

Who Shouldn't Reduce Time's Arrow?

Anti-reductionists about time hold that time possess an intrinsic direction: the distinction between past and future is an irreducible fact about the spacetime structure of the world.¹ Anti-reductionists embrace

ANTI-REDUCTIONISM: there is a metaphysically fundamental asymmetry between past and future.

Reductionists, by contrast, hold that there is no intrinsic direction of time, and the various temporal asymmetries (of knowledge, intervention, causation, and the like) can be explained in terms of an underlying thermodynamic asymmetry. For reductionists, facts about the entropy gradient of the universe explain all there is to know about the apparently time-directed structure of our world.² Hence, reductionists embrace

REDUCTIONISM: facts about the direction of time reduce to facts about the entropy gradient of the universe.

Humeans about laws hold that laws of nature are mere regularities in the instantiation of categorical properties throughout fundamental physical space (e.g., spacetime).³ The array of categorical properties instantiated throughout physical space(-time) is known as the Humean Mosaic. Humeans endorse

¹ Maudlin (2007) is the most well-known anti-reductionist.

² The most well-known recent attempt at explaining the temporal asymmetries in terms of the thermodynamic asymmetry comes from Albert (2000), and is refined in his 2015, while the general reductionist position goes back to Reichenbach (1956) and is developed by Sklar (1981).

³ The most famous Humean, of course, was David Lewis (see his 1994, for instance). Humeanism about laws is summarized superbly by Loewer (1996, 2012). The fundamental space in question for Lewis' brand of Humean Supervenience was, of course, a four-dimensional set of spacetime points. But a broader Humeanism could replace four-dimensional spacetime with, say, a high-dimensional state space.

HUMEANISM: the laws of nature reduce to patterns in the Humean Mosaic.

According to anti-Humean views, reality has a certain kind of fundamental nomic structure: the laws of nature are things like metaphysically primitive facts, brute necessitation relations between universals, or regularities that are entailed by facts about fundamental dispositions.⁴ Anti-Humeans endorse

ANTI-HUMEANISM: the laws of nature do not reduce to patterns in the Humean Mosaic, and instead reflect primitive facts, fundamental dispositions, relations between universals, etc.

There are a number of different versions of ANTI-HUMEANISM. For example, *primitivists* think that the laws are just certain kinds of fundamental facts (or, perhaps, fundamental entities).⁵ For present purposes I will understand these fundamental facts as consisting in a primitive law-operator \mathbf{L} acting on a universally quantified proposition φ , so that $\mathbf{L}(\varphi)$ is a fundamental fact, to be read ‘it is a law that φ .’ In addition to the primitive-operator view there is the *necessitarian* view, associated with Dretske (1977), Tooley (1977), and Armstrong (1983). According to this view, the laws are brute necessitation relations between universals. We may have a universal F , a universal G , and a relation of brute necessitation $N(-,-)$, such that $N(F,G)$ explains why all F s are in fact G s. And finally, there are *dispositionalist* accounts of laws, according to which properties endow certain fundamental dispositions on their bearers, and the laws of nature somehow stem from these fundamental dispositions. The orthodox version of dispositionalism (e.g. from Bird (2007)) has it that each fundamental disposition directly entails some corresponding nomic fact – e.g., the fact that charges are fundamentally disposed to repel like charges entails that it is a law that all like charges repel – while other dispositionalists (such as Demarest (2017)) think that the relationship between dispositions and laws is less direct; e.g., that the laws are systematizations of particular matters of fact, *including* facts about the pattern of instantiation of the fundamental dispositions. What unifies these various accounts of law (and what makes them anti-Humean) is that they all hold that there is

⁴ For an overview of anti-Humean views of natural necessity, see Hildebrand (2020).

⁵ Maudlin (2007) advocates such a view, though I am not sure whether he thinks of laws as facts, entities, or as comprising some other *sui generis* category. Chen and Goldstein (2022) explicitly think of laws as fundamental facts.

some kind of irreducible, non-categorical stuff in the world that gives rise to the nomic facts, rather than the nomic facts reducing to facts about the distribution of categorical properties and relations.

ANTI-REDUCTIONISM is often paired with ANTI-HUMEANISM, while REDUCTIONISM is often paired with HUMEANISM.⁶ It is often believed that the way in which anti-Humean laws govern presupposes a fundamental direction of time. For Maudlin (2007) especially, an antecedent commitment to a governing conception of laws has been taken to motivate ANTI-REDUCTIONISM.

