Fundamentality and Time's Arrow

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ABSTRACT. The distribution of matter in our universe is strikingly time asymmetric. Most famously, the Second Law of Thermodynamics says that entropy tends to increase toward the future but not toward the past. But what explains this time-asymmetric distribution of matter? In this paper, I explore the idea that time itself has a direction by drawing from recent work on grounding and metaphysical fundamentality. I will argue that positing such a direction of time, in addition to time-asymmetric boundary conditions (such as the so-called "past hypothesis"), enables a better explanation of the thermodynamic asymmetry than is available otherwise.

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§1 Introduction

The distribution of matter in our universe is strikingly time asymmetric. Most famously, the Second Law of Thermodynamic says that entropy tends to increase toward the future but not toward the past. But what explains this time-asymmetric distribution of matter? The received understanding in the philosophy of physics is that the thermodynamic asymmetry is fully explicable from time-asymmetric boundary conditions, including the low entropy of the early universe (see, e.g., Albert 2015 and Loewer 2012). This paper examines whether we get a better explanation of the thermodynamic asymmetry if we posit an intrinsic direction of time in addition to time-asymmetric boundary conditions.

I will build on recent work by Tim Maudlin. Maudlin (2007a, chapter 4) argues that spacetime has an intrinsic temporal direction such that earlier states of the universe produce later states but not vice versa. This intrinsic direction of time is meant to help explain the thermodynamic asymmetry. Maudlin's account, however, has been little discussed in the literature.[1] The reason, I think, is that he is not explicit about what the posited direction of time consists in and how it helps explain the

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1 Callender (2011b) and North (2011) do not mention Maudlin's account in their surveys of the thermodynamic asymmetry. Frisch (2014) discusses Maudlin's views about the metaphysics of time but does not attribute an original account of the thermodynamic asymmetry to him. North (2008) mentions the view in a footnote. Loewer (2012, 133–34) questions whether an intrinsic direction of time in Maudlin's sense can help explain the thermodynamic asymmetry.

thermodynamic asymmetry. In the following, I will spell out a way of understanding the intrinsic direction of time that draws from recent work on grounding and metaphysical fundamentality.[2] I argue that positing a direction of time in this sense helps explain the thermodynamic asymmetry because it solves a puzzle that arises for existing explanations in terms of asymmetric boundary conditions (such as the so-called "past hypothesis").

My plan for the rest of the paper is as follows: In §2, I introduce the puzzle about the time asymmetry of Thermodynamics. In §3, I sketch Maudlin's explanation of the thermodynamic asymmetry in terms of an intrinsic direction of time. In §4, I spell out the idea that time has an intrinsic direction. In §5, I argue that positing an intrinsic direction of time in this sense resolves a puzzle that arises for existing explanations of the thermodynamic asymmetry.

§2 The Thermodynamic Asymmetry

The Second Law of Thermodynamics says that entropy tends to increase toward the future but not toward the past. This time asymmetry is puzzling given the (almost) time-reversal invariance of the underlying fundamental dynamical laws of physics.[3] Time-reversal invariant laws are such that for

2 See, e.g., Fine (2012), Rosen (2010), and Schaffer (2009, 2016). See also Raven (2015) and the references therein.

3 There is empirical evidence for a time asymmetry in the decay of K^0-mesons that may show that the

every process that is in accordance with these law, the time-reverse process is also in accordance with them. So, since the fundamental dynamical laws allow for the entropy of isolated systems to increase toward the future, they also allow the time-reverse behavior: that is, for the entropy of such systems to increase toward the past. Hence, it needs to be explained why the entropy of isolated systems tends to increase toward the future but never (or only very rarely) increases toward the past.

"Typicality arguments" provide a seemingly convincing account of why entropy increases toward the future. The physically possible states of the universe can be represented in an abstract space called "phase space." Each point in phase space represents a fully specified possible microstate of the universe at some time. Thermodynamics coarse-grains phase space by dividing it up into regions (macrostates) whose members are indistinguishable in their macroscopic properties. For example, there is a region in phase space that corresponds to all microstates that are macroscopically indistinguishable

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fundamental dynamical laws are not completely time-reversal invariant (Sachs 1987). K^0-mesons, however, are exotic subatomic particles that are not constituents of ordinary objects. So, a corresponding time asymmetry in the fundamental dynamical laws would plausibly have nothing to do with the thermodynamic asymmetry, which concerns the macroscopic level (see North 2011 and Price 2011, §3.9.2; but see Maudlin 2007a, 136–37). Albert (2000, ch. 7) proposes that the thermodynamic asymmetry might be partly due to a lawful time asymmetry that is part of one interpretation of Quantum Mechanics, namely GRW. GRW, however, is contentious and other interpretations of Quantum Mechanics lack this time asymmetry (see Wallace 2013).

from the present microstate of the universe. Typicality arguments involve a natural measure over regions in phase space. This natural measure entails that for any macrostate of non-maximal entropy the vast majority of microstates that are macroscopically indistinguishable from it evolve toward future states of higher entropy.

