On Solving the Problem of the Direction of Time

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Abstract There is an apparent contradiction between the time-reversal invariant fundamental laws and our experience of temporal asymmetries. Call this the problem of the direction of time. While the standard approaches attempt to solve this problem reductively, Maudlin argues that a fundamental direction of time is indispensable. This chapter explores the question of when positing such fundamentals is justified and when one should look for reductive explanations. In particular, it examines whether assuming a fundamental direction of time or providing a reductive explanation is better. Moreover, it shows how the problem of the direction of time can serve as a case study to address general issues in inductive metaphysics. Specifically, it raises the questions of how to bridge the gap between our manifest and our scientific image of the world and how to weigh up different explanatory strategies against each other.

Keywords arrow of time, reductive explanations, primitive explanations, fundamentality

1) Introduction

There is an apparent contradiction between the time-reversal invariant fundamental laws and our experience of temporal asymmetries. On the one hand, the dynamical laws of physics are time-reversal invariant: the time-reverse of a process that is compatible with the laws of nature is compatible with the same laws of nature. On the other hand, we deal with many temporal asymmetries in higher-level physics: the temporal direction does make a difference.

Most prominently, we experience many irreversible processes that always have the same direction in time. For example, we only experience ice cubes melting in water and cooling it down, but we never experience water spontaneously heating up and forming ice cubes. This asymmetry is reflected in the phenomenological second law of thermodynamics that states that entropy increases over time. Nevertheless, the underlying dynamical laws of physics are time-reversal invariant and therefore allow for both types of processes, i.e., those that increase in entropy towards the future and those that increase towards the past.

The problem of the direction of time now lies in the question of the origin of this apparent contradiction: If the direction of time cannot be reduced to the fundamental laws of nature, what is the reason for the direction of time? Or as Wallace (2012, 262) puts it: “if there is no fundamental directedness in fundamental physics, how does it come to be present in other areas of physics?”

There are three main solution strategies for this problem in the literature. First, one could take the apparent contradiction between the temporal asymmetries we experience and the time-reversal invariance of the fundamental laws of nature as motivation to eliminate the direction of time as an ontic feature of the world. Instead, one could reduce it to epistemic features, such as the way we deliberate (see, e.g., Price 1996, 2007). Second, one could reduce the direction of time to more fundamental physical features, as suggested most recently by David Albert (2000, 2015) and Barry Loewer (2007, 2012, 2020). Third, as an alternative to eliminating or reducing the direction of time, one could take the direction of time as a primitive feature of the world, as pursued in particular by Tim Maudlin (2007). In this paper we will focus on the latter two.

The aim is to investigate the general advantages and disadvantages of positing or not positing a fundamental arrow of time, and therefore pursuing either a primitivist or reductivist solution strategy. Moreover, we will examine how these considerations relate to more general metametaphysical considerations. In particular, we will argue that depending on the weight one gives to the manifest or scientific image of the world, and depending on the notion of fundamentality one assumes, the reasons for adopting a reductive or primitive solution strategy will prevail.

In detail, we proceed as follows. In section 2, we provide a short review of the extant reductivist and primitivist solution strategies. In sections 3 and 4, we examine various reasons for positing and not positing fundamentals, respectively—both for the problem of the direction of time and for metaphysical questions in general. In section 5, we connect the discussion of sections 3 and 4 to more general issues in inductive metaphysics, focusing in particular on the gap between our manifest and our scientific image of the world, and the problems of weighing up different explanation strategies in light of different notions of fundamentality. Finally, section 6 concludes the paper.

2) Brief review of extant solution strategies

There are two general solution strategies for the problem of the direction of time that attempt to provide an ontological answer to the problem. The first one is to reduce the direction of time to more fundamental features of the physical world. The alternative is to take the direction of time as a primitive feature of the physical world. Both reductivist and non-reductivist solution strategies are pursued in the literature, but the latter is arguably non-standard. In the following section, we provide a brief review of extant approaches that pursue one or the other.