Hence, our views about laws potentially constrain or motivate our views about the direction of time. This paper explores the views about laws that best motivate an anti-reductionist position regarding the arrow of time. In Section 1, I briefly review one of the central reasons given for pairing ANTI-HUMEANISM with ANTI-REDUCTIONISM – namely the so-called Direction of Motion problem – and note a recent criticism of this argument from Lichtenstein (2021). In Section 2, I aim to state clearly what combinations of views about laws I think motivate ANTI-REDUCTIONISM: such commitment stems, I will argue, from the belief that the laws have time-directed contents – which may be motivated either by consideration of how anti-Humean laws govern *or* by empirical considerations regarding potentially time-asymmetric dynamical laws – in conjunction with the belief that the laws are metaphysically fundamental – to which most (though not all) anti-Humeans are committed. In Section 3, I present a novel argument that those who embrace the aforementioned views about laws of nature have good reason to embrace ANTI-REDUCTIONISM. Thus, even if Maudlin’s original arguments fail, one who wishes to motivate an anti-reductionist view of time’s arrow via an anti-Humean conception of laws may still have ample room to do so, and such a move may be advisable even to anti-Humeans who don’t believe that the laws govern via time-directed ‘production.’

1. *The Traditional Pairing and its Discontents*

As noted, ANTI-HUMEANISM is often paired with ANTI-REDUCTIONISM. Why? One reason is that such a pairing appears to be forced on someone – like Maudlin (2007) – who thinks that the anti-Humean laws govern the mosaic by *producing* later states from earlier states, along one direction of time. According to Maudlin, later states of the universe are causally produced from earlier states, and hence ontologically depend on those earlier states. But this arguably runs into trouble if the direction of time is reduced to some underlying thermodynamic asymmetry. For, if the direction of time

⁶ This dichotomy has been most prominently discussed by Loewer (2012).

depends on the *global* entropy gradient of the universe, then what makes it the case that some state is in our past is that it was of lower entropy than the present state, and what makes it the case that some state is in our future is that it will be of higher entropy than the present state. But if this is the case, then the direction in which objects are moving, at present, depends in part on facts about the entropy of future states of the universe. And if this is so, then there is a feature of the present state of the universe (namely the signs of objects' present velocities) that ontologically depends on the future state (as 'motion' is a temporally-directed notion). But since the future state is taken to depend on the present state via nomic production, this appears to instate a vicious circle: the future state depends on the present state via production, and yet the present state depends on the future state insofar as the latter fixes the direction of time. This is the Direction of Motion Problem.⁷

It is first worth pausing to acknowledge two different ways in which the direction of time might be reduced to an underlying thermodynamic asymmetry. Here are two possibilities.

ENTROPIC REDUCTION: the future is the direction of increasing entropy.

BOUNDARY REDUCTION: the future is the direction that points away from a low-entropy boundary state (the so-called Past Hypothesis).⁸

⁷ The basic worry about damaging circularity was raised by Maudlin (2007), but this particular formulation of the Direction of Motion Problem is adapted from Lichtenstein (2021), who goes on to critique the argument.

⁸ As a historical matter, ENTROPIC REDUCTION is often associated with 'stronger' forms of reductionism on which "the entropic theory of temporal direction, if it is to be plausible at all, should be viewed as a 'scientific' reduction motivated by an empirical discovery of a property (relation) identification" (Sklar 1981, 119). The reduction of the direction of time to the direction of entropy increase is, therefore, much like the reduction of water to H₂O. By contrast, those who adopt BOUNDARY REDUCTION tend to have a more deflationary understanding of the direction of time: there is just a four-dimensional mosaic, and it so happens in our world that there is a low-entropy boundary in one temporal direction which allegedly gives rise to certain metaphysically/nomically contingent asymmetries in a particular direction of time. Consider: 'the past is the direction of the Past Hypothesis' is not as plausible a claim of metaphysically necessary identification as 'water is H₂O' or (perhaps) 'the future is the direction of increasing entropy', since the Past Hypothesis is consistent with certain microstates that would realize a globally inconsistent entropy gradient, such that the temporal asymmetries of records, causation, etc., would not be uniformly pointing in one direction. This is not to say that BOUNDARY REDUCTION *must* involve a 'weaker' form of reduction (I am sure that one could develop a semantics for 'past' on which this is not so), but it is more naturally construed as such, and this more metaphysically modest picture seems to be what boundary-reductionists have in mind. (Personal communication with David Albert and Barry