We can then give the following typicality argument for why entropy increases toward the future:

> **Typicality Argument.** For any macrostate of non-maximal entropy, the overwhelming majority of compatible microstates evolve into macrostates of higher entropy. So, evolution toward higher entropy in the future is typical in the sense that most microstates compatible with the relevant macrostate undergo this evolution.[4]

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4 Typicality accounts explain why most compatible microstates evolve toward higher entropy by appeal to, for example, principles of indifference or features of the dynamics (cf. Frigg 2009, Frigg and Werndl 2012, and Maudlin 2007b). These accounts need to be distinguished from probabilistic accounts, such as Albert (2000, 2015), which invoke a probability distribution over initial conditions in the absence of appeals to such features. See Frigg (2009, 99) and Maudlin (2007b, §3) for comparisons of the two accounts (see also Albert 2015, 6–8, fn 2). I am following Maudlin in using a typicality approach, but everything I say in this paper could be adapted to a probabilistic approach. Thanks to an anonymous referee for discussion of this point.

The argument seems to explain why states of non-maximal entropy evolve into future states of higher entropy by showing that such evolution is, in a mathematical sense, typical: it is the evolution associated with overwhelming majority of compatible microstates. I have been talking about the whole universe, but everything in the preceding paragraphs applies, mutatis mutandis, to relatively isolated sub systems, such as glasses of water or boxes of gas.

Typicality arguments like the one above, however, cannot by themselves explain the thermodynamic asymmetry because they equally apply in both temporal directions. Neither the combinatorial assumptions in the argument nor the time-reversal invariant laws of physics introduce any time asymmetry (cf. Callender 2004, 196). For example, it is also true that the overwhelming number of microstates compatible with the current, relatively low-entropy macrostate of the universe have evolved from microstates of higher entropy *in the past*. Having evolved from a state of higher entropy in the past, therefore, is (in the mathematical sense) as typical for a system as evolving into a state of higher entropy in the future. So, the above typicality argument, if applied in the backward direction, falsely predicts that entropy was higher in the past (see, for example, Price 1996, 30 and Maudlin 2007a, 134). This is a version of the so-called "reversibility objection."

An adequate explanation of the thermodynamic asymmetry requires a reply to the reversibility objection. Typicality arguments would explain why entropy increases toward the future. But we still need to explain why typicality arguments do not also entail that entropy was higher in the past. Why is entropy-increase typical with respect to the future but not with respect to the past? A recent account by

Tim Maudlin is intended to answer this question.[5]

§3 Maudlin's Production Account

Maudlin (2007a, 109) posits "an irreducible intrinsic asymmetry in the temporal structure of the universe" and he takes this intrinsic direction of time to underlie an explanatory relation he calls "production." He insists that "[t]he basic temporal asymmetry of past-to-future underlies the very notion of production itself, so that without it there can be no production." (ibid. 175) Production, in turn, is supposed to enable a distinctive kind of explanation of events in terms of how they have been produced (ibid. 173).

The intrinsic direction of time, according to Maudlin, helps explain the thermodynamic asymmetry because it gives rise to production. Production is meant to account for why typicality arguments of the sort discussed above work in the forward but not in the backward direction. Maudlin argues that typicality arguments do not work in the backward direction because microstates in our universe other than the initial state (which has no past) have an atypical past due to how they have been produced:

> If we are to maintain that typicality arguments have any explanatory force—and it is very hard to

5 See Callender (2011a), North (2011), and Sklar (1992) for a survey of other responses to the "reversibility objection."

> see how we can do without them—then there must be some account of why they work only in one temporal direction. Why are microstates, except at the initial time, always atypical with respect to backward temporal evolution? And it seems to me we *have* such an explanation: these other microstates are *products of a certain evolution*, an evolution guaranteed (given how it *started*) to produce exactly this sort of atypicality. This sort of explanation requires that there be a fact about which states produce which. (Maudlin 2007a: 134; *italics in the original*)

The last sentence shows that Maudlin considers production essential to his account of the thermodynamic asymmetry. He insists that the explanation "requires that there be a fact about which states produce which." Maudlin, however, does not elaborate on how the intrinsic direction of time gives rise to production or how production helps explain the thermodynamic asymmetry.