The general idea of reductive explanations is that more fundamental physical features account for the arrow of time. So it is reductive in the sense that the arrow of time is not fundamental, but derivative.[3] The most prominent versions of reductive explanations are thermodynamic approaches. Specifically, there are two different types of thermodynamic approaches that attempt to reduce the temporal asymmetries to local or global thermodynamic features, respectively.[4]

The most prominent representative of a local thermodynamic approach is Hans Reichenbach (1956). Reichenbach seeks to reduce the direction of time to facts about local systems when they branch off (i.e, when they come into being):[5]

> The entropy of the universe is at present low and is situated on a slope of the entropy curve (...). In the vast majority of branch systems one end is a low-point, the other a high point (of entropy, KS & MV). (Reichenbach 1956, 136)

Global thermodynamic approaches, on the other hand, go back to Ludwig Boltzmann's work on statistical mechanics. They have recently been pursued by Albert (2000; 2015) and Loewer (2007; 2012; 2020), who assume that the universe as whole started in a particular state of low entropy:

> The proposal is to add to the fundamental dynamical laws the following two claims.
> (PH) a statement specifying the macro state of the universe at one boundary (which is assumed to be one with a very low-entropy condition satisfying certain further symmetry conditions).
> (PROB) a uniform probability distribution over the physically possible initial conditions compatible with PH; that is, the initial macro state of the universe. (Loewer 2007, 300)

To explain local thermodynamic behaviour, both approaches need to make additional statistical assumptions regarding the (local or global) low-entropy states, which we will not discuss here. Thus, the general idea of these thermodynamic approaches is that asymmetric (local or global) boundary conditions together with certain statistical assumptions explain the arrow of time.

Apart from the prevailing thermodynamic approaches, there are other less common reductivist approaches to solving the problem of the direction of time, drawing on considerations from quantum field theory (QFT) or general relativity (GR). In particular, one can turn to CP (charge conjugation parity symmetry) or T (time reversal symmetry) violation, or restrictions of Einstein's field equations to explain the direction of time.

The former QFT approach is pursued, for example, by Bryan Roberts (2022) and Kian Salimkhani (forthcoming). Roberts presents a two-part argument:

> First: time is symmetric if and only if reversing the time translations is a symmetry; otherwise it is asymmetric. Second: if a theory has a 'law of motion' describing change over time, then that change must share a common structure with time, through a representation. Like a table casting a shadow on the floor, the asymmetries of time cast a shadow onto our best theories of motion. (Roberts 2022, 219)

As part of this argumentation, Roberts takes T violation as direct evidence for an arrow of time:

> T violation means that the standard time reversal operator T does not provide a representation of time translation reversal, $t \rightarrow -t$. The experimental evidence for this provides strong evidence that time itself has an arrow. (Roberts 2022, 217-218)

Salimkhani, on the other hand, employs the ontological reducibility of the spacetime metric to matter field dynamics in the context of a dynamical approach to relativity theory to be able to bolster Earman's (1989, 46) adequacy conditions on spacetime theories: granted that matter field symmetries are more fundamental than spatiotemporal symmetries, the fundamental directionality in the matter field dynamics due to CP and T violation then explains the derivative directionality of spacetime. Both authors also provide several reasons for why common strategies in the literature to dismiss CP and T violation as a source for the arrow of time fail.

The latter GR approach has been argued for in particular by Mario Castagnino, Olimpia Lombardi, and Luis Lara (2003).[6] Specifically, Castagnino et al. suggest that appropriate restrictions of Einstein's field equations, which every physical universe should meet, lead to solutions that are typically time-directed and therefore explain why our universe is time-directed:

> (i) if certain conditions are satisfied, it is possible to define a global arrow of time for the universe as a whole, and (ii) the standard models of contemporary cosmology satisfy these conditions. (Castagnino et al. 2003, 877)

Thus, the general idea of these two reductivist approaches is that the direction of time is a non-primitive (non-fundamental) feature of the physical world.[7]

Second, the alternative to a reductive explanation is to view the direction of time simply as a primitive feature of our world. The most prominent non-reductivist or primitivist approach is due to Maudlin (2007), who argues that there is a fundamental direction of time that determines the direction in which states are produced and laws of nature operate. Maudlin can be read to provide this fundamental directionality in terms of a non-standard approach to topology, dubbed line-based topology (see Maudlin (2011; 2015); see Salimkhani (forthcoming, 8-10) for a summary). The general idea of such a primitivist approach à la Maudlin is to take the arrow of time as a feature of our physical world that is not further reducible to (or: not grounded in) other features:

> I believe that it is a fundamental, irreducible fact about the spatio-temporal structure of the world that time passes. (…) The passage of time is an intrinsic asymmetry in the temporal structure of the world, an asymmetry that has no spatial counterpart. It is the asymmetry that grounds the distinction between sequences which run from past to future and sequences which run from future to past. (Maudlin 2007, 107-108)

Given these two general solution strategies, the question arises as to whether assuming a fundamental direction of time or providing a reductive explanation of the arrow of time is better. To this end, we will discuss various possible reasons for positing or not positing a fundamental direction of time in particular, as well as fundamentals in general, in the next two sections.