ENTROPIC REDUCTION is associated with Reichenbach 1956 and Sklar (1981), among others, while BOUNDARY REDUCTION is perhaps the more popular modern view, for which the standard-bearer is Albert (2000). Each of these views (when conjoined with Maudlin-style nomic primitivism) face the Direction of Motion problem, though in slightly different ways. In the case of ENTROPIC REDUCTION, it is clear: the global entropy gradient determines the direction of time, so the present direction of motion for any physical system depends on the entropy of ‘later’ states being higher than the present state. In the case of BOUNDARY REDUCTION, it is slightly less clear: one may respond to the Direction of Motion Problem by saying that the present direction of motion of a system does not depend on future states of the universe, but *only* on the existence of a low-entropy boundary in the ‘past.’ If this is true, then there is no Direction of Motion Problem, since only past states fix a direction of time and hence there is no circularity.

But boundary-reductionists may still face a variant of the Direction of Motion Problem.⁹ Start first with our world: we find ourselves in a present macro-state, and in one temporal direction there is a low-entropy ‘initial’ state which is extremely *improbable* given the present macro-state, and in the other temporal direction there is evolution to a state of thermal equilibrium which is extremely *probable* given the present macro-state. It is this asymmetry, according to Albert (2000, 2015) that explains the temporal asymmetries of records, intervention, causation, and the like. But now imagine that we find ourselves in a world with low-entropy boundaries in *both* temporal directions (both a low-entropy ‘Past Hypothesis’ and a low-entropy ‘Future Hypothesis’). In such a world there would be no globally consistent asymmetry of records, causation, and the like. For, if we are located at a time in which the entropy of the universe is higher in the immediate ‘past’ (i.e. immediately closer to the Past Hypothesis) and lower in the immediate ‘future’ (towards the Future Hypothesis), it is precisely the so-called *future* state that is improbable, and all of the temporal asymmetries that Albert explains in terms of the Past Hypothesis would be ‘reversed.’ Hence, it is crucial for the boundary-reductionist that there is no low-entropy ‘future’ state – at least, not in our immediate future

Loewer has confirmed as much.) Thanks to an anonymous referee for pushing me to clarify the stronger/weaker versions of reductionism at work.

⁹ Thanks to Barry Loewer and an anonymous referee at *Erkenntnis* for helping to set me straight on this matter.

vicinity.¹⁰ But if this is so, the Direction of Motion Problem is reinstated: the present direction of time depends on facts about the entropy of future states of the universe.

Does the Direction of Motion Problem, then, push anti-Humeans to be anti-reductionists about time's arrow? Lichtenstein (2021) has recently argued that it does not. Lichtenstein argues that the apparent circularity is unproblematic, because the sense in which earlier states depend on later states is different from the sense in which later states depend on earlier states. In particular, the kind of dependence at work in the first instance is non-causal, while the kind of dependence at work in the second instance is causal. And Lichtenstein argues that there is no particularly damaging circularity involved in claiming that "earlier states of the universe... causally explain later states, while... later states noncausally explain at least some features of earlier states" (2021, 1168). Therefore, one can coherently, and without explanatory circularity, adopt both ANTI-HUMEANISM (plus a temporally productive account of anti-Humean 'governance') and REDUCTIONISM, which he calls 'reduction-plus-production.'

I think the jury is out on the circularity question. On the one hand, we could embrace Lange-style transitivity principles linking causal and noncausal explanations, which would reinstate the explanatory circle.¹¹ Such transitivity principles are controversial, but if Lichtenstein's response to the Direction of Motion Problem is to succeed, it will rest on contested questions about the link between different types of explanation. On the other hand, the circularity argument seems to presuppose that the signs of objects' velocities – with respect to the direction of productive evolution – are part of the intrinsic state of those objects (such that whatever grounds the sign of an object's velocity thereby grounds the object), which is not entirely obvious – it may be, for instance, that the 'signs' of velocities are taken to be coordinate-dependent representational devices, rather than being genuine physical properties of the system. Whether the argument goes through at all depends on what we think count as the 'properties' or 'intrinsic states' of physical systems, and whether Lichtenstein's response to the argument succeeds depends on sticky issues about how different types of explanation link up with each other.

¹⁰ This rings especially true for 'weak' BOUNDARY REDUCTION (see fn. 7) since this view simply understands temporal direction in terms of 'happstance' asymmetries of records, causation, etc., whereas on a stronger form of reduction that in some way rigidifies 'past' such that our past-talk picks out a single temporal direction globally, it is not quite as clear.