There are two main worries about Maudlin's account. The first worry is that Maudlin says too little about the direction of time. He specifies that this direction is an ontological primitive that is mathematically represented by an orientation of the spacetime manifold (Maudlin 2007a, 134). This orientation distinguishes, at each spacetime location, which temporal direction is the future and which is the past. But thinking of the direction of time as an orientation leaves open *how* the future direction is different from the past direction. Maudlin seems to think that we have a good enough intuitive grip on the direction of time to understand how it underwrites that earlier states produce and, thus, explain later states. But what exactly is the nature of this direction such that it has this relevance for explanation? (cf. Loewer 2012, 133)

The second worry is that it is unclear what role an intrinsic direction of time that underwrites production could play in explaining the thermodynamic asymmetry. Nothing about production seems to rule out that low-entropy macrostates have been produced from earlier states of higher entropy (cf. Maudlin 2007a, 177; see also Loewer 2012, 133). The time asymmetry of production, therefore, cannot explain the thermodynamic asymmetry by itself. To account for why entropy-increase is typical toward the future but not toward the past, Maudlin's account needs to be supplemented with restrictions on the boundary conditions. Maudlin (2007a, 134) seems to acknowledge this need in the above passage when he emphasizes that production guarantees that microstates in our universe have an atypical, low-entropy past only "given how it [i.e., production] started." This appeal to how production started seems to presuppose the special initial boundary condition of the actual universe.

But bringing in the boundary conditions in this way threatens to make production superfluous in an explanation of the thermodynamic asymmetry. Standard explanations (more on which later) account for why entropy increases toward the future but not the past in terms of time-asymmetric boundary conditions, without assuming in addition that time has an intrinsic direction (see Albert 2000). But what then can an intrinsic direction of time add to our understanding of Thermodynamics? How is it supposed to explain the phenomena better? In the rest of the paper, I will address these two worries.

§4 The Grounding Model of Time's Arrow

In this section, I will address the first worry for Maudlin's account. I will flesh out the idea that time has an intrinsic direction that underwrites production by taking a page from recent work on metaphysical grounding. An influential view in contemporary metaphysics is that of "a hierarchical edifice ordered from the more derivative to the more fundamental, down to the foundational level (if there is one) or else endlessly without foundations." (Raven 2015, 323; see also Fine 2001, Rosen 2010, and Schaffer 2009) Let us call this view "leveled fundamentality:"

> **Leveled Fundamentality**. Entities at less fundamental levels exist in virtue of entities at more fundamental levels.

The relation that structures this hierarchy is called '*grounding'*. Grounding backs explanations by indicating how an entity exist in virtue of more fundamental entities, its grounds (Schaffer 2016, 50). Paradigmatic examples include the relation between sets and their members, wholes and their parts, truths and their truthmakers, and mental and physical states.

The guiding idea behind grounding is the "intuitive notion of one thing holding in virtue of another" (Fine 2012, 37). Three aspects of grounding will be important for what follows: First, grounding is a determination relation that is not (mere) necessitation. As Fine (2012, 38) points out, it is metaphysically necessary that if it is snowing, then 2 + 2 = 4. But 2 + 2 = 4 is not the case in virtue of the fact that it is snowing. So, grounding, when it obtains, expresses a determination that is stronger than (or at least different from) mere necessitation. Second, grounding is asymmetric: if *A* exists in virtue of *B*, then *B* does not exist in virtue of *A*. And, third, grounding gives rise to relative fundamentality: if *A* exists in virtue of *B*, then *B* is metaphysically more fundamental than *A*. These three features do not define or exhaustively characterize grounding. Grounding has other features in addition, such as that it is supposed to be metaphysically primitive (see Fine 2012, Rosen 2010, and Schaffer 2009). However, my argument in what follows will only turn on the fact that grounding is an asymmetric, extra-modal determination that gives rise to relative fundamentality.

Maudlin's idea that time has an intrinsic direction is naturally understood in analogy with grounding. If the fundamental dynamical laws are deterministic in both temporal directions (as is empirically plausible), then the state of the universe at a time *t1* lawfully necessitates its later state at *t2*, but its state at *t2* equally lawfully necessitates its earlier state at *t1*. Maudlin (2007a: 175) argues that even in such circumstances earlier states would determine later states in a way in which later states would not determine earlier states. And this asymmetric determination would obtain because time has an intrinsic direction. But what exactly does the direction of time add to the way in which earlier states determine later states? And how is this direction relevant to explanation?

According to the interpretation I propose, the direction of time is analogous to grounding. Using the 'in virtue of' locution, we can express the resulting view as follows:

Timed Fundamentality (TF). States at later times exist in virtue of states at earlier times.