3) Arrow of time: To posit...

Standard reasons for positing a fundamental direction of time include (1) capturing intuitions and time’s special role, (2) stopping an explanatory regress, (3) avoiding specific problems of the reductive explanations at issue, and (4) indispensability arguments. Let us take these in turn.

(1) Often, primitive explanations reflect our pre-theoretical intuitions about concepts that are integral to our manifest image of the world. The direction of time case seems paradigmatic for this. Indeed, the most immediate reason for positing a fundamental arrow of time is that it best captures our pre-theoretical intuitions. Since our manifest image of the world includes the concept of time as a phenomenon that distinguishes between past and future and that continuously flows towards the future (see, e.g., Callender 2017), a primitive direction of time appears to capture this image better than any reductive explanation ever could.

Now, one can arguably be sceptical about the use of intuitions in philosophy, or generally the relevance of the manifest image for settling these disputes. The primitivist therefore fares better by adding observations within the scientific image, particularly from physics, that is, by drawing instead on the special role that the direction of time has in physics' practice, for example. On this note, one could take inspiration from Maudlin's (2007, 105) take on laws of nature that "nothing in scientific practice suggests that one ought to try to reduce fundamental laws to anything else" and argue that nothing in scientific practice suggests that one ought to try to reduce the direction of time to anything else. Or, one could point to the generally accepted differences between time and space, and link this to specific features of time, like the passage or the direction of time (Maudlin 2007, 107).

However, either way, it is unclear how intuitions about time or observations about the special role of the direction of time can decide between reductive and primitive explanations. Typically, such intuitions and observations will not straightforwardly contradict reductive explanations. The relevant intuitions (about the flow of time or the distinction between a fixed past and an open future) are too coarse-grained to distinguish between a fundamental and a derivative status of the directionality of time. Similarly, for the special role of the direction of time in physics, it does not matter whether the direction of time is conceived as primitive or reductive, as long as its special role for physics is preserved. What is more, there are now at least attempts in physics to reductively explain various spatiotemporal aspects. This indicates that general negative claims like 'there can be no further reduction of X' or 'physics' practice does not provide any reason for reducing X' may need to be revised at some point. Arguably, primitivists like Maudlin are acutely aware of that (e.g., Maudlin 2007, 106).

Interestingly, there is a way of making said points for primitivism in a slightly more decisive manner. We will come back to it when discussing indispensability arguments below. But, first, let us turn to the explanatory reasons for positing a fundamental.

(2) The most important explanatory reason is that fundamentals stop the explanatory regress. In this perspective, providing a reductive explanation only shifts the metaphysical

burden, but does not resolve it. For example, if we provide a reductive explanation for the arrow of time in terms of (local or global) boundary conditions, CP violation, or restrictions of Einstein's field equations, the question arises as to whether these assumptions themselves require further explanation. Thus, we obtain an explanation for the arrow of time only at the cost of raising the question of the status of other assumptions.

In a global thermodynamic approach, for example, we may need to explain the assumption of a low-entropy initial state, since such a state seems very unlikely, at least if one considers it as a bare fact.[8] If we consider all metaphysically possible initial states and apply statistical-mechanical considerations to these possible initial states, an initial state with high entropy appears to be the most likely (see Carroll 2010). Accordingly, the question arises as to the reason for this unlikely initial state. While proponents of a global thermodynamic approach argue that we do need such an explanation since we can understand the past hypothesis (and the statistical postulate) in terms of laws of nature, others argue that this is exactly what is at stake (see Callender 2004 vs. Price 2004). Similarly, further explanations may be needed for the violation of CP symmetry in the QFT approach and the restrictions of Einstein's field equations in the GR approach. In both approaches, the violation or restriction requires further explanation, if it is not to be taken as a brute fact.

Thus, for the seemingly more fundamental assumptions, the question arises anew as to whether we should posit them as fundamental or explain them reductively. In the case of the latter, an explanatory regress is about to begin. What is more, it seems that we need to assume some kind of (more fundamental) asymmetry for explaining a non-primitive arrow of time anyway. No ought from is. No asymmetry from symmetry. While this is quite obvious for the thermodynamic and the CP violation approach, it is a little less obvious for the GR approach. First, the global thermodynamic approach makes an assumption about a particular low-entropy state (i.e., the past hypothesis) and a statistical postulate for the early universe, but not for the late universe (even though this asymmetry may be justified as a law of nature). Similarly, the local thermodynamic approach assumes that entropy is low when isolated systems come into being, but not when they cease to exist. Second, the CP violation approach assumes fundamental CP-violating and thus asymmetric fundamental laws of physics.