¹¹ See Lange (2018) for such a transitivity principle linking scientific and metaphysical explanation. Berker (2018) invokes similar principles linking different types of grounding-relations, e.g. metaphysical and 'normative.'

2. *Who Shouldn't Reduce Time's Arrow?*

So far, I don't think there are clear reasons one way or another as to whether anti-Humeans should be anti-reductionists. In what follows I aim to offer a reason. The purpose of this section is to first get clear on just what principles about laws motivate ANTI-REDUCTIONISM, and the purpose of the next section is to explain why this is the case. In short, the principles are:

TIME-DIRECTEDNESS: some scientifically fundamental laws have temporally asymmetric contents.

NOMIC FUNDAMENTALITY: the scientifically fundamental laws are metaphysically fundamental (or are derived directly from metaphysically fundamental facts).

In the remainder of this section I aim to clarify TIME-DIRECTEDNESS and NOMIC FUNDAMENTALITY, and explain why someone might be attracted to each.

2.1. *Time-Directedness*

The basic idea behind TIME-DIRECTEDNESS is that some scientifically fundamental laws of temporal evolution in some way 'pick out' a direction of time in their contents. For illustrative purposes we may imagine such laws to be asymmetric functions from 'earlier' states of the world to 'later' states. Examples of laws of temporal evolution include Schrodinger's Equation and Newton's Second Law of Motion. The Second Law, for instance, says that the force on an object is equal to its mass multiplied by the second derivative of its position:

$$F = m \frac{d^2x}{dt^2}$$

Since laws like $F = m \frac{d^2x}{dt^2}$ and the time-dependent Schrodinger Equation are time-reversal invariant,¹² they are not usually taken to contain any time-asymmetric contents. A defender of TIME-

¹² Though, Schrodinger's Equation is not as obviously time-reversal invariant as the Second Law, because the former is a first-order differential equation. Whereas the negative sign vanishes when twice differentiating a function of $-t$, the

DIRECTEDNESS (at least one who thinks that these laws in particular contain time-asymmetric contents) would then have to say that (e.g.) the standard representation of the Second Law of Motion as an undirected differential equation is in some way incomplete. A truly faithful representation of such laws (the idea goes) would include a restriction that states evolve exclusively in one direction of time.

Why think that TIME-DIRECTEDNESS is true? One reason is that TIME-DIRECTEDNESS seems necessary if the way in which anti-Humean laws govern is via temporally-asymmetric *production*. This is clearly a commitment of Maudlin-style anti-Humeanism, according to which there are primitive laws that essentially govern the mosaic via productive causation. But other anti-Humean accounts of laws – such as dispositionalist accounts – may also be cashed out in productive terms. If the laws stem from anti-Humean ‘productive’ relations between events or entities, or from essentially ‘productive’ dispositional properties, then the laws will presumably themselves have time-directed contents. For instance, if charges are fundamentally disposed to repel like charges, and the fundamental disposition to repel is productive (i.e., cashed out in terms of a disposition to ‘produce’ certain particle trajectories in the future), then very plausibly the dispositionalist law will be of the form <it is a law that all like charges repel>, where the notion of ‘repellence’ invoked in the law is time-directed by virtue of the time-directedness of the productive disposition. Hence, generally speaking, any brand of ANTI-HUMEANISM, the metaphysics of which is productive, comes naturally with TIME-DIRECTEDNESS, since the laws must have temporally asymmetric contents in order to get the time-directed productive explanations off the ground.¹³

The above argument may be resisted as follows. Perhaps productive explanation can be cashed out without putting any time-direction in the laws themselves. Suppose, for instance, you have the following necessary and sufficient conditions for production: x produces y iff (i) for some φ

same is not true for a first-order equation: i.e., $\frac{d}{dt}f(-t) = -f'(-t)$, via the chain rule, but $\frac{d^2}{dt^2}f(-t) = f''(-t)$. Hence we must perform a time-reversal operation (which involves replacing the wavefunction ψ with its complex conjugate ψ^*) in order to make time-reversal work.

¹³ Not all versions of ANTI-HUMEANISM (even primitive-operator ANTI-HUMEANISM) are strictly committed to TIME-DIRECTEDNESS – at least not by virtue of any commitment to a metaphysics of production. Most notably, Chen and Goldstein (2022) have proposed an anti-Humean view on which the laws are primitive facts that govern the mosaic by *constraining* the space of possibilities, rather than via temporal production. Assuming that the laws are fully time-reversal invariant, such a view treats a world and its time-reverse as the same physical possibility. Such anti-Humean views are not productive, and so not committed to TIME-DIRECTEDNESS for this reason in particular.

such that $\mathbf{L}(\varphi)$, $\varphi \vdash (x \text{ at } t_j \rightarrow y \text{ at some adjacent time } t_k)$ and (ii) $j < k$. It might, then, be sufficient to supplement temporally *undirected* laws of nature with either a fundamental or nonfundamental arrow of time in the ontology, to get productive explanation off the ground.¹⁴ No need, therefore, to put an arrow of time in the law's content. The issue with this approach is that the laws, in conjunction with states of the world, are taken to *explain* later states of the world on the productive anti-Humean picture. And if $\mathbf{L}(\varphi)$ is an undirected dynamical law, and S_0 is a state of the world which obtains at t_0 , even supplementing these facts with an arrow of time which guarantees that t_0 is earlier than t_1 , will be insufficient to account for the fact that a state S_1 obtains at t_1 . The thought, here, is that $\mathbf{L}(\varphi)$ and the fact $\langle S_0 \text{ obtains at } t_0 \rangle$ entail only that a state S_1 obtains at *some* adjacent time, whether that time is before or after t_0 . Hence, supplementing these facts with a fundamental direction of time, i.e., with the fact $\langle t_0 \text{ is before } t_1 \rangle$ does not suffice to explain the fact $\langle S_1 \text{ obtains at } t_1 \rangle$. The viability of productive explanation depends, therefore, on the assumption that it is part of the propositional content of a dynamical law that its own productive arrow aligns with the past-to-future direction of time.¹⁵

TIME-DIRECTEDNESS might, under certain circumstances, be motivated by broader empirical considerations. For instance, the decay of neutral K mesons famously violates CP-invariance – i.e., it is not invariant under both parity and charge conjugation. And it is a consequence of the CPT theorem that any process that violates CP-invariance also fails to be time-reversal invariant (on any quantum field theory that is Lorentz invariant, local, and whose Hamiltonian operator is self-adjoint) – else the process would fail to exhibit CPT-symmetry. This arguably suggests that the dynamical laws have at least *some* time-asymmetric contents, even if rare, which would be sufficient to establish TIME-DIRECTEDNESS. Similarly, while the Schrodinger Equation in the standard quantum-mechanical formalism satisfies a form of time-reversal invariance, the dynamical laws of certain quantum theories manifestly do not. For instance, spontaneous collapse theories like GRW are clearly time-reversal invariant, since wavefunction collapses can only occur in one direction of time; in the other temporal direction, highly localized wavefunctions could only discontinuously spread back out! It is clearly not obvious that GRW or any other collapse theory it is

¹⁴ We would then have two facts: an undirected nomic fact $\mathbf{L}(\varphi)$ and the fact that there is a particular direction of time, which falls outside the scope of the law-operator, and is no part of the law's content. And really, the arrow of time would be found either in the ontology (in the nonfundamental case) or in the geometry of physical space.

¹⁵ Many thanks to Eddy Chen and Ted Sider for raising this objection to me.

true, but if we do have reason to believe in GRW, we thereby have reason to believe in TIME-DIRECTEDNESS. Hence there are at least two reasonably widespread views that are committed to TIME-DIRECTEDNESS: (a) that the laws govern via production, and (b) that the laws have some time-directed contents because they empirically fail to be invariant under time-reversal.

2.2. *Nomic Fundamentality*

Who is committed to NOMIC FUNDAMENTALITY? I claim that most anti-Humeans are. Let's take each of the most prominent anti-Humean views in turn.

It is clear that Maudlin-style primitive operator views, according to which the laws are fundamental facts that consist in primitive law-operators attached to universal generalizations, are committed to NOMIC FUNDAMENTALITY. After all, on such views the scientifically fundamental laws of nature are just metaphysically primitive facts of the form $\mathbf{L}(\varphi)$.

It is similarly clear that on Armstrong-style necessitarian accounts, the laws are metaphysically fundamental. On such views, the laws are brute necessitation-relations between universals. Every fundamental law corresponds to some metaphysically fundamental fact that two universals stand in a brute relation of co-necessitation. These facts are metaphysically fundamental, since they are not grounded in or analyzed in terms of anything else.

Things are slightly less clear for dispositionalist anti-Humean views. According to what Hildebrand (2020) calls 'orthodox' dispositionalism (e.g., as in Bird 2007), the laws derive directly from the modal relations that essentially individuate fundamental properties. Orthodox dispositionalism therefore implies that nomic facts like <it is a law that all like charges repel> directly derive from fundamental disposition-facts like <charges are disposed to repel like charges>. In this sense orthodox dispositionalism is committed to NOMIC FUNDAMENTALITY, namely because the laws are directly derived from fundamental facts about the dispositions of fundamental properties. And what is important for present purposes is that, on orthodox dispositionalism, laws will only contain time-directed contents to the extent that they inherit such time asymmetry from the metaphysically fundamental disposition-facts.

On other versions of dispositionalism, it isn't as clear that there is a commitment to NOMIC FUNDAMENTALITY. Mumford (2004), for instance, suggests that we can dispense with law-talk entirely and instead interpret fundamental science in terms of properties and their fundamental dispositions. Clearly such a view is not committed to the letter of NOMIC FUNDAMENTALITY. But it is committed to the idea that the dispositional facts that *replace* nomic facts are metaphysically

fundamental. And insofar as properties (via their dispositions) have temporally asymmetric productive powers, or insofar as empirical considerations push us to think that the *dispositions* are time-directed, all of the arguments of the previous subsection carry over to the fundamental dispositional facts on a Mumford-style view. Yet some dispositionalists, like Demarest (2017), think that laws of nature are best systematizations of particular matters of fact, and yet that these particular matters of fact involve dispositions rather than categorical properties. On such dispositionalist views, there is no commitment to NOMIC FUNDAMENTALITY.

To recap: most anti-Humeans are committed to NOMIC FUNDAMENTALITY. Anti-Humeans that think that the fundamental laws or fundamental dispositions are ‘productive’ have good reason to think that the fundamental nomic or dispositional facts have time-asymmetric contents, and anyone who thinks that the fundamental laws/dispositions have time-asymmetric contents insofar as some laws fail to be time-reversal invariant are similarly committed to the conjunction of NOMIC FUNDAMENTALITY and TIME-DIRECTEDNESS. I will argue in the next section that the conjunction of these views makes the view that time’s arrow is metaphysically fundamental look well-motivated.

3. *Why not?*

I claim that the conjunction of TIME-DIRECTEDNESS and NOMIC FUNDAMENTALITY motivates ANTI-REDUCTIONISM. Why? I will argue that the TIME-DIRECTEDNESS, NOMIC FUNDAMENTALITY, and REDUCTIONISM together conflict with the following popular and intuitively plausible metaphysical principle:

PURITY: No derivative concepts can be part of the content of fundamental facts.

PURITY comes from Sider (2011, 2020). One reason for embracing it is that whatever grounds a derivative concept might also be thought to ground any facts which involve that concept. It would, after all, be somewhat bizarre if there were metaphysically fundamental laws which satisfied TIME-DIRECTEDNESS, and yet the presupposed direction of time was not itself fundamental. One might be inclined to insist that the ‘true’ contents of the fundamental laws, in this case, are fundamentally non-time-directed facts about the distribution of entropy throughout the four-dimensional mosaic, rather than the derivative fact of which time-direction is the future and which is the past. If this is the case, however, it would be difficult to see how the essentially time-directed laws could ever get

off the ground, jeopardizing TIME-DIRECTEDNESS. If one accepted that a derivative concept like the direction of time, which is grounded in the global entropy gradient of the Humean Mosaic, did figure ineliminably in the laws of nature, then those laws would also seem to be partially grounded in facts about the distribution of entropy across the mosaic. Yet, the laws would then no longer be fundamental, violating NOMIC FUNDAMENTALITY.

PURITY can be contested, but it is an intuitively plausible principle that is widely promoted in the grounding literature. In addition to Sider, deRosset (2013), Rosen (2010), Dasgupta (2014), and Builes (2019) have all advocated some principle to the effect that fundamental facts cannot have nonfundamental entities or concepts as constituents.¹⁶ For intuitive support, Sider (2011) says that “When God was creating the world, she was not required to think in terms of nonfundamental notions like city, smile, or candy” (106). No one, moreover, would take seriously a fundamental law of nature which involved the notion of a city, and it would even be thought objectionable if fundamental physical laws involved, say, the notion of a molecule.

There are further reasons to believe in PURITY in the case of laws of nature in particular, and it is arguably the orthodox view among philosophers of physics.¹⁷ As Hicks and Schaffer (2017) discuss, some of the reasons for supposing that derivative properties do not enter into fundamental physical laws include a desire to keep ‘gruesome’ properties out of the scientifically elite laws, as well as the fact that such a constraint makes clear how fundamental laws can serve as epistemic guides to new “metaphysical joints” in nature.¹⁸ Hence, a desire to preserve PURITY is a potentially strong motivation in favor of treating the direction of time as fundamental, given that one thinks that laws are themselves fundamental and time-directed.

¹⁶ I am aware of only one criticism of this principle in the extant literature, from Merricks (2013).

¹⁷ See, e.g., North (2013): “This brings me to a very general principle that guides our physical theorizing, from which the other principles I use all extend: the dynamical laws are about what’s fundamental to a world. The dynamical laws relate what’s fundamental to what’s fundamental, where what’s fundamental includes the fundamental space and its structure, and the fundamental ontology. The dynamical laws govern the fundamental level of reality; that is why they are a guide to the fundamental nature of the world” (p. 186).

¹⁸ Hicks and Schaffer come themselves to deny that the scientifically fundamental physical laws must include only fundamental properties, concepts, etc. However, they take this to motivate treating laws of nature as merely convenient summaries, rather than metaphysically fundamental facts. Hence PURITY – which is about fundamental facts – is not violated.

Consider first how things look for the denier of NOMIC FUNDAMENTALITY, such as the Humean who thinks that the laws reduce to patterns in the Humean Mosaic. Humeans can embrace both TIME-DIRECTEDNESS and REDUCTIONISM precisely because their laws are derivative features of reality. Consider a time-directed representation of the Second Law of Motion: it is a law that for all y , y obeys $F = m \frac{d^2x}{dt^2}$, where the time-derivative is in some way (and for whatever reason) restricted to the change from past to future. The universally quantified statement φ is grounded by facts about the Humean Mosaic – say, by all of the instances of physical systems and events that obey the Second Law – plus, perhaps, a totality fact, such as a negative existential (e.g. $\sim \exists x(x \text{ fails to obey the Second Law})$). That the Second Law is a *law* is grounded by global facts about the distribution of categorical properties in conjunction with facts about simplicity and informativeness. The only fundamental facts which enter this picture are particular facts about the fundamental properties and relations instantiated by spacetime *points* (at least on the Lewisian formulation). Hence, any distinction between past and future which enters into the content of the Second Law does not enter into any metaphysically fundamental facts. Therefore, whether or not the direction of time is irreversibly defined in terms of the distribution of thermodynamic properties, PURITY is not violated. The universally quantified propositions which *are* time-directed, according to TIME-DIRECTEDNESS, express nonfundamental facts.

For the advocate of NOMIC FUNDAMENTALITY, however, things look different. If TIME-DIRECTEDNESS is maintained, we again have time-directed universally quantified propositions, but these propositions are not grounded by facts about individual spacetime points and the properties they instantiate, but rather by the fundamental fact that it is a *law* that for all y , y obeys $F = m \frac{d^2x}{dt^2}$, or by fundamental relations between universals, or by fundamental non-Humean powers. These law-facts metaphysically ground the relevant universally quantified propositions, either directly or by way of grounding their instances. The fundamental fact $\mathbf{L}(\varphi)$ inherits its propositional content from φ , so NOMIC FUNDAMENTALITY and TIME-DIRECTEDNESS together entail that fundamental facts invoke the direction of time in a way that time-directed Humeanism does not. And if these views are supplemented with a reductive explanation of the arrow of time, PURITY will be violated.

There is, of course, the possibility that the time-directed language in certain fundamental laws could be replaced by their definitions to avoid PURITY violations. But it is not especially clear how such a replacement would go, or how compelling it would be given the original motivations for TIME-DIRECTEDNESS. Such a translation scheme would start off with the simple step of replacing

phrases like ‘with respect to the forward direction of time’ with phrases like ‘with respect to the direction of increasing entropy,’ ‘with respect to the direction pointing away from the Past Hypothesis,’ and the like. But concepts like ‘entropy’ are not fundamental either; nor are concepts like ‘macro-state’ needed to define entropy and the Past Hypothesis. Entropy (in the Boltzmannian formulation), for instance, involves notions like *volumes in phase space*, which themselves depend on logically complex and modally laden facts about what other micro-states (of which there may be continuum-many) *would* together realize particular values of macroscopic variables.

I can’t myself see exactly how such a translation – one that eliminates reference to things like macro-states, sizes of phase space regions defined by those macro-states, etc. – would go. But even if it were to work, it would add enormous and perhaps infinite complexity to the laws. For example, if we suppose that the Past Hypothesis refers to the state of a particular spacelike hypersurface Σ (in this case, the ‘initial’ time), and we suppose that Σ is grounded in all of its spacetime *points*, we would have to substitute reference to Σ with reference to perhaps infinitely many points. And as already noted, notions like ‘macro-state’ and ‘phase space volume,’ when defined in solely microphysical terms, will presumably be highly logically complex and even counterfactual. Thus the laws would abound with added complexity if we were to replace concepts/entities like entropy, macro-state, particular times, etc., with their fundamental definitions. If one believes (as many anti-Humeans do, despite the fact that they don’t treat simplicity as constitutive of laws) that simplicity is a guide to lawhood (see Chen ms, for instance), or that an account that allows for relative nomic simplicity is more attractive (all else equal) than one that is committed to the laws being highly complex, then it will be highly preferable to treat the direction of time as fundamental, to ensure that the ‘purification’ of fundamental laws does not add enormous complexity.

I will flag one further reason that the defender of TIME-DIRECTEDNESS may wish to avoid REDUCTIONISM. Imagine a (highly improbable) world at which global entropy, as a function of time, is not monotonically increasing and has several local maxima and minima well within the relaxation time from the ‘initial’ state. It seems that according to ENTROPIC REDUCTION, the direction of time in such a world reverses at each extremum, since the direction of entropy increase reverses. As for BOUNDARY REDUCTION, I think there is arguably such a consequence, insofar as the asymmetries of records, causation, and the like would seem to reverse whenever a ‘later’ state is of lower entropy than an ‘earlier’ one – and something like a low-entropy ‘Middle Hypothesis’ or ‘Future Hypothesis’ may have just as good of a claim as the Past Hypothesis to be laws. But recall the two motivations discussed in Section 2.1. for TIME-DIRECTEDNESS, one concerning the nature

of productive explanation and the other concerning potential failures of time-reversal invariance. A world with many local entropy extrema looks messy from the perspective of REDUCTIONISM plus a metaphysics of production. For, the arrow of production in such a case would point *towards* local entropy maxima and *away from* local entropy minima in *both* temporal directions. This would mean that states of the universe which are local entropy maxima are ‘over-produced’ in that they have two sufficient but distinct sources of production. And it means that states of the universe which are local entropy minima aren’t produced by *anything* at all, so that the universe is littered with states that have no productive origin whatsoever. Such pernicious over/under-determination looks implausible, but it appears to be a consequence of a production-based metaphysics of law in conjunction with a reduction of time’s arrow.

And with respect to the second potential motivation for TIME-DIRECTEDNESS, there seems to be a similar issue when we consider universes with no globally consistent entropic arrow. For, failures of T-symmetry would demand that once we have placed a coordinate system on the entire spacetime manifold, with a single t -dimension, there must be a single direction of t on which, for example, GRW collapses are permitted by the laws. But if the ‘direction of time’ referenced in time-directed laws is reduced to a thermodynamic asymmetry, then the laws will permit certain intervals of t to disagree on the ‘direction of time.’ But then the direction of time is certainly not the same as what is picked out by time-asymmetric laws, if there are any.¹⁹

4. Conclusion

The aim of this paper has been to clarify the connection between the metaphysics of laws and the direction of time. While anti-Humean conceptions of law have often been paired with anti-reductionist stances regarding the direction of time, this pairing has rested on somewhat shaky

¹⁹ Defenders of REDUCTION may respond that if the direction of time-reversal asymmetry disagrees with the direction of the thermodynamic arrow, it is the latter that genuinely picks out the ordinary distinction between ‘past’ and ‘future.’ This may be true, but it wouldn’t undermine the motivation to treat *some* asymmetry in the spacetime manifold as being metaphysically fundamental. Further, a proposal along the lines of Lichtenstein (2021) on which there are certain metaphysical constraints on the initial states of the universe that guarantee that the thermodynamic asymmetry aligns with the fundamental arrow of time or the direction of anti-Humean ‘production,’ may be consistent with my arguments here. But this would not undermine the argument that the productive arrow picked out by the fundamental laws or fundamental dispositions must itself be a metaphysically fundamental direction of time, to remain consistent with PURITY.

foundations, and it has not always been clear what versions of anti-Humeanism carry with them commitments to anti-reductionism about time's arrow. I have offered a new argument that many versions of anti-Humeanism naturally motivate an anti-reductionist position. Consequently, to those who wish to motivate their anti-reductionism via their account of laws, there may be reputable ways to do so.

Acknowledgments

Thanks to Ted Sider, Eddy Chen, and two anonymous referees at *Erkenntnis*, for helpful comments on earlier drafts of this paper.

The author reports no conflict of interest.

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