The analogy with grounding provides a blueprint for how we should understand the determination signified by 'in virtue of'. First, the determination in grounding is more than mere necessitation. So, a direction of time, understood in analogy with grounding, adds a distinctive determination over and above mere lawful necessitation. Second, the determination in grounding is asymmetric. So, even if lawful necessitation goes in both temporal direction, this extra-modal determination goes only from earlier to later states. And, third, the analogy with grounding tell us what a direction of time adds to our metaphysics: earlier states are metaphysically more fundamental than the later states that exist in virtue of them.

Moreover, the analogy with grounding shows how the direction of time underwrites what Maudlin calls "production." Production for Maudlin (2007a, 174) is analyzed in terms of the fundamental dynamical laws and the primitive direction of time. TF makes clear what the direction of time adds to the laws of nature to yield production. The laws of nature, given the state of the universe at some earlier time, constrain its state at all later times (either deterministically or by specifying probabilities). But it is only because of the intrinsic direction of time that earlier states are metaphysically more fundamental than later states and that later states exist in virtue of them. Think of the laws like the bed of a river and think of the direction of time like the water pressure. The laws of nature chart out how the world must evolve, but the intrinsic direction of time is the driving force that gets this evolution going.

We then get the following metaphysical picture: Fundamental physical reality consists of the physical state of the world and the fundamental physical laws. Moreover, it is part of the physical state that there is a primitive temporal direction that distinguishes the future direction from the past direction. TF is an interpretation of what this primitive direction adds to our metaphysics: It is part of the world's metaphysical structure that all states in time, other than the initial state, are metaphysically non-fundamental and exist in virtue of the initial state and the laws of nature. So, all of reality can be explained in virtue of just the initial state of the world and the fundamental physical laws.[6] Maudlin's notion of *production* captures this generation of all other states from the initial state and the laws of nature: these other states are produced from the laws of nature operating on the initial state.[7] By contrast, if time has no direction, then all states in time are equally fundamental and there is no explanation in terms of production. The various temporal states then stand in co-dependence relations due to the laws of nature, but there is no sense in which later states exist in virtue of earlier states.

A natural suggestion is that according to the view I am proposing there is more than an analogy between the direction of time and grounding. I indeed think that an attractive interpretation of Maudlin's view is that earlier states ground later states. However, I will not defend this view in this

6 TF thus presupposes anti-Humeanism about laws of nature because to explain the entire state of the world from just the initial state and the laws of nature, the laws need to be metaphysically prior to the entire state of the world. Maudlin (2007a) holds that the laws are sui generis entities. But TF is equally compatible with the laws being grounded in (or identical to) instantiations of higher-order universals (Armstrong 1983), dispositional properties (Bird 2007), or primitive subjunctive facts (Lange 2009).

7 See Maudlin (2007a: 182). My preferred view is that, production being transitive (Maudlin 2007a: 175), the initial state produces all later states by way of producing intermediate states. States then become less and less fundamental as time passes. However, all that matters for my argument below is that the initial state is the only state in time that is metaphysically fundamental.

paper. My goal is to flesh out a way of understanding the idea that time has an intrinsic direction that can underwrite explanation. Grounding demonstrates the intelligibility of this idea by exemplifying an extra-modal, asymmetric determination relation that supports explanation. It does not matter for my purposes whether the direction of time is a sui generis relation that merely shares important features with grounding or whether it actually is an instance of grounding.[8]

Why should we interpret Maudlin's view in analogy with grounding? There are four good reasons in favor of TF. First, interpreting the view in this way explains how the direction of time can do what Maudlin wants it to do. My interpretation makes clear how the direction of time is relevant for explanation and how these explanations can be time asymmetric even if the laws of nature are time symmetric. Moreover, as I will show in the next section, the direction of time, so understood, helps explain the thermodynamic asymmetry.

8 It would be most natural to identify grounding with Maudlin's notion of production. However, grounding is typically regarded as a primitive, whereas production is analyzable in terms of lawful evolution (which supplies necessitation) and the direction of time (which supplies extra-modal determination). One might also directly identify the direction of time with grounding. But the direction of time lacks the element of necessitation that is also often associated with grounding. An interesting variation of Maudlin's view, which would make it more straightforward to identify production and grounding, would take production as primitive and analyze laws and temporal direction in terms of it.

Second, the interpretation fits well with how Maudlin himself describes his view. Maudlin (2007a, 182) says that it is a consequence of his view that “the total state of the universe is, in a certain sense, derivative: it is the product of the operation of the laws on the initial state.” My account captures this idea because it entails that all states in time other than the initial state are metaphysically non-fundamental. Moreover, Maudlin (ibid. 175) points out that in cases of production one event is the “*ontological* ground” of another event. This language fits well with my proposal, which construes the direction of time in analogy with metaphysical grounding.

Third, there are no other obvious candidates for fleshing out Maudlin's view. I can think of two alternatives: One alternative interpretation reduces the direction of time to the asymmetric distribution of things in time. According to this interpretation, time has a direction because certain (statistical) asymmetries in the distribution of matter obtain in the forward direction but not the backward direction (see, e.g., Dowe 2000, ch. 8). Maudlin, however, wants the direction of time to be metaphysically prior to the asymmetric distribution of things in time. If the asymmetric distribution of matter is already needed to explain the direction of time, then, according to Maudlin (2007a, 134), it would be circular to appeal to the direction of time to explain this distribution. Yet, Maudlin wants to appeal to the direction of time to explain the thermodynamic asymmetry, which is part of the asymmetric distribution of matter in time.[9]

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9 This account also would not make the direction of time an intrinsic feature of spacetime (Maudlin 2007a: 127–130).

The other alternative interpretation is to understand the direction of time in terms of tensed properties. According to 'tensed' or 'A-theories' of time, temporal states instantiate the fundamental, objective properties of *being past*, *being present*, or *being future*. These tensed properties can then define a direction of time. For example, take the state in time that is present. The two temporal directions are then objectively different in that the states in one direction have the tensed property of *being past* and the states in the other direction have the property of *being future*.[10]

This interpretation, however, leaves unclear how the direction of time is relevant to explanation. Why do states that have the tensed property of being past explain the state that has the property of being present while states that have the tensed property of being future do not explain this state? To the extent that we think that the direction of time underwrites an asymmetry of explanation, we do so because we think that it involves an asymmetric determination of later states by earlier states. But no such determination is part of the framework of tensed properties, and so we still face the challenge of fleshing out what this determination is and how it gives rise to explanation. Hence, if we want to understand the relevance of the direction of time for explanation, there is no obvious alternative to TF.

Fourth, a challenge for proponents of an intrinsic direction of time is to establish how this direction is connected to any observed physical asymmetries (see Price 2011, §3.9.2). If there is no

10 Some A-theories combine a commitment to fundamental tensed properties with the claim that either the future (Growing Block Theory) or past and future (Presentism) are not real. Maudlin (2007a: 108–109), however, wants to maintain the reality of both past and future.

such connection, then what is the reason for positing such a direction in the first place? Interpreting the direction of time in accordance with TF meets this challenge because, as I will argue below, such a direction enables a better explanation of the thermodynamic asymmetry than is available otherwise. We, thus, have good reasons to interpret Maudlin's view in accordance with TF.

In the rest of this section, I will address some worries about TF. A first worry is that how earlier states determine later states cannot be analogous to grounding because paradigmatic instances of grounding, such as the relations between wholes and their parts or sets and their members, are either synchronous or atemporal. In reply, I argue that there are plausible instances of grounding that obtain between entities at different times. For example, the fact that Obama is a former president in 2017 is arguably grounded in him being president in 2015.[11] Or, the fact that my current belief that water is wet is about H2O is plausibly grounded in my (or my linguistic community's) past interactions with H2O. If these are at least conceivable cases of grounding, then a relation can obtain across time and still be analogous to grounding.

A second worry concerns indeterminism. Grounded entities metaphysically supervene on a full specification of their grounds (Schaffer 2016, 94). By contrast, if the fundamental laws of physics are indeterministic, then even a full specification of the world's state at one time fixes at most a probability

11 Thanks to an anonymous referee for suggesting this example. Of course, the fact at 2017 that Obama is a former president may not be purely about 2017. But what matters for the example is that it obtains at 2017 and that it is grounded in another fact that obtains at 2015.

distribution over later states. How then can the determination between earlier states and later states be analogous to grounding?

In reply, I argue that indeterminism is compatible with the core idea of grounding, which is that once an entity's grounds have been fully specified, no more complete account of that in virtue of which it exists can be given. As Fine (2012, 39) points out, "all that is properly implied by the statement of (metaphysical) ground itself is that there is no stricter or fuller account of that in virtue of which the explandandum holds. If there is a gap between the grounds and what is grounded, then it is not an explanatory gap." The relation between earlier states and later states has this kind of completeness even if the laws are indeterministic. If the fundamental physical laws allow chancy events, we still can provide complete explanations of these events in terms of the conditions that fix their chances (Hitchcock 1999). Earlier conditions together with the laws of nature fix the chances of later events, and so no more complete or stricter explanation of why these events occur can be given. Chancy events, hence, occur wholly 'in virtue' of earlier events and the laws of nature because the remaining gap is not an explanatory gap.[12]

A third worry says that the consequence of TF that earlier states are metaphysically more fundamental than later states is implausible or even plain weird. In reply, I argue that this aspect of TF is motivated because it underwrites an important aspect of our ordinary conception of time. Maudlin's (2007a, 127) "basic approach to ontology is always to start with the world as given (the manifest

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12 See Emery (manuscript) for an independent argument that grounding can be indeterministic.

image).” Part of the manifest image (before we study philosophy or modern physics) is that the world starts in some initial state and then the laws operate on that initial state to produce all later states (see Ney 2011). According to this picture, the initial state has a special metaphysical status because it, together with the laws, generates all other states.

TF uses the notion of metaphysical fundamentality to underwrite this special status of the initial state. A theological metaphor that nicely describes the relevant aspect of our intuitive view of time is that to create the world in its entirety, God only needs to create its initial state and the laws of nature: everything else is then generated from the laws operating on the initial state. Now, a similar metaphor is also often used to introduce the idea of metaphysical fundamentality. Here the idea is that to create the world in its entirety, God only needs to create all fundamental facts (see, e.g., Schaffer 2009, 351). So, by regarding only the world’s initial state as fundamental, TF underwrites our intuitive view that this state is metaphysically special. The consequence that later states in time are non-fundamental, thus, is not an artifact of my view but helps explain an aspect of our commonsense understanding of time. Moreover, I will argue in the next section that this feature also helps explain the thermodynamic asymmetry.[13]

13 Another potential difference between time and grounding is that grounding putatively needs to be well-founded whereas time may go back ad infinitum (cf. Schaffer 2016, 95–96). But it is not clear that there is a real disanalogy here because it is at least an open question whether grounding needs to be well-founded (see Raven 2015, 328 and the references therein).

§5 Explaining the Thermodynamic Asymmetry

The currently most influential account of the thermodynamic asymmetry appeals to time-asymmetric restrictions on the boundary conditions without positing an intrinsic direction of time. Albert (2015, 5) has coined the term "past hypothesis" for the posit that "the universe had some particular, simple, compact, symmetric, cosmologically sensible, very low-entropy initial macrocondition." The past hypothesis is a non-dynamical fundamental physical law that restricts the initial boundary condition of the universe to a state of, among other things, extremely low entropy. Albert (2000, 2015) argues that the past hypothesis, together with the fundamental dynamical laws and plausible statistical assumptions, explains the thermodynamic asymmetry.[14] But I will argue that we get a better explanation of the thermodynamic asymmetry if we, in addition, posit a direction of time in the sense of TF.

The past hypothesis explains why entropy increase is typical toward the future but not toward the past.[15] The original typically argument considers the entire region in phase space of microstates that

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14 Boltzmann (1964), Callender (2011a), Feynman (1967), Greene (2004), Horwich (1987), Loewer (2007, 2012), Penrose (1989), and Price (1996) defend roughly similar accounts although they do not all agree with Albert's way of stating the "past hypothesis."

15 Albert defends a probabilistic account of the thermodynamic asymmetry that combines the past hypothesis with the "statistical postulate," a probability distribution over the possible microstates

are compatible with the current macrostate. Conditionalizing on the past hypothesis means that we consider only a proper sub region of this original region. Specifically, we exclude all microstates that are incompatible with the past hypothesis. This exclusion is justified because the past hypothesis is posited as an additional fundamental laws and so micro-histories that are inconsistent with it are nomologically impossible. Hence, to determine what evolution is typical for a given macrostate we consider the region in phase space that corresponds to microstates that are both macroscopically indistinguishable from it *and* are compatible with the past hypothesis.

Typical microstates in this restricted region evolve toward higher entropy in the future. Hence, it still is typical for entropy to increase toward the future. But the modified typicality argument does *not* entail that entropy was higher in the past. If we consider the region of microstates in phase space that are both compatible with the current macrostate and have evolved from an initial state of very low entropy (as the past hypothesis demands), it is not the case that the overwhelming majority of microstates in this region, given a natural measure, have evolved from a past state of higher entropy. In fact, the overwhelming majority of these microstates plausibly are such that entropy (perhaps with minor exceptions) monotonically decreases toward the past. Hence, it is typical that entropy was lower in the past. Adding the past hypothesis to our fundamental physical theories thus seems to explain the

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compatible with the past hypothesis (Albert 2015, 4). In the following, I am adapting Albert's account by adding the past hypothesis to a typicality account (cf. Frigg 2009, 1002 and Maudlin 2007a, 176).

thermodynamic asymmetry because it entails a modified typicality argument that makes the correct predictions for the future and the past.[16]

Accounts in terms of a past hypothesis, however, face the following puzzle. The past hypothesis is understood as a fundamental physical law that restricts the distribution of matter at one temporal end of the universe to, among other things, extremely low entropy. The past hypothesis, however, puts no similar restrictions on any other time. It does not entail, for instance, that entropy also is extremely low ten billion years after the initial state. There is then a question of why the past hypothesis restricts the state of the world at the time it does rather than at some other time.[17] Call this question the "time bias

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16 Earman (2006) raises a technical worry about Albert's past hypothesis, arguing that it cannot be meaningfully stated. Winsberg (2004) worries that even granted that Albert's account shows that the entropy of the whole universe was lower in the past, we still have no reason to expect that the entropy of most relatively isolated sub systems, such as glasses of water or boxes of gas, also was lower in the past. Conditionalizing on the past hypothesis would then not recover the full content of the thermodynamic asymmetry. See Albert (2015, 65), Callender (2011a, 100–02), and Wallace (2010, 519) for discussion of these worries. In what follows, I will set these worries aside since my goal is only to show that if the past hypothesis account works, then we get an even better explanation of the thermodynamic asymmetry by positing an intrinsic direction of time in the sense of TF.

17 Of course, the fact that entropy is extremely low at one temporal end of the universe puts, given the

question:”

Time bias question. Why does the past hypothesis restrict the distribution of matter to a state of, among other things, extremely low entropy at one temporal end of the universe rather than at any other time?

The time bias question arises because the past hypothesis gives special treatment to one time, the moment we regard as the “initial moment,” vis-a-vis all other times.

The time bias question needs to be distinguished from two other questions about the past hypothesis. Albert (2015, 5) formulates the past hypothesis as a restriction on the “initial macrocondition” of our universe. One natural question is then why the past hypothesis restricts the initial state of the universe rather than its final state. Proponents of the past hypothesis, however, have an answer to this question. If there is no intrinsic metaphysical difference between the initial and the final moment in time, then models of the universe that only differ with respect to which of these moments the past hypothesis restricts represent one and the same physical universe. So, the past hypothesis is best understood as restricting *one* temporal end of the universe, which is then implicitly defined as the “initial” moment because the past hypothesis applies to it. The time bias question,

dynamical laws, some restrictions on how matter is distributed at other times. But it does not put the *same kinds* of restrictions on these other times.

however, still arises because we can still ask why the past hypothesis applies to one temporal end of the universe rather than any other state.

Another question that needs to be distinguished from the time bias question is whether the past hypothesis itself needs to be explained. Some authors have argued that the macrostate described by the past hypothesis is, in some sense, 'special' or 'improbable', and so it needs to be explained why it obtains.[18] But regardless of whether this question requires an answer, it is different from the time bias question. The time bias question arises even if the macrostate described by the past hypothesis is not special or improbable. Whatever restrictions the past hypothesis places on the distribution of matter, if it applies only to one time, then there is a question of why it applies to this time rather than any other time.

Existing explanations of the thermodynamic asymmetry in terms of the past hypothesis have no resources for answering the time bias question. These accounts assume that time has no direction and that all states in time are intrinsically on par (see Loewer 2012, 117). But if all states in time are intrinsically on par, then there is nothing about the state to which the past hypothesis in fact applies that could explain why the past hypothesis applies to it rather than any other state. According to this view, the state restricted by the past hypothesis is distinctive in that it is a temporal boundary condition, but this distinctive location in spacetime, by itself, does not make it any more apt to be restricted by a

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18 See Carroll and Chen (2004) and Carroll (2009, ch. 15). See also the exchange between Callender (2004) and Price (2004).

fundamental law than any other state.

How important is it that an explanation of the thermodynamic asymmetry answers the time bias question? We do not, in general, think that fundamental laws need to be explained. So, you might think that it also does not need to be explained why the past hypothesis applies to the state to which it does apply. But I will argue that we get a better explanation of the thermodynamic asymmetry if we can answer the time bias question.

First, the past hypothesis cries out for explanation in a way in which other fundamental physical laws do not. Most other candidates for fundamentally physical laws, even laws that are, like the past hypothesis, non-dynamical, apply to all states in time. For example, it may be a fundamental law that "every thermally conductive object at a given moment also is electrically conductive." But although this law is non-dynamical, it applies to every moment in time: it says that at no moment in time is there an object that is thermally conductive but not electrically conductive. So, the past hypothesis's time bias is especially surprising since it is not shared by any other known candidate for a fundamental physical law.

And, second, even if answering the time bias question is not needed to explain the thermodynamic asymmetry, we get a better explanation of the phenomena if we can answer it. Suppose applying the past hypothesis to the world's initial state (together with other plausible assumptions) fully accounts for why our universe behaves thermodynamically. If we then, in addition, can answer the time bias question, we have an account of why the past hypothesis applies to the state in time to which it in fact applies, viz., the initial state. Hence, we understand better how different pieces in our explanation, namely the past hypothesis and the initial state, fit together, gaining a more unified, and so better explanation. In the rest of the paper, I will argue that positing an intrinsic direction of time in the way introduced in §4 answers the time bias question.[19]

My proposed understanding of the direction of time entails that the initial state is the only state in time that is metaphysically fundamental.[20] All other states in time are non-fundamental and are

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19 There may be other ways of answering the time bias question. Albert (2015) introduces the past hypothesis in the context of Humean reductionism about laws of nature (see Loewer 2012). According to Humeanism, laws of nature are mere patterns in the distribution of non-modal properties across spacetime. The time bias of the past hypothesis then may be explained in terms of the time-asymmetric distribution of these properties. Humeanism about laws, however, is controversial. Most importantly in this context, some philosophers have argued that the very fact that Humean laws of nature are partly explained in terms of the actual distribution of non-modal properties prevents them from in turn explaining this distribution (see, e.g., Maudlin 2007a, 172. See Hicks and van Elswyk 2015, Lange 2013, and Loewer 2012 for discussion).

20 I am following Albert (2000, 2015) in assuming that time has an initial moment to which the past hypothesis applies. Albert never clarifies how to understand his account without this assumption. Callender (2004, 114: fn 11) argues on Albert's behalf that if time is continuous, then "the earlier [the past hypothesis is] placed, the better." The time to which the past hypothesis applies would then still have a special explanatory status because we could explain most of temporal reality in

produced from the operation of the fundamental laws on the initial state. It follows from this picture that all of reality can be fully explained from just the initial state and the fundamental laws. Other states in time are metaphysically special too. For example, the final state in time is such that no other state exists in virtue of it. But the initial state is the only state in time such that all other states can be explained by applying the fundamental laws to it.

This special status of the initial state then explains why the past hypothesis applies to it rather than to any other state. The past hypothesis is supposed to be a fundamental law and so part of a complete explanation of physical reality. The metaphysical picture I defend entails that reality is fully explicable from applying the laws to the initial state but not by applying them to any other state. So insofar as the past hypothesis is part of a complete explanation of physical reality, it needs to apply to the initial state. It then follows from TF and the status of the past hypothesis as a fundamental law that the past hypothesis applies to the initial state in time. So, positing an intrinsic direction of time in the sense of TF answers the time bias question.[21]

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terms of just this state and the fundamental physical laws.

21 Frisch (2014, 231) also discusses Maudlin's proposal that a time asymmetry of production helps explain the thermodynamic asymmetry. Frisch, however, concludes that an account of the thermodynamic asymmetry needs to take as fundamental *either* some restriction on the boundary conditions or a direction of time (or causation). My above argument shows that the real upshot is that we need to take both a restriction on the boundary conditions and an intrinsic direction of time

Let me end with two remarks about this argument. First, you might worry that the argument proves too much. If the past hypothesis's status as a fundamental law explains why it applies only to the initial state, would it not follow, by the same logic, that all other fundamental laws also only apply to the initial state? Yet, as pointed out above, all other plausible candidates for fundamental laws apply to all states in time. But TF does not imply that all fundamental laws apply exclusively to the world's initial state. It only entails that any fundamental law must apply *at least* to the initial state. And this latter fact is enough to explain why the past hypothesis, given that it applies only to one state in time, applies to the world's initial state rather than any other state in time.

Second, I am assuming that our universe has a temporal direction from past to future. If it turns out that, instead, a state somewhere in the middle is metaphysically fundamental such that less fundamental states are produced from it in both temporal directions, then my argument would entail that all fundamental physical laws apply to this middle state. However, if Maudlin is right that our universe has a temporal direction from past to future, then this direction explains why the past hypothesis applies to the world's initial state.[22] Here, it is important to keep separate the order of

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as fundamental.

[22] It is a further question what, if anything, explains why time has a direction from past to future rather than (for example) two directions heading away from a midpoint. My project in this paper, however, is only to assess whether given that there is a direction of time from past to future, this direction could help explain the thermodynamic asymmetry.

explanation and the order of discovery. We think that the initial state is metaphysically fundamental and time has a direction toward the future because we can explain many other facts in terms of simple restrictions on this initial state, such as the past hypothesis, and the fundamental dynamical laws. This is our evidence that the initial state is more fundamental than other states. But in the order of explanation we use the metaphysically fundamental status of the initial state to account for why the past hypothesis applies to this moment rather than to any other moment.

§6 Conclusion

I have argued that positing an intrinsic direction of time to the effect that later states in time exist in virtue of more fundamental earlier states provides a deeper explanation of the thermodynamic asymmetry than is available otherwise. It explains why certain fundamental restrictions on the distribution of matter, such as the past hypothesis, apply to the initial moment in time rather than to any other moment. Moreover, I have shown that an intrinsic direction of time in this sense can be modelled with the standard resources of contemporary metaphysics, namely analogies to metaphysical grounding.

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