Surprisingly, the GR approach appears to do without this assumption of asymmetries. Here, we seem to get an asymmetric explanandum from a symmetric explanans. The reason why we can do without an asymmetric assumption, despite the time-reversal invariance of Einstein's field equations, is that one identifies all solutions with their time-reversed counterparts. This is based on their indiscernibility: Since the (restricted) field equations are time-reversal invariant, we obtain a time-reversed counterpart for each time-directed solution. Yet the time-directed solutions and their time-reversed counterparts can be identified with each other since they share all intrinsic and extrinsic properties, or so argue the proponents of the GR approach (Castagnino et al. 2003, Bartels & Wohlfarth 2014b). However, the restrictions of Einstein's field equations and/or the measure-theoretic argument in the GR approach could be understood as introducing the asymmetry. One way to look at this is to say that assuming orientable time and dynamical matter-energy is tantamount to assuming the asymmetry. Another way is to suspect that, conceptually, a null set (a set of measure zero) is not equivalent to the empty set. Hence, the reasoning goes, the set of symmetric solutions, that are being discarded, is, albeit of measure zero, not empty. So, one is, after all, neglecting solutions that don't fit the desired conclusion. This can be seen as engineering the result.

A primitive direction of time avoids these generic pitfalls of reductive approaches. However, strictly speaking, the argument from avoiding explanatory regress only provides a reason why 'something' should be considered fundamental or why 'some' fundamental asymmetry should be assumed. Without additional reasoning, it is unclear why a primitive arrow of time, specifically, is best to do the job. Why not take the (local or global) boundary conditions, CP violation, or the constraints of Einstein's field equations as the regress-stopping fundamental facts? To be able to decide which fundamental fact is the best choice, we need more specific reasons, as discussed next. It should also be noted that several philosophers have expressed general scepticism towards the foundationalist rejection of infinite regress (e.g., Morganti 2014, McKenzie 2022).

(3) Here is the third reason. Reductive approaches can face new explanatory, conceptual, or metaphysical issues. Positing fundamentals is not plagued with these problems.

In the case of local or global thermodynamic approaches, we must assume that the entropy of the universe is on a slope at present (Reichenbach 1956) or that the universe started in a macro-state of low entropy (Albert 2000, Loewer 2007), respectively. It is not clear whether we can make sense of the notion of the entropy of the universe at all (see, e.g., Earman 2006). Apart from this conceptual problem, the metaphysical status of the reduction base can be controversial. Take again Albert and Loewer. They use the past hypothesis and the statistical postulate as their reduction base, both understood as laws of nature, since, for them, laws of nature require no further explanation—arguably, this is controversial. To this end, they engage with a particular account of laws of nature, namely David Lewis's (1994) best systems analysis, and relax it to allow for propositions about particular states of the universe as laws of nature.

The non-mainstream reductive approaches raise similar questions. In the case of CP violation, many have argued that CP violation cannot serve as a reduction base, since it allegedly only affects certain exotic particles (see Price 2011, Loew 2018; but see Salimkhani forthcoming). In the case of the GR approach, the question arises as to how the necessary restrictions to Einstein's field equations can be justified. In addition, proponents have to explain how we can infer that our universe is directed from the fact that solutions are merely typically directed (see, e.g., Bartels & Wohlfarth 2014a, Voggenauer 2025).

Moreover, for any global approach, whether thermodynamic or not, the question arises as to how local thermodynamic behaviour and all other local asymmetries can be derived from global assumptions.[9] A primitive arrow of time that determines the direction of how states are produced locally, as proposed by Maudlin, could potentially overcome this explanatory gap.

(4) A fourth and final reason provides an indirect inference to primitivity. If an entity is indispensable for (certain) explanations, the reasoning goes, it is fundamental. So, if the arrow of time is indispensable for explaining, say, 'which states produce which' (Maudlin 2007, 134), this is a reason to posit it as fundamental. What we encounter here is basically a refined version of the 'special role' argumentation in (1). It elaborates on what this 'special role' consists in precisely, namely its explanatory or conceptual indispensability. This is a decisive refinement since it clarifies that nothing else can fill in the gap. Accordingly, the resolution is now sufficiently fine-grained to be able to distinguish between a derivative and a fundamental arrow of time.

Importantly, there is a shift in the underlying notions here: Indispensability arguments rely on an upward-directed concept of fundamentality as determination rather than the standard downward-directed concept of fundamentality as independence. This makes for a potential problem for the inference to primitivity: Can an entity be explanatorily indispensable but non-primitive (in a dependence sense)? At the very least, the differing usage of 'fundamentality' and the relation between the two concepts (independence and determination) needs to be discussed carefully. Philosophers like Karen Bennett (2017) will arguably insist on a priority of the independence notion of fundamentality. Accordingly, the indispensables are indispensable because they are independent, not the other way around.

What is more, tying primitivity to determination seems to generally blur the standard distinction between fundamentals and non-fundamentals in terms of dependence: non-primitives (that is, dependent entities) may also very well determine (e.g., atoms determine tables). Proponents of primitivity from indispensability can, however, respond that non-primitives may not do so indispensably. Still, caution is advisable. That non-primitives can serve as grounds in all kinds of determination relations signals that inferring primitivity from indispensability is valid only if the entity is indispensable for ‘all’ explanations. Arguably, demonstrating this is quite a task. Nevertheless, it appears to be the best route for the primitivist. In fact, that seems to be exactly what Maudlin is after: the distinction of before and after due to the direction of time is indispensable for any kind of explanation in physics.

In summary, positing a fundamental arrow of time may be argued to cover our intuitions best or even be indispensable for certain explanations and for stopping an explanatory regress. These are strong reasons for positing fundamentals in general and can be strong reasons for positing a fundamental arrow of time in particular, if properly argued. However, there are also serious reasons against positing a fundamental arrow of time, as we will lay out next.

4) Or not to posit

Important reasons for dispensing with a fundamental direction of time include (1) metaphysical parsimony, (2) concerns about the explanatory power of fundamentals, and (3) possible redundancy and inconsistency issues. We now discuss these reasons in detail.

(1) A standard reason for not positing a fundamental is the maxim of metaphysical parsimony. The posit of a primitive feature introduces a new ontological entity (or category) that we could possibly do without. A primitivist about the direction of time introduces an additional entity in the fundamental ontology. Non-primitivists reject this: in their view, there are promising reductive explanations for the arrow of time that rely on posits that we need to introduce anyway (CP-violating processes or, in the GR case, really any kind of matter field). So, the argument goes, we can do without positing a fundamental arrow of time. All three reductive approaches build on empirically and metaphysically uncontroversial aspects of modern physics, which were originally introduced to explain other physical phenomena. Even introducing boundary conditions for the universe or restricting Einstein’s field equations means following a common practice in physics. In general, we add boundary conditions or constraints to apply physical theories to specific physical phenomena. In any case, we do not add these phenomena by fiat as primitive facts to our existing body of physical theories.

Therefore, one could argue that adapting extant theories appears to better suit the state of our current physics and physical practice than introducing novel entities that are not familiar to any of our best theories. Thus, by introducing a primitive arrow of time, we unnecessarily introduce an ontological entity that would be better reduced to entities that are already part of our ontology. Notably, Maudlin rejects this reasoning forcefully by arguing that ontological parsimony is not an aim in itself:

> Accepting unanalyzable primitives into one's ontology may seem like philosophical dereliction of duty: after all, much of metaphysics is devoted to providing analyses or reductions. But the exact point of these reductions is not always clear: ham-fisted appeals to Ockham's Razor or a hankering for Quinean desert landscapes do not stand up as justifications for accepting the most bare-bones ontology that can be contrived. (Maudlin 2007, 105)

We tend to agree that "less is not always more, and certainly less is not always more justified" (Maudlin 2007, 105). However, as we will discuss below, there are quite general and subtle reasons for thinking that the bar for accepting entities as irreducible primitives ought to be raised nevertheless.

(2) In addition to the argument from metaphysical parsimony, there is likewise an explanatory reason for not positing fundamentals that concerns the explanatory strength of primitives. In fact, this reason is twofold. First, there is the general worry that a primitive is a posit and not an explanation. A reductive explanation tells a certain story of why the explanandum obtains. Primitive 'explanations', however, 'explain' by simply positing the explanans, by identifying explanans and explanandum. By positing a fundamental arrow of time, we simply presuppose it but do not attempt to explain it.

Second, primitive posits need not necessarily help explain other features of our world. In the case at hand, the question arises whether a primitive arrow of time can do crucial explanatory work, like explaining the many temporal arrows that we experience and that were part of the reason to assume a primitive arrow of time in the first place (see, e.g., Loewer 2012). Consequently, it may seem that we should instead look for explanatorily more fruitful reductive explanations—both for primitives in general and for the direction of time in particular.

This is all the more true if we adopt a scientifically informed metaphysics: often, primitive explanations are not considered fruitful in the sciences either.[10] In the case at hand, all three reductive approaches discussed in this paper appear to provide more fruitful explanations and rely more directly on explanatory strategies common to the sciences themselves. First, in the case of a thermodynamic approach, the arrow of time is explained by boundary conditions (in addition to the dynamical laws). Second, the CP violation approach draws on already accepted fundamental laws of nature. Third, the GR approach explains by restricting Einstein's field equations.

(3) Finally, an intricate reason against positing fundamentals is the danger of introducing an explanatory or ontological redundancy, or worse: an inconsistency. Suppose a reductive explanation of an entity E on the basis of established fundamentals is feasible but not pursued. Then positing E as primitive introduces a redundancy. If the arrow of time can be reduced to local or global constraints on the dynamics, CP-violating laws, or restrictions of Einstein's field equations, positing a primitive arrow of time adds a redundant explanation. We have two explanations, one reductive and one primitive. Now, one might be tempted to downplay this issue: after all, redundant explanations are plenty. But we are concerned with metaphysics here. Accordingly, pragmatism about explanations misses the mark. The explanatory redundancy is explicitly accompanied by an ontological redundancy: we include more than needed as part of the fundamental ontology. This is unacceptable with respect to the metaphysical issue we are concerned with here.

More importantly, such redundancies can be worse than one might think. The surplus primitive posit (or explanation) may impede or interfere with other established fundamentals (or explanations). The key problem behind this objection is that fundamentality is usually taken to imply consistency. Especially if we understand fundamentality as (ontological) independence, which is arguably the received view, fundamentals are thought to be "freely modally recombinable" (Bennett 2011). Accordingly, they cannot contradict each other: If fundamentals are truly independent, they should be combinable without restriction. No inconsistencies can arise from positing a truly independent entity. The flip side is that positing some entity as primitive is no innocent measure. One needs to be fairly certain that it is truly independent. Arguably, this is a difficult task, since, in principle, one needs to take into account all other fundamentals when wishing to add one.

In practice, however, there may be ways to narrow down what needs to be taken into account. For instance, the different fundamental matter fields posited in particle physics will likely not turn out to be redundant or inconsistent. Also, there is a straightforward recipe for adding new fundamental fields. This is because matter fields are posited based on a rigid theoretical framework and a good understanding of their dependent and independent features. Similar ways of simplifying the difficult task may also apply to the case at hand. For example, it seems reasonable to expect that an asymmetry in time can at most depend on the subset of asymmetric posits ('no asymmetry from symmetry'). The practical lesson then is that, granted we need to assume some kind of asymmetry in order to explain an asymmetry, we should assume as few as possible, that is, we should only assume asymmetries that are truly independent of each other. For example, if we have good reasons to believe that there is an intimate dependence relation between CP violation and the direction of time, it seems advisable to avoid positing both as primitive.

We can also turn this around. We can interpret theoretical inconsistencies (or unsatisfactory explanations) as unresolved tensions within the fundamental posits. In other words, hidden dependence relations among allegedly independent posits can occasionally show up as theoretical inconsistencies. For example, one might think that quantum matter fields, the Heisenberg uncertainty principle, gravity, and a continuous metric field are all fundamental, that is ontologically independent, and therefore posit them as fundamental. Then, inconsistencies will arise and further scrutiny will show that these posits are, in fact, not independent (Salimkhani 2024). Thus, if entities are assumed as independent (hence, freely modally recombinable) but are not, this may lead to inconsistencies. This nicely demonstrates that a high bar for accepting entities as irreducible primitives is not just about rejecting dull metaphysics where “the metaphysician’s work is quickly, and uninspiringly, done” (Maudlin 2007, 106). Rather, it is about putting consistency in the spotlight.

In summary, dispensing with a fundamental arrow of time appears to be the metaphysically more parsimonious and explanatorily more powerful alternative. In the next section, we examine how these reasons for and against positing a fundamental arrow of time relate to more general metametaphysical considerations, focusing in particular on the notions of fundamentality underlying the different solution strategies.

5) Connecting to Inductive Metaphysics

In particular, the problem of the direction of time serves to demonstrate (1) how the gap between our manifest and our scientific views of the world might be bridged, and (2) how different explanatory strategies might be weighed up against each other.

(1) Bridging the gap between our manifest and scientific image of the world: Let us first recall that the direction of time is an important part of both our manifest and our scientific image of the world. Regarding the former, we make a clear distinction between past and future in everyday life. We view time as something that passes, i.e., that flows from the past to the future (see Callender 2017). We only remember the past and only live and deliberate towards the future. Regarding the latter, there are many asymmetric phenomena in physics and beyond, even though our fundamental laws of nature are mostly time-reversal invariant. In physics, we deal, for example, with the second law of thermodynamics, Carbon-14 decay, baryon asymmetry, the asymmetry of radiation, and (potentially) the collapse of the wave function. Beyond physics, most of the special science laws are causal laws and thus come with an inherent direction. Even

if some of these asymmetries may be regarded as purely phenomenological or epistemic, they are nevertheless an important part of our science.[11]

The importance of the direction of time to both our scientific and manifest image is the reason why solving the problem of the direction of time not only involves several physical theories, but also our everyday conception of time. Accordingly, the problem of the direction of time can serve as a paradigmatic example of how to strike a balance between scientific considerations and everyday experiences for solving metaphysical problems.

What if science contradicts inferences from everyday experience? Usually, we then prioritize the scientific insight as more robust. For example, the scientific refutation of our everyday conception of simultaneity is prioritized, and rightfully so. A crucial reason for accepting this prioritization specifically (as opposed to a merely general endorsement of Einstein's theory) seems to be that Einstein's theory also explains why the two conceptions of simultaneity diverge and provides a limiting procedure to connect the two. The scientific image links to the manifest image. What is more, while our everyday experience may be rather detached from fundamental physics, it is arguably often in touch with and reflected in our higher-level theories. That there is a problem of the direction of time is supported by the apparent mismatch of fundamental physics with both higher-level physics and everyday experience.

Still, justifying metaphysical inferences by everyday experience does seem problematic. Essentially, such inferences seem highly speculative and the justifying everyday experiences are, at most, mere placeholders for future scientific findings. The question therefore arises whether everyday experience can play a substantial role in metaphysics at all. The placeholder worry might, however, be interpreted pragmatically: Even if justifying metaphysical inferences by everyday experiences appears problematic in general, they can still play a heuristic role, for example, by fueling a fruitful skepticism towards controversial philosophical implications from physics.

Specifically, everyday experience may help to guard against naive literalism when it comes to interpreting physical theories. In the debate on the problem of the direction of time, the resilience of our manifest image of time as an asymmetric phenomenon underwrites the importance of asymmetries in physics, even though the fundamental laws of nature are mostly time-symmetric. In this vein, Maudlin (2007) can be taken to argue for a fundamental arrow of time based on intuition (see also Loew 2018, 487), conceptual arguments, and fundamental physics. Our everyday experience of temporal asymmetries thus serves not only as a pre-theoretical heuristic, but also as a major reason not to be too easily satisfied with the idealized view that physics is based solely on time-reversal invariant fundamental laws of nature.

(2) Weighing up different explanatory strategies: Here is another reason why the problem of the direction of time is an interesting case study for inductive metaphysics. It serves to clarify various questions in connection with explanation: among other things, when we should stop asking for further explanations, how different competing explanations can be traded off, and how methodological and conceptual issues are intertwined in explanations.

First, the problem of the direction of time raises the question of when one should stop asking for further explanations. One argument against a primitivist solution strategy was that it solves the problem only by introducing a novel primitive entity that has no real explanatory power. As seen, the primitivist may counter the reductionists that they too must make some unexplained assumptions unless they accept an infinite explanatory regress. Therefore, the problem of the direction of time raises the question of what are good reasons to stop asking for further explanations.

One option is to draw on our explanatory practices in everyday life and in the sciences. Aligning with our everyday explanatory practices could suggest that we stop asking for further explanations of phenomena that common sense regards as mere facts. In contrast, following our scientific explanatory practices suggests that we should at least look for some boundary conditions, underlying fundamental laws or other restrictions that explain the phenomenon under consideration, etc. Accordingly, evaluating the relationship between our manifest and our scientific image of the world not only affects which concepts should play a role in explanations, but also which explanatory strategies we should resort to.

Read and LeBihan (2021, 6–7), for example, suggest how physics could provide a criterion for when an explanation is to be accepted as fundamental, in connection with the question of whether string theory has sufficient explanatory power. They argue that it matters for physical explanations whether we consider a theory as the final theory or not. If we consider the physical theory as only a part of the full story, we could accept some assumptions as unexplained: the underlying theory has some unexplained components anyway, which only a final theory can fix. Accordingly, for the purpose of the problem of the direction of time, the explanation of boundary conditions for statistical-mechanical considerations, CP-violating laws of nature, or restrictions of Einstein's field equations could be accepted as unexplained, since only a final theory can provide the missing explanation of why exactly these boundary conditions, laws, or restrictions hold. This may help to undermine the third reason in section 3 for positing a fundamental entity, namely that reductive approaches can face new explanatory, conceptual, or metaphysical issues.

Second, since the debate on the direction of time involves several explanation strategies, it can serve as a case study for inferences to the best explanation in metaphysics. As seen, the potential explanation strategies refer to various scientific theories and pre-theoretical intuitions. The debate on the problem of the direction of time therefore allows to evaluate the general virtues of primitive and reductive solution strategies, as well as the merits of various metaphysical posits in terms of primitive stipulations, boundary assumptions, and restrictions of laws of nature. Specifically, the various reductive explanations of the direction of time draw on assumptions of statistical mechanics, quantum field theory, or general relativity, which all conflict in one way or another with our pre-theoretical intuitions. Solving the problem of the direction of time is therefore a matter of weighing up the virtues of different solution strategies and different metaphysical posits to decide which explanation is better than others. Weighing up the different approaches is not limited to different solution strategies and metaphysical posits, but also extends to the more general question of how different metaphysical methodologies, such as including everyday experience as opposed to focusing exclusively on scientific theories, should be evaluated.

With regard to the latter, the question arises as to whether and how metaphysical content and methodology are linked. Nina Emery (2023) argues, put roughly, that content naturalism presupposes methodological naturalism, since there is no reason to accept the content if one does not accept the methodology that produced that content. Similar considerations may concern the connections between metaphysical concepts, general metaphysical methodologies, and inferred metaphysical content, specifically with regard to the problem of the direction of time. Building on our presentation above, it appears that the verdict on whether to adopt a reductivist or a primitivist solution strategy depends on the notion of fundamentality one assumes.

Interestingly, the two solution strategies (i.e., assuming and not assuming a fundamental direction of time) not only disagree on what is fundamental, but also appear to draw on different concepts of fundamentality itself, namely, fundamentality as independence and fundamentality as determination (for a general overview, see, for example, McKenzie 2022). These conceptual differences then also explain the different metaphysical methodologies used. As a downward-looking concept, fundamentality as independence is linked to a non-primitivist methodology that prioritizes reductive arguments, whereas, as an upward-looking concept, fundamentality as determination is linked to a primitivist methodology that emphasizes indispensability arguments. Thus, pending a reconciliation of the two concepts of fundamentality, pending insights on their relation, the justification for positing a fundamental arrow of time ultimately depends on which concept of fundamentality is given priority.

To summarize, the problem of the direction of time allows investigating the questions of what role everyday experience can play in metaphysics at all, how to strike a balance between scientific considerations and everyday experience, how inference to the best explanation applies in metaphysics, and how metaphysical content and methodology are connected.

6) Conclusion

We argued that the problem of the direction of time concerns an important feature of our world, one for which both scientific and everyday conceptions are, in fact, taken seriously. Promising avenues for solving the problem of the direction of time utilize both primitive and reductive explanation strategies. Thus, solving the problem involves assessing the virtues of various incompatible proposals and exploring links between metaphysical background concepts, methodologies, and the content of metaphysical inferences. Specifically, studying the problem of the direction of time demands for a closer look at the underlying notion of fundamentality and weighing up between indispensability and reductive arguments. The scientific relevance of the problem, as well as its metametaphysical implications, make it a perfect case study for inductive metaphysics.

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[3] This does not mean that the more fundamental assumptions cannot also be in need of further explanation, as will become clear later on.
[4] For an overview of thermodynamic approaches, see Callender (2021).
[5] For discussion, see Winsberg (2004) and Fernandes (2022).
[6] See also Bartels & Wohlfahrt (2014a) and Voggenauer (2025).
[7] Causal set theory, an approach to quantum gravity (see Dowker 2013 and Wüthrich 2012), may be viