarity.* Lewis' reason for taking naturalness or concepts in terms of which it can be defined as primitive is that he needs it for many of his metaphysical projects and he cannot see how to analyze it in terms that don't presuppose it. He writes

> Many philosophers are skeptical about the distinction between natural and gruesome properties. They think it illegitimate, unless it can somehow be drawn in terms that do not presuppose it. It is impossible to do that, I think, because we presuppose it constantly. Shall we say that natural properties are the ones that figure in laws of nature? - Not if we are going to use naturalness of properties when we draw the line between laws of nature and accidental regularities. Shall we say that they are the ones

[14] I use "property" to cover relations.

[15] Properties include not only monadic properties but relations. On Lewis' account properties are sets of possible individuals, n-place relations are ordered n-tuples of possible individuals. Fundamental individuals are either points of space time or point like entities and every such set is a property.

> that figure in the content of thought? - Not if we are going to say that avoidance of gratuitous gruesomeness is part of what constitutes the correctness of an ascription of content. Shall we say that they are the ones whose instances are united by resemblance? - Not if we are going to say that resemblance is the sharing of natural properties. Unless we are prepared to forgo some of the uses of the distinction between natural and unnatural properties, we shall have no easy way to define it without circularity. That is no reason to reject the distinction. Rather, that is a reason to accept it - as primitive, if need be."

It is important to emphasize that on Lewis' account which properties are perfectly natural is a matter of metaphysics. While fundamental laws relate perfectly natural properties it is not appearing in a law that makes a property perfectly natural but rather connecting perfectly natural properties is required for a generalization to be a law. Lewis says

> 'Natural properties' suggests to some that it is nature that makes them natural: in other words, that it is contingent which properties are natural. That was not my intention. The properties that figure in the fundamental laws of nature are natural, but that is not because figuring in the laws makes them natural. Rather it is because regularities are fit to compete for the status of law hood only when formulated in terms of perfectly natural properties" [16]

Echoing Socrates, we can rephrase Lewis as saying "properties are not natural because they appear in laws but generalizations are laws (partly) because they connect natural properties."

If a property is perfectly natural it is metaphysically necessary that it is perfectly natural although whether or not it is instantiated is contingent. There are alien perfectly natural properties that as a matter of contingent fact are not instantiated in the actual world. Lewis says that even though appearance in a law of physics doesn't make a property perfectly natural physics is our best guide to which properties are perfectly natural, or at least the non-alien ones.[17] On the assumption that physics has been doing its job well he gives as examples of good

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Lewis ( ) fn 4 p 218.

[17] "And we may reasonably hope that physics-present day physics, or anyway some not-too-distant improvement thereof-will give us the inventory of all the perfectly natural properties and relations that ever appear in this world" (199Perfecty natural properties4 p.474). This makes it clear that he thinks that the existence of perfectly natural properties is a posit of metaphysics presupposed by physical inquiry.

candidates for perfectly natural properties *charge, mass,* and *spin.* These are determinable quantities that come in determinate quantitative values; e.g. mass of 1 gram.[18] There may be necessary connections between perfectly natural determinates instantiated at the same point e.g. being 1 gram necessarily excludes other values of mass but there are no necessary connections between properties instantiated at distinct points. Lewis also thinks that vector valued magnitudes like EM field values can qualify as perfectly natural even though there is some controversy concerning whether they should be so counted.[19]

In order for perfectly natural properties to perform some of their metaphysical jobs Lewis requires that they are intrinsic to the individuals that instantiate them and are categorical. A property is intrinsic to its bearer only if its instantiation is metaphysically independent of the instantiations of properties by individuals in totally distinct space-time regions.[20] A property is categorical iff it is individuated independently of laws and causal relations. Categorical properties contrast with dispositional properties and powers which are individuated partially or wholly in terms of their nomological and causal connections.

The assumption that all fundamental properties are intrinsic and categorical enables Lewis to formulate a principle of recombination in his account of possible worlds. The principle says that given a space-time and the set of perfectly natural properties every mathematically possible way of combining instantiations of perfectly natural properties to fill that space-time is a possible world and every possible world is such a combination. A proposition is metaphysically necessary if it is true at every possible world. On this account it is due to their role as fundamental constituents of possible worlds that perfectly natural properties deserve to be described as "carving nature at its joints."

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[18] Lewis also thinks that there are also degrees of naturalness. The property *green* is less natural than the property *charge* but more natural than the property *grue.* Fundamental laws involve perfectly natural properties but special science lawful regularities may involve properties that are less natural than the perfect ones.

[19] The problem is that since vectors possess direction they may not be intrinsic. See Basse (2010) for discussion

[20] Of course, the instantiation of a categorical quantity (e.g. mass of five grams) may be incompatible with the instantiation of a distinct categorical quantity (mass of 6 grams) at the same point.

Lewis describes his version of Humeanism as "the doctrine that all there is in the world is a vast mosaic of local matters of particular fact, just one little thing and then another" (1986, ix) His name for the distribution of perfectly natural properties throughout all of space-time is "the Humean mosaic" (HM). The mosaic is Humean since there are no necessary connections among fundamental property instantiations at different points or in different regions. Relations can also be perfectly natural but Lewis tentatively proposes that the only perfectly natural relations instantiated in the actual world are geometrical and topological; e.g. distances between points.[21] He calls this addition to Humeanism "Humean Supervenience" (HS). HS is a contingent claim that Lewis thinks is plausibly true of our world but worries that it might be violated by quantum mechanics.[22]

Lewis doesn't say much about fundamental entities but seems to hold that they are particulars that have no parts. They are instantiated at space time points or are space-time points themselves. I will suppose the latter since fundamental entities other than space-time points can be eliminated in favor of points that instantiate perfectly natural properties that characterize the entities.[23] So, for example, a Newtonian particle is a trajectory through space time each of whose points instantiates the same mass value. On this account a field is not a fundamental entity since it exists throughout all of space-time but a field is composed of points that instantiate field values which are fundamental.

On Lewis' account the metaphysically fundamental ingredients of contingent reality are exhausted by the distribution of perfectly natural properties and relations in space-time. All truths at the actual world including truths about laws, causation, probability, nomological necessity etc. supervene on the HM. This means that any two worlds with exactly the same

[21] It is not clear whether Lewis thinks of the geometrical principles that describe distance relations at a world, e.g. the triangle inequality for Euclidian geometry, as necessary truths or as laws that describe regularities involving them. The latter understanding is more suited for a throughgoing Humeanism.
[22] The reason is that quantum states seem to involve fundamental entanglement relations between quantum systems. There are ways of responding to this that save the letter of HS but have other costs. Se Loewer (1996) Esfeld (2014)
[23] See Hall (2010) for a discussion.

HMs are exactly alike in every other respect i.e. they are the same world. In metaphorical terms, all God had to do to create the universe is to create the HM. Everything else followed. To support this claim Lewis developed accounts of laws, probability, counterfactuals and causation on which these supervene on the HM. His accounts are all controversial but they make it at least plausible that our world is Humean.

The BSA specifies how laws supervene on possible worlds by identifying which regularities in the HM qualify as fundamental laws.

> 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; an 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. (1994a p.478)

Lewis' account seems at once both too broad and too narrow. It is too broad since it counts any theorem of the best system that expresses a regularity as a law. So, the disjunction of Schrodinger's equation and the mass of the earth would count as a law. It is better to restrict the name "fundamental law" to those propositions that are axioms of the best system or, since candidate systems will typically have more than one optimal axiom formulation, count axioms of any such a formulation as a fundamental law and call theorems "nomologically necessary."[24] Fundamental laws according to the BSA are, of course, not metaphysically fundamental since they and their being laws supervene on the HM. The account may be too narrow since Lewis restricts "law" to those theorems that express regularities. But there are some propositions that may play a role in systematizing the HM that are not normally considered to express regularities but nevertheless may deserve to be called laws.[25]

[24] For example, classical mechanics has a number of different formulations e.g. Newtonian, Hamiltonian, Lagrangian,. We can call the axioms of any of these formulations fundamental laws or relativize the notion of "fundamental law" to particular formulations.

[25] I have in mind, for example, the "past hypothesis" that specifies the low entropy microstate of the universe around the time of the big bang that plays a central role in statistical mechanics. Since adding it to the dynamical laws and statistical mechanical probability distribution increases the informativeness of the system at little cost in simplicity it qualifies as a law.

Objective probabilities enter Lewis' account together with laws by letting deductive systems include sentences that specify objective probabilities of events.

> Consider deductive systems that pertain not only to what happens in history, but also to what the chances are of various outcomes in various situations - for instance the decay probabilities for atoms of various isotopes. Require these systems to be true in what they say about history....Require also that these systems aren't in the business of guessing the outcomes of what, by their own lights, are chance events; they never say that A without also saying that A never had any chance of not coming about. (1995 p.480)

By including probability functions in the language in which laws are formulated a system can increase its informativeness enormously at little cost to simplicity without adding additional fundamental ontology. On this account objective probabilities are always linked to laws. They are objective although not fundamental features of the HM. They are not subjective degrees of belief although they guide degrees of belief via a principle Lewis calls "the Principal Principle." (PP). The PP says that a person's degree of belief that A ought to match the objective probability of A as long as she has no inadmissible information.[26] Lewis thought objective probabilities are always associated with indeterministic dynamical laws but his account also applies to objective probabilities compatible with theories with deterministic dynamical laws like those found in statistical mechanics and Bohm's version of quantum theory.[27] The fact that Lewis' BSA extends to cover probabilistic laws is one of its great advantages.

The BSA says that laws and objective probabilities are determined by the systematization of the HM that optimally balances informativeness and simplicity. Lewis characterizes informativeness in terms of number of possibilities excluded, fit in terms of likelihood of the

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[26] Lewis' initial version of the PP says that one's degree of belief that A given that the objective probability of A is x and that one has no "inadmissible" evidence should be x. Information that bears on an event over and above its bearing on the event's probability is inadmissible. It turns out that there is a conflict between Lewis' Humean account of probabilities and the PP that led Lewis to modify the PP (Lewis 1994) and subsequently to a vast discussion. See especially Ismael (2008).

[27] See Loewer (2001)

world given the system, and simplicity in terms of syntactic complexity, number of axioms and number of constants. The reasons he includes these in his characterization of the law determining best system is that these are among the criteria that have been employed in the history of physics to evaluate proposals for fundamental theories and it is evident why they are desirable in a systematization.

Lewis' discussions of the criteria for evaluating systems are sketchy, inadequate and incomplete. Simplicity, as it is appealed to in evaluating physical theories is a complicated matter involving considerations of the forms of equations, numbers of fundamental constants, and ease of deriving significant consequences. Lewis' account of informativeness in terms of number of possibilities excluded is much too crude. It is not merely the quantity of information that is valuable in a theory. Some information is more important than other and especially important is how the information is organized. It counts in favor of a system if it organizes information so as to provide understanding by showing how disparate phenomena are related to each other and in a way that it can be used for explanation and prediction. One way in which proposals for fundamental theories does this is by way of distinguishing dynamical laws and initial conditions.[28] For example, the dynamical laws of classical mechanics specify how the state of a system of particles (i.e. their positions and momenta) evolve to states at subsequent times. By making this distinction dynamical laws are able to provide information about how a system would evolve were it to begin in alternative states. Probabilistic laws provide information about the HM via their role guiding belief according to the PP. Adding probability to the language in which candidates for law determining systems can be formulated requires additional criteria for evaluating the goodness of candidate systems that measure informativeness. Lewis suggests degree of fit by which he means the probability of the mosaic given the candidate system. This encounters difficulties and a better way of evaluating probabilistic informativeness is needed. [29] The criteria for evaluating candidate systems requires more discussion than I can give it here. For now, it suffices to understand Lewis' proposals for the criteria for evaluating systems as gesturing in the direction of the criteria actually used by physicists to evaluate proposals for fundamental theories.

The guiding idea of the BSA is that what makes a regularity a law is its place in a system that organizes information about events and regularities by subsuming them under more general regularities and ultimately under the axioms of an optimal system. Proponents of governing and powers views may also think that, as a matter of fact, lawful truths of our world can be

[28] The importance of the distinction between dynamical laws and initial conditions is emphasized by Ned Hall (2015). See also Callender (2021) for a discussion of criteria on a systematization for it to perform the jobs that physics expect laws to perform.

[29] Adam Elga (2008) points out that there are problems with Lewis criteria for evaluating probabilistic laws in terms of fit and suggests an alternative.

systematized and that looking for a systematization is a good way to look for laws. But they don't think that it is systematizing that makes regularities lawful but rather lawfulness comes from the necessary connections that enforce regularities. While proponents of necessitarian views claim to be able to imagine worlds that contain laws that are not components of a system but in which there is a single isolated law, for example, that all ravens are black, Humeans think that such imaginings are flights of fancy disconnected from actual science. According to the BSA laws are by nature components of a system of laws.[30] This difference makes for an important difference between the ways the two approaches think of how laws explain. On governing accounts laws explain an event by playing a role in bringing the event about or constraining what events can occur. On powers accounts laws explain by pointing to the powers that bring events about. Because Humean laws don't literally govern or involve powers non-Humeans often claim that they don't explain at all.[31] But this misunderstands the ways that laws are involved in explanations on Humean accounts. As mentioned, one way Humean laws explain is by showing how seemingly disparate phenomena are related to each other. Vivid examples of this are provided by Newtonian mechanics' unification of celestial and terrestrial motions and Darwinian natural selection's unifcation the evolution of all life forms. Another way in which Humean laws are involved in explanations is by backing counterfactuals and singular casual claims. [32] For example, Newtonian laws back counterfactuals concerning

[30] As mentioned earlier the concept of law of nature that took root in the 17th century included both the idea that laws describe how God governs and also that since God is supremely rational that they are components of a mathematical systematization. See Harrison (2019) Ott(2019)

[31] The objection to Humean accounts is that if what makes a regularity a law is the HM it would be circular for the law to explain the HM. But this depends on thinking of laws as explaining by playing a role in producing or governing the HM. Humeans reject this account of how laws explain. See maudlin ( ) and Lange ( ) for the objection and Loewer ( ) for a rebuttal.

[32]This is discussed in Hicks (fort).

the motions of projectiles e.g. if the cannon's angle had been greater the shell would not have hit the target. Much more needs to be said about how Humean laws explain. For now, I just want to emphasize that from the Humean perspective the idea that laws explain by enforcing regularities is left over from the theological origin of the concept of laws of nature and so the fact that Humean laws don't explain because they don't enforce is not a serious objection.

Lewis' formulation of the BSA relies essentially on his distinction between perfectly natural properties and the rest since if there is no restriction on which properties can be referred to in the basic predicates of a candidate system the BSA collapses. Let Fx be a predicate that is true of only individuals that exist at the actual world and suppose with Lewis, that individuals are world bound. Then VxFx is maximally informative on Lewis' account of informativeness since it excludes all possibilities except the actual world. It is also very simple and consequently wins the competition for the world's best theory. But VxFx entails all truths and so renders all generalizations nomologically necessary thus trivializing the BSA. This is absurd. We can dismiss VxFx as unqualified to be a candidate for a best system since no one will be awarded a Nobel prize for proposing it but that is not enough. Further restrictions on the vocabulary in which candidates for optimal system are formulated are needed since we also want to exclude gerrymandered grue-like predicates from laws. The remedy according to Lewis is to restrict candidates for best theory to those that are formulated in a language whose basic non- logical and non-mathematical predicates refer only to perfectly natural properties and relations. Since it is physics and not the special sciences that aims to find perfectly natural properties this restricts Lewis' account to an account of fundamental laws of physics. However, the idea the

best systems idea can be applied to special science properties as well but exactly what makes a special science regularity lawful requires more discussion that I leave for elsewhere.[33]

Although it was Lewis who proposed that there are perfectly natural properties and emphasized their importance in the BSA both governing and powers views of fundamental laws also presuppose the existence of elite fundamental properties. On Armstrong's governing view a fundamental law is a necessitation relation between universals and on powers views only select fundamental properties possess the power to produce lawful regularities. On all three views only elite properties appear in fundamental laws. Hicks and Schaffer call the claim that only elite fundamental properties appear in fundamental laws "Link."(2017) They observe that if it is true then propositions that express laws but refer to different fundamental properties express different laws even if they belong to systems that mathematically equivalent. They argue against Link by examining the way physicists actually formulate and use laws in explanations and predictions. For example, there are alternative formulations of classical mechanics Newtonian, Hamiltonian, Lagrangian, and so on, whose basic equations refer to different properties but are treated by physicists as specifying the same dynamical laws.[34] If Link is right then at most one of these can be the correct formulation. On governing accounts at most one of the laws can do the governing and on powers accounts at most one of the powers mentioned in one of the formulations can bring about subsequent events. On the BSA at most one of the properties that occur in the formulations can be perfectly natural. Hicks and Schaffer point out that the BSA, governing and powers accounts are all committed to Link. But, as we will see, the PDA is different since it is not committed to there being a unique set of

[33] Callender and Cohen develop an account of special science laws by appealing to Lewis' best system approach restricted to special science predicates. An account that connects special science laws more directly to fundamental laws is in Loewer (2020)

[34] Jill North (forthcoming) provides some reasons to think that these different formulations specify different laws only one of which could be the actual laws.

fundamental properties or a uniquely correct formulation of laws that physicists treat as equivalent.

The BSA should not be thought of as an analysis of the concept of law of nature but instead as a proposal for the best way of understanding what fundamental laws are in physics. The 17th century conception of natural law is an amalgam of the idea that laws describe how God governs the motions of bodies and the idea that the rules that describe these motions are simple, mathematical, and systematic.[35] The BSA dispenses with the fist aspect and promotes the second. The question is whether this revised concept of law captures the way fundamental laws are used in physics and be justified by its philosophical virtues. Proponents claim that it describes how the concept of fundamental law is actually employed in physics and argue in its favor is that it frees the concept of law from its theological origins and dispenses with the obscure metaphors of governing and powers. Since it builds the aim of theoretical physics to find simple and informative systems into its characterization of laws it provides the beginnings of an answer to the question of how physics finds fundamental laws and by connecting them with unification why they are worth finding. Further, it can be naturally extended to accommodate non-dynamical laws and laws that specify probabilities including probabilities compatible with deterministic dynamical laws.

Opponents of Lewis' Humean BSA argue that its virtues, whatever they may be, are outweighed by its vices. In particular, proponents of necessitarian accounts argue that Lewis'

[35] Ott (2020) describes how the 17th century concept of law included both governing and systematizing especially in Berkeley.

Humean BSA violates intuitions to the effect that worlds that match with respect to their HMs may differ in their laws and that laws need not be components of a world's Lewisian best system.[36] More importantly proponents of both governing and powers views argue that Lewis' BSA fails to account for the roles of laws in explanation, induction, and grounding causation.[37] From the perspective of necessitarian accounts regularities in a Humean world appear to be flukes holding by coincidence or chance and so not capable of supporting explanations and inductive inference. I think these objections can be answered and I and others have argued so elsewhere.[38] Here I want to discuss some other problems for Lewis' BSA that result from its reliance on Lewis' metaphysics of perfectly natural properties and their role in the BSA and propose an alternative account that avoids these problems.

The BSA's problems with perfectly natural properties

The first problem with building the BSA on the metaphysics of perfectly natural properties is that contemporary physics apparently posits fundamental entities, properties and relations that are not perfectly natural properties and are not compatible with HS. Quantum theory, in particular creates difficulties for HS's commitment to restricting perfectly natural relations to metrical ones and to perfectly natural properties always possessing determinate values.

[36] Thought experiments that mine these intuitions are discussed by Carroll (19xx). From its origin the concept of law of nature was an amalgam of the idea that laws govern (or describe how God governs) motion of matter and that they form a system (since God is perfectly rational) that mathematically describes the motion of matter. Since these components can be separated it is not surprising that we can tap into anti Humean intuitions.

[37] Carroll, Armstrong, Maudlin, Foster, Emery, Lange, Lazorovici make arguments all along these lines.

[38] Loewer 1996,2012, 2020 Beebee (2000), Hicks, Miller. See also Bhogal (2020) for a recent survey of objections to Humean accounts and Humean responses.

The problems arises because quantum mechanics posits entangled states that on their face value seem to involve relations other than metrical relations between (among) occupants of distinct regions of ordinary space time and in which some properties fail to possess determinate values. For example, a pair of electrons in the EPR state

EPR) $1/\sqrt{2}|UP1\rangle|DOWN2\rangle - 1/\sqrt{2}|DOWN1\rangle|UP2\rangle$

is in a state in which neither electron has a determinate spin but the spins of the electrons are correlated. Even worse for Lewis' account are states in which particles lack determinate location since it is difficult to see how such states can be understood in terms of points or individuals occupying points in 3-dimensional space instantiating properties. Lewis was worried about quantum mechanics saying

> I am not ready to take lessons in ontology from quantum physics as it now is. First, I must see how it looks when it is purified of instrumental frivolity...of double thinking deviant logic..and - most of all - when it is purified of supernatural tales about the power of the observant mind to make things jump. (1986 p. xi)

However, there are a number of versions of quantum theory that have been purified of instrumental frivolity and which have explicit ontologies and laws. Almost all these accounts violate HS in one way or another. Specifically, it is difficult to see how HS can accommodate the quantum mechanical state.[39] Further conflicts with HS come from quantum gravity theories that posit entities that are not point like (e.g. strings and branes), space-times that have more

[39] See Loewer (1996) for a way of saving the letter of HS by positing that the fundamental physical space is 3n dimensional configuration space and the QM state is a field in it. Michael Esfeld, Eddy Chen, Harjit Bhogal and Z Perry and others have proposed versions of Bohmian mechanics that are compatible with HS but at the cost of excluding the wave function from fundamental ontology. On their account the fundamental ontology consist solely of point particles. Their idea is to construe the quantum state not as part of the ontology but as systematizing the trajectories of particles. That is, more along the lines of the way that Lewis understands laws. This approach is compatible with HS but at the risk of adding a possibly a very complicated description to the best systematization.

than 3+1 dimensions and even ones in which space-time is not fundamental but is claimed to emerge from something more fundamental. So, there is reason to think that HS is not true or, at least that physicists don't feel constrained by it. Lewis understood HS to be a conjecture that might turn out to be false so might not grieve if it is given up since the Humean mosaic can be expanded to include properties that are instantiated by regions (or individuals) that are larger than point size (like strings) and relations other than geometrical relations (like entanglement relations) while maintaining the idea that the mosaic consists of the instantiations of perfectly natural properties and relations.

There are further developments in contemporary physics that call the entire Humean ontological basis on which Lewis' BSA is built into question. Some current physical theories posit fundamental properties and quantities that are not intrinsic to the regions in which they are instantiated and are not categorical and whose ontologies don't fit easily into the framework of individuals and properties. It has been claimed that this is the case for quantum field theory and the standard model of elementary particles. For example, French and McKenzie argue that QFT and the standard model contain symmetry principles that individuate certain fundamental quantities and entities and so imply that the properties and entities instantiated in distinct regions are not intrinsic and involve necessary connections.

> …the properties through which the fundamental constituents of matter interact in terms of gauge transformations, and these bring in their wake the appropriate gauge bosons, then it looks as if we have no choice but to say that the properties such as charge and color are not the sort of properties that lone objects can have, and hence that these properties are not after all intrinsic.

Another example is that the symmetry principles of the standard model entail that it is metaphysically impossible for there to be fermions with their particular masses unless there is

a Higgs field. This seems to make mass a non-intrinsic property so it doesn't qualify as perfectly natural. Tim Maudlin goes further suggesting that it is not right to think of QFT on the model of entities bearing properties and relations. According to Maudlin the QFT representation of certain quantities (e.g. quark color) as fiber bundles implies that these quantities are not metaphysically independent:

> We should note that adopting the metaphysics of fiber bundles invalidates a set of modal intuitions that have been wielded by David Lewis under the rubric of the Principle of Recombination. According to Lewis, Hume taught us that the existence of any item puts no metaphysical constraints on what can exist adjacent to it in space. This invites a cut-and-paste approach to generating metaphysical possibilities: any object could in principle be duplicated elsewhere, immediately adjacent to the duplicate of any other item (or another duplicate of itself)... Duplication is supposed to be a metaphysically pure internal relation between items. But from the point of view of fiber bundle theory, it makes no sense to 'copy' the state of one region of space-time elsewhere even in the same space-time, much less in a disjoint space-time. There is no metaphysical copying relation such as the Principle of Recombination presupposes.[40]

One could try to save the letter of Lewis' Humeanism in the face of these examples by adding further fundamental relations and understanding the space-time as higher dimensional thus further violating HS. But an alternative would be to admit that a true fundamental theory may posit an ontology that is not representable in terms of a Humean Mosaic while seeing if it is

[40] Se Maudlin 2007 .p.103)

possible to save the core idea of the BSA that what makes a proposition express a law is not governing but its role in systematizing. I will return to this suggestion shortly.

The BSA also faces a number of difficulties due to its reliance on perfectly natural properties that are primarily philosophical. Here are three problems that will lead to my revision of the Lewis' account.

The first problem is that since perfectly natural properties are categorical it appears that they are or have unknowable quiddities. Quiddities are for properties what haecceities are for individuals- a something we know not what- that makes it the property it is independently of its causal and nomological relations. A consequence is that categorical properties can swap causal and nomological roles in different possible worlds or even within a single world without any way of our knowing. So, for example, if negative charge and positive charge are perfectly natural properties then there are two possible worlds which have the same nomological structures but in which instantiations of positive and negative charge switch places. It is also possible that within a single possible world there are distinct categorical properties that play indiscernible nomological roles. For example, there is a world in which there are 10 different perfectly natural properties all playing the role of negative charge. Such metaphysical possibilities lead Lewis and Langton to endorse a view they call "Ramseyan humility", the view that there are facts which are irremediably unknowable since there is no way to discover which world we are in. I am not sure that Ramseyan humility really does follow or, if it does, that this is a problem. My worry is that since quiddities apparently make no scientific difference it would be better for a scientific metaphysics to avoid them if possible. Avoiding quiddities means that fundamental properties are not categorical but possess some of their nomological

roles essentially. This seems plausible in its own right since theories posit properties along with laws that involve them. It is difficult to think that a property could be mass if it didn't play the nomological role of mass or that anything that does play that role could be anything other than mass. One version of this view called "nomic structuralism" claims that a property just is a node in a web of nomological relations. Nomic structuralism avoids positing scientifically meaningless metaphysical distinctions but it has struck some philosophers as unsatisfactory since it seems to imply that all there is to reality is structure without content. Russell referred to this view with the cryptic remark "There are many possible ways of turning some things hitherto regarded as 'real' into mere laws concerning the other things. Obviously, there must be a limit to this process, or else all the things in the world will merely be each other's washing."[41] Russell seems to be saying that there must be some fundamental properties that are not individuated by laws. So, we are left with a puzzle. It seems unsatisfactory that all fundamental properties are categorical as Lewis' account requires but also unsatisfactory that all are individuated by the laws to which they conform. Perhaps some properties are one and some the other and some a combination of a quiddity together with essential laws. But we are left without a principle that tells us which are which. It would be better for our metaphysics of laws and properties to be non- committal about this issue and leave it to physics to decide, if it needs to, which fundamental properties are categorical and which are fundamental dispositions and which are mixtures of the two.[42]

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[41] The view that all properties are individuated entirely in terms of their necessary connection to one another

[42] Michael Esfeld (2019) has developed a view he calls "super Humeanism" in which the only fundamental property is being a particle and the only fundamental relation is distance. All other predicates and function terms in a theory are understood as devices for systematizing particle trajectories in much the same way that the BSA treats probabilities. This avoids issues re quiddity swapping. But in my view it takes Humeanism too far since the axioms of the systematization will need to be immensely complicated to informatively systematize particle trajectories for a world like ours. (see Callender)

A rather different problem with Lewis' BSA was raised by Bas van Frassen (1989). Van Frassen pointed out that it seems possible for there to be a true theory T that optimally satisfies the criteria implicit in physics i.e. fulfills all of Steven Weinberg's dreams for a TOE, and yet not be the Lewisian Best system since its fundamental predicates fail to refer to perfectly natural properties. If so the class of propositions T claims express laws may not match the class deemed laws by the Lewisian BSA. Lewis claims that physics aims to locate perfectly natural properties and the fundamental properties of contemporary physics are the best candidates we have for perfectly natural properties but, as Heather Demarest points out, that a theory that optimally accounts for the motions of all bodies and satisfies other desiderata on a fundamental theory doesn't coincide with the best systematization of the distribution of perfectly natural properties.[43] Physics aims to find nature's scientific joints, but these may not coincide with her Lewisian metaphysical joints, assuming she has them, and this can result in a mismatch between laws of the BSA and the laws according to ideal physics. Here is an example of how this can come about. On Lewis' account there is a possible world in which different perfectly natural properties (i.e. properties with different quiddities) play the nomic role that we think mass plays in our world (assuming our world is Newtonian) in different space time regions. If so, then the language in which the best system is formulated will contain different predicates for each of these mass properties and one of the axioms of the system will be a disjunction specifying the behavior of each of these mass properties. It would thus be more complicated than the best systematization formulated in the language of physics which counts these properties as identical. It could turn out that the system that results by dropping some of the

[43] See Demarest (2017) for an account of how this can happen.

disjuncts associated with regions with few particles will be sufficiently simpler to overcome the decrease in informativeness. If this is the case, then the laws specified by that system will specify the Lewisian laws while the physicist's theory will be the usual Newtonian theory even though mass is not a perfectly natural property. Call this "the mismatch problem."[44]

A defender of Lewis' view of the role of perfectly natural properties might respond that the possibility of mismatch is not a problem at all but simply a consequence of realism about laws and properties. One might claim that there are metaphysical facts about which properties cut nature at its joints and even a theory that satisfies all the other scientific desiderata but is mistaken about which properties are perfectly natural is simply wrong about the laws. But it seems to me that this takes realism too far. It is presumptuous for a metaphysician to say to, for example, Steven Weinberg who believes he has found a theory that optimally satisfies all scientific criteria including truth that he may not have discovered the fundamental scientific properties and laws. If one thinks, as I do, that it is physics not metaphysics that determines where nature's joints are this response is not appealing.[45]

There is a third problem with the role of perfectly natural properties in Humean account of laws distinct from but closely related to the mismatch problem that Shamik Dasgupta calls "the

[44] The mismatch problem is discussed by van Frassen (1989), Loewer (2007) and Demarest ( ) who suggested its name.

[45] Another response to the mismatch problem is to argue that since perfectly natural properties are "reference magnets" it won't arise. David Lewis suggested this in conversation (Sept 2001). I don't know of an explicit argument although Cian Dorr remarks that "natural properties are widely held to be easier to refer to, ceteris paribus. So, arguably, a situation where people ended up with true scientific theories stated in a language whose basic predicates were too unnatural for the axioms to meet the bar for law hood would have to be quite remote and unusual." (Dorr 2019)

problem of missing value."[46] The problem is that if perfect naturalness is a metaphysical primitive there needs to be an explanation of why physicists should value and aim to find the best systematization of truths expressed in the language of perfectly natural properties as opposed to systematizations of truths in other languages? A TOE that optimally satisfies all scientific criteria but fails to match the Lewisian best system because it is not formulated in the language of perfectly natural properties does not seem to lack any value of interest to science. In fact, satisfaction of Lewis' requirement that the law determining optimal system is formulated in the language of perfectly natural properties may come at the cost of satisfying some of the criteria that science does value.

Dasgupta observes that there are many collections of predicates whose instantiations can serve as the supervenience bases for all truths and instead of formulating the best system in terms of systematizing all the facts specified in the language of perfectly natural properties we could formulate best systems accounts in terms of a language whose primitive predicates refer to the perfectly natural* or perfectly natural** properties and so on, Such systems plausibly will determine different so called "laws"; laws*, laws**, and so on. The question is "what is it about perfectly natural properties that makes them suitable to guide physical theorizing and determine which propositions are those that physics seeks to find and call laws?" It is not adequate to simply claim that "they are the ones that guide physical theorizing because they are perfectly natural" or because "they cut nature "at the joints." This would be, to borrow Lewis' quip, like saying that someone has strong arms just because he is called "Armstrong."

[46] Dasgupta (2018). Dasgupta's discussion is detailed and subtle. I understand him as providing an argument that an adequate account of laws should explain what it is about laws so characterized that makes discovering them objectively valuable for scientists.

Why does a property deserve to be called "perfectly natural" or "a joint of nature?" Lewis assumes that reality comes with perfectly natural properties and that it is the job of physics to find them and laws characterized in terms of them. It is supposed to be an objective matter what the optimal system and the laws are and that physicists ought to try to find them. The problem is that without an explanation of why it has such normative force we have no more reason to think that the best theory formulated in the language of perfectly natural properties rather than the best theory formulated in the language of perfectly natural* or natural** properties determines the laws that physicists aim to find. Dasgupta puts this by saying that value is missing from Lewis' perfectly natural properties.[47]

Notice that if we had a solution to the mismatch problem and could show that discovering or attempting to discover a TOE is objectively valuable we would also have a solution to the problem of missing value.[48] Dasgupta argues that accounting for the value possessed by our division of the world into scientifically fundamental properties is to understand them as *relative* to us and our values and worries that this leads to the kind of anti-realism and relativism associated with Nelson Goodman. I will later argue that the PDA provides an account of the source of the value of the properties that physics counts as fundamental that is objective and realist without sliding into pernicious relativism.

[47] Dasgupta observes that it is ironic that Lewis raises exactly the missing value problem to accounts of objective probabilities which take them to be metaphysically fundamental propensities. He writes "Objective probabilities are supposed to be credence guiding via Lewis' Principal Principle and its ilk but Lewis thinks that there is no explanation of why a metaphysically primitive propensity should guide credence. P.5 I just paraphrased Lewis' famous objection to anti-Humean conceptions of objective chance, because my objection to realism is exactly analogous. Ironic, then, that the problem with realism can be found in the writings of someone I take to be an arch realist! But ironies aside, let us review Lewis' argument so as to use it as a guide."

[48] I owe this observation to David Albert in conversation.

To recap the problems with tying the best systematization account of laws to perfectly natural properties in the way the BSA does are a) there may be fundamental laws which do not connect perfectly natural properties, b) there are fundamental properties in physical theories seem to have at least some of their nomological roles necessarily and c) it leads to the mismatch and missing value problems. Even if one is not convinced that the philosophical problems raised against building the BSA on the basis of perfectly natural properties are devastating one might find it attractive to see if it is possible to save the idea that propositions express lawful regularities in virtue of their role in systematizing without depending on this metaphysical assumption. That is what the PDA attempts to do.

The PDA

The primary reason Lewis calls the BSA a "package deal" is that it explains

> "why the scientific investigation of laws and of properties is a package deal; why physicists posit natural properties such as the quark colors in order to posit the laws in which those properties figure, so that laws and natural properties get discovered together. " (Lewis 1983 p368)

But Lewis' BSA is a methodological not a metaphysical package. Even though the BSA says that laws are posited together with instantiations of perfectly natural properties and the space-time in which they are instantiated the properties and space-time are metaphysically more fundamental. In contrast, the PDA is a package on which fundamental properties, space-time, and an optimal systematization of the fundamental property instantiations are metaphysically

on a par. All are determined together. By making this alteration in the BSA I will argue that the PDA avoids the problems encountered by the BSA.

The question that immediately arises is "if the PDA is a package in which includes both the fundamental properties and the laws earn their places by their role in systematizing what is it that they systematize? Without an answer to this question what prevents the PDA from emptiness or succumbing to the trivialization that befalls Lewis' BSA sans a preferred language? The worry is that without Lewis' requirement that the candidates for best system systematize the distribution of perfectly natural property instantiations there is nothing to prevent the PDA from selecting "gruesome" properties and ontology as fundamental or even Lewis' Fx as a fundamental property and VxFx as the best theory? Answering this question involves a brief discussion of the nature and goals of physics.

The best way of understanding the enterprise of physics is that it begins, as Quine says, "in the middle" with the investigation of the motions of macroscopic material objects e.g. planets, projectiles, pendula, pointers, and so on.[49] Physics advances by proposing theories that include laws that explain the motions of macroscopic objects and their parts. These theories may (and often do) introduce ontology, properties/relations, and laws beyond macroscopic ones with which it began and go onto to posit laws that explain their behaviors. For example, in order to account for the melting of ice, the spreading of smoke, the growth of plants and so on it was proposed that these and other macroscopic objects are composed of tiny particles in motion.

[49] David Albert suggested the aptness of Quine's way of putting characterizing physics.

To explain the behavior of these particles it was posited that these particles are electromagnetically charged, that they produce electromagnetic fields and satisfy Maxwell's laws. Often, as in the case of classical mechanics and Maxwellian electromagnetics, conflicts arise between theories whose resolutions lead to the introduction of further theories with additional ontology, laws and space-time structures.[50] The ultimate goal of this process is the discovery of a theory of everything (TOE) that specifies a fundamental ontology and fundamental laws that that cover not only the motions of macroscopic objects with which physics began but also whatever additional ontology and quantities that have been introduced along the way. A true TOE systematizes its fundamental ontology and satisfies, to the greatest extent possible, the criteria that physicists have developed for evaluating fundamental theories i.e. truth, simplicity, informativeness, fit and so on. In other words, a true TOE is very much like a Lewisian best system. Most important among these criteria is that the fundamental ontology and properties of a candidate TOE provides an explanatory supervenience basis for whatever non-fundamental that has been introduced to account for macroscopic physical phenomena. By this I mean that it is possible to see or make plausible that macroscopic and special science facts and laws are grounded in fundamental facts and laws.[51]

Like the BSA the PDA is based on the idea that there exists an optimal systematization of the distribution of fundamental ontology and properties and that this systematization determines the fundamental laws. But unlike the BSA the PDA does not assume the existence of Lewis'

[50] Examples of this are the development of special relativity to resolve conflicts between classical mechanics and electromagnetic theory and the development of quantum mechanics to account for the stability of atoms.
[51] For this to be the case David Albert and I have argued that the TOE needs to include a probability distribution over physically possible histories of the universe. We call the package of fundamental dynamical laws and the probability distribution "the Mentaculus" and argue that specialscience laws, counterfactuals, and probabilities are all derivable from it. See Albert (2000,2015) and Loewer (2021)

perfectly natural properties at the outset but rather posits a system of fundamental properties and laws together as described by the world's optimal TOE. The PDA does this by explicitly building into the criteria for a candidate TOE that it provides the basis for explanation and prediction of the motions of macroscopic objects. These objects and their motions are initially described in terms of the languages with which physical investigation begins. This requirement replaces the role that the language of perfectly natural properties plays in the BSA. Instead of requiring that candidates for optimal systematization are all formulated in the language of perfectly natural properties it allows proposals for the fundamental language that specifies fundamental ontology and properties to vary along with systematizations. Candidates for the package consisting of a fundamental language and systematization of the instantiations of its fundamental predicates are evaluated by how well they account for macroscopic phenomena and how well they systematize it and the further ontology it introduces. Fundamental laws of the world are the axioms of its TOE.

Because the fundamental ontology and properties of the world's TOE need not be metaphysically fundamental in the way Lewis' perfectly natural properties supposed to be I will call them "scientifically fundamental." Because the distribution of the scientifically fundamental ontology and properties plays the same role that the Humean mosaic plays in Lewis' BSA I call it "the scientific mosaic" (SM). So, the answer to the question of what a TOE systematizes according to the PDA is that it is it systematizes the distribution of the TOE's fundamental properties and ontology; i.e. its SM. The condition that a TOEs fundamental ontology provides the basis for explaining the motions of macroscopic objects immediately excludes VxFx from being a TOE. While VxF is maximally informative in the sense that it

excludes all possibilities except the actual one it doesn't provide information expressed in the language scientists use to describe the motions of macroscopic objects and so doesn't explain any macroscopic phenomena. The fact that a TOE provides accounts of the motions of macroscopic phenomena as described in ordinary languages and that grueifying language results in unneeded complexity penalizes gruesome predicates keeps the TOE's language from being gruesome.

The scientifically fundamental properties are the scientific joints of the world but they need not play all the roles that perfectly natural properties are supposed to play in Lewis' metaphysics. Specifically, they need not be intrinsic and categorical and need not satisfy the recombination principle in an account of possible worlds or be reference magnets in an account of meaning. This isn't to deny that there may be Lewis' perfectly natural properties that do all these and that their distribution is in some sense metaphysically fundamental but it is to claim that the scientifically fundamental properties may not be identical to them and it is the scientifically fundamental properties that figure in the laws. The SM is the supervenience base for all contingent truths just as the HM is claimed to be on Lewis account. For Lewis contingent reality consists of and is exhausted by the HM. Talk of laws, probabilities, counterfactuals, causes, cats, circuses and everything else contingent are ways of talking ultimately about the HM. Similarly, talk of laws, probabilities, counterfactuals, and so on are ways of talking about the SM. So far as I can see Lewis' accounts of these, or improved versions, can provide accounts of their reductions to the SM if they provide reductions to the HM.

We might worry that it is risky to build an account of laws that depends on the existence of a TOE since our world may not have one. Physicists have not yet found a TOE since

there is, as of now, no theory that satisfactorily combines general relativity with quantum mechanics that applies at very high energy scales and covers the very early universe, black holes and dark matter. What the ontology and laws of such a theory turn out to be and even if there is such a TOE is not known. But there is reason to hold that the standard model of effective quantum field theory together with GR- what Frank Wilczek calls "Core Theory implies all the lawful macroscopic regularities that hold in everyday life. Sean Carroll writes

> . I will argue that we have good reason to believe that this model is both accurate and complete within the everyday-life regime; in other words, that the laws of physics underlying everyday life are, at one level of description, completely known. This is not to claim that physics is nearly finished and that we are close to obtaining a Theory of Everything, but just that one particular level in one limited regime is now understood".[52]

By "everyday life" Wilczek and Carroll mean not just everyday macroscopic phenomena but also phenomena of special sciences. Their reason for believing this is that the core theory explicitly limits the physical situations in which it holds, so far the evidence supports it, and the special sciences apply within these limits., This gives support to the belief that there is a TOE of our world or a theory close enough to play the role of a TOE determining the fundamental laws. The PDA proposes that the world's fundamental laws are axioms of a true TOE for the world and so entails that there are laws only if the world has a true TOE. We don't want to say that if it turns out that our world fails to have a TOE but it does have a theory that is

[52] Carroll (2021). In addition to the quantum field theory of the standard model and GR a theory capable of accounting for special science laws and macroscopic phenomena needs to include laws that underlie statistical mechanics. One way of doing this has been developed by David Albert and myself that consists of adding a probability distribution over the dynamically possible histories of the universe. We call this package "The Mentaculus" (Albert 2000, Loewer 2021) It is likely that any adequate TOE will include the Mentaculus.

sufficiently close that there are no laws. So I suggest that the PDA is modified to say that even if the world doesn't have a theory that covers all physical phenomena the laws are determined by a theory that comes closest to being a TOE as long as it is sufficiently close. So according to the PDA there are laws only if the world is sufficiently orderly for there to be a system that covers the majority of physical phenomena. While this is at odds with intuitions that are based on the governing conception of laws as mentioned earlier these intuitions derive from the theological origin of the concept of law of nature and the Humean PDA is proposed as a replacement for that conception that better fits the practice of physics and Humean philosophical views.

A different worry is that it may turn out that there are multiple formulations of TOEs for our world that differ in their fundamental properties and even in their laws. In fact, this seems inevitable since it is plausible that what is basic for one language will be defined in another and there may be more than one language in which a TOE can be formulated. If this is the case, then the basic predicates and fundamental properties of a world won't be unique but relative to a language theory triple. So the PDA is not committed to Hicks and Schaffer's principle Link. This is a major departure from Lewis' account which claims that there is a unique set of perfectly natural fundamental properties for each world. It also may turn out that given a fundamental language there is not a unique best systematization and so the set of laws is not unique and this may seem more problematic. There is not much worry if the alternative systematizations agree on the nomological necessities although they disagree on which are axioms). But it seems possible that for the actual world there may be systems that are

scientifically optimal but differ on which propositions they count as lawful.[53] We may hope that this won't be the case, but should it turn out to be it is plausible that all TOEs will agree on the core theory. If there is disagreement it will only in the highly theoretical parts of a theory.[54] Lewis envisioned this possibility for his version of the BSA and suggested that the laws are propositions that are those that are entailed by all optimal systems. Another response, also suggested by Lewis, is that there are further criteria on candidate systems whose satisfaction results in selecting systems that agree on laws. Failing that a better proposal is to accept that both being a law and being a scientifically fundamental property is system relative.[55]

Virtues of the PDA

The PDA is a major improvement over Lewis' BSA. It earns its Humean credentials by rejecting the non-Humean view that laws "govern" or are the product of fundamental necessary connections in favor of the view that laws systematize. It preserves the Humean feature that being a law supervenes on the distribution of instantiations of scientifically fundamental properties. But unlike Lewis' BSA it doesn't rely on the world being, as Putnam says "ready-made" with a unique division into metaphysically fundamental properties that physics has the job of revealing. Instead, it allows that there may be multiple ways of dividing

[53] Although two systems may disagree on which generalizations are laws since laws must be true the generalizations must be mutually consistent.
[54] Recall that one of the requirements on a law determining TOE is that it is true. Alternative TOEs may differ on what propositions they count as laws but they must be consistent with one another.
[55] On a governing account of laws there must be a unique set of laws that govern. But on Lewis' BSA and the PDA laws don't govern but what makes a sentence express a law is its role in systematizing. I see no problem in there being more than one best systematization of the truths expressible in a language.

up deserving the title “scientifically fundamental” in virtue of being parts packages that optimally satisfies criteria developed within physics.

I discussed five problems that result from basing the BSA on perfectly natural properties. The four are 1) The BSA endorses Link but Link seems at odds with how physicists treat fundamental properties and laws, 2) Quantum mechanics and the QFT of the standard model posit fundamental properties and relations that violate HS or are not intrinsic to the regions in which they are instantiated and are not categorical and whose ontologies don’t fit easily into the framework of individuals and properties. 3) we know fundamental properties by the laws they are involved in suggesting that they are not categorical, 4) the mismatch problem, 5) the problem of missing value. The PDA handles all five.

According to the PDA there need not be a unique collection of fundamental properties. Different TOEs that differ in their basic predicates and functions and so differ in what properties they count as fundamental may still entail the same nomological necessities. This is illustrated by Newtonian and Hamiltonian formulations of classical mechanical laws. The BSA is committed to saying that the properties of at most one of these theories are perfectly natural.

Unlike the BSA the PDA has no difficulty accommodating quantum mechanics, string theory or the QFT representation of quantities (e.g. quark color) as fiber bundles since it makes no commitment to the structure of the fundamental space-time or to whether the quantities referred to by predicates and function symbols in a TOE are intrinsic or categorical.

One of the most interesting features of the PDA is that it is non-committal about whether fundamental properties are categorical or dispositional. This is due to the fact that theoretical

terms are uninterpreted except in so far as their meanings are given by their roles in the TOE. These meanings are constrained by the TOEs accounting for the motions of macroscopic objects but this allows for the predicates in the theory to be interpreted as referring either to categorical or dispositional properties. Consider, for example, in Newtonian mechanics the predicate "mass" can be interpreted as referring to either a categorical or to a dispositional quantity. If the latter, then mass necessarily satisfies the Newtonian laws. But these necessary connections should not offend Humean sensibilities. Such necessities are in a sense "verbal." They are artefacts of the best systematization imposed by it rather than determining its laws. In general, the PDA allow the predicates and function terms that occur in a TOE to be interpreted either as referring to either to categorical properties or to properties that necessarily satisfy some or all of the laws in which they occur. This doesn't solve the problem of whether *scientifically* fundamental properties are categorical or dispositional but it does suggest that this is not a problem that needs to be solved by an account of scientifically fundamental properties and laws.

The PDA doesn't say anything about what properties are *metaphysically* fundamental or even if there are metaphysically fundamental properties. At its most metaphysically fundamental level reality might be a whole that possesses many different structures. But it is compatible with the PDA that there is a unique fundamental structure consisting of space times filled with Lewis' perfectly natural properties. The PDA just claims that these properties need

not be scientifically fundamental and it is not the systematization of their distribution of that determines the laws.[56]

As mentioned above, if a predicate is interpreted as referring to a property that is individuated by some of the laws in which it occurs and so satisfies the laws necessarily this should not disturb a Humean since the necessity is imposed from above by the law in contrast to the powers view the law is a consequence of the power. Humeanism is not committed to their being no necessary connections between properties but only to laws not being determined by necessary connections between properties and to there not being necessary connections between metaphysically fundamental properties. The PDA says nothing about metaphysically fundamental properties- even that there are any- and according to the laws are determined by the best systematization. [57]

Heather Demarest has proposed a different way of combing a best systems account of laws with necessary connections.[58] According to Demarest fundamental properties are powers or potencies that necessarily connect objects that instantiate them. Laws are axioms of the system that best systematizes the distribution of the properties in all worlds in which they are

[56] A similar idea is developed in Bhogal and Perry (forthcoming)
[57] A third way of understanding the properties in the PDA is along the lines of Michael Esfeld's SuperHumeanism. On this account the only fundamental ontology consists of point particles and the only fundamental relations are distances between particles. Predicates that seem to refer to properties are interpreted in a manner similar to Humean accounts of laws and probabilities as devices for summarizing the totality particle distance relations. On this account the property referred by e.g. "mass" is not intrinsic to a particle that instantiates it but its value supervenes on the totality of interparticle distances. This account fits the general approach of the PDA in that macroscopic physical properties supervene on particle positions. But by obliterating the role of laws and probabilities on the one hand and fundamental physical magnitudes on the other it is at odds with the criteria physics employs for evaluating candidate fundamental theories. Callender points out that it is often incompatible with formulating initial value problems. See Callender (2020 and Loewer (forhthcoming)
[58] See Demarest (2017)

the fundamental properties. This is an ingenious idea that enables powers accounts to avoid the mismatch problem and also solve the problem of combining multiple powers.[59] Unlike the PDA it is genuinely anti-Humean since what makes a generalization a law is that its predicates refer to properties that are necessarily connected. In contrast, the PDA counts as Humean since what makes a generalization lawful is its being entailed by a TOE. If the properties referred to in a generalization are dispositional it is because they appear in the law.

The mismatch problem cannot arise on the PDA since the scientifically fundamental predicates and the fundamental theory are determined together with each other as a package. While there is no guarantee that science will ever discover a TOE for the world the PDA does guarantee that if one is discovered its axioms will be fundamental laws and the generalizations it entails will be nomologically necessary. The PDA also points towards a solution to Dasgupta's missing value problem without sliding into relativism. . Dasgupta's asked why systematizing the distribution of instantiations of Lewis' perfectly natural properties is more valuable than systematizing the distribution of natural* or natural ** or….. properties. This is a way of challenging to explain why systematizing perfectly natural properties are of value to physics at all. The PDA answers to challenge by providing an account of why it is valuable to systematize the instantiations not of perfectly natural properties but of scientifically fundamental properties. The reason it is of value to discover scientifically fundamental properties is that they are components of a TOE that optimally satisfies criteria that have been developed and shaped by science. These criteria are designed to achieve the aim of organizing, predicting, and

[59] Since an object may be subject to multiple powers the powers account needs to be supplemented with a principle or law about how they combine. Demarest's account does this.

explaining truths, initially about macroscopic phenomena and then about all phenomena in its domain. It is evident that discovery of a TOE and its lawful regularities is epistemically valuable for the community of scientists and that it has consequences that are valuable more generally. There some relativism remaining in this account since a true TOE is responsible for accounting for the behaviors of macroscopic objects as characterized in the human languages with which physics begins and it is required to satisfy criteria that have been developed within the community of science. To this degree being a TOE is relative to human scientists. But this doesn't take away from the fact that it is an objective matter that a whether or not a theory is a TOE or that if it is that is objectively valuable.

Lewis' metaphysical viewpoint is that of a God surveying all of reality to find its best systematization. God knows which properties are perfectly natural and knows their distribution in space-time. It is the job of physics to find the laws by finding its best systematization. But as Quine says that while

> It is understandable […] that the philosopher should seek a transcendental vantage point, outside the world that imprisons [the] natural scientist and mathematician. He would make himself independent of the conceptual scheme which it is his task to study and revise. "Give me που στω [a place to stand]", Archimedes said, "and I will move the world." However, there is no such cosmic exile. […] The philosopher is in the position rather, as Neurath says, "of a mariner who must rebuild his ship on the open sea".[60]

[60]W. V. Quine in (notes for Sign and Object, November 5, 1944) as quoted by Verhaegh (2018)

The PDA takes Quine's view seriously. It replaces the view that reality is composed of metaphysically given perfectly natural properties and replaces it with the view that scientifically fundamental properties and laws are the product of science working from within the world. It thus results in an account of laws and fundamental properties that is more friendly to contemporary physics and an account that to a certain extent transcends the debate between Humeans and certain non-Humeans. Because it provides an account of the scientific joints of the world that doesn't rely on metaphysics alone but on the aims of science it rejects the ultra-realists view that, in Putnam's words, there is a "ready-made world" and endorses a more modest realism, also in Putnam's words, that "the mind and the world make up the mind and the world."*

*I am enormously grateful to David Albert and Jenann Ismael for comments on earlier drafts.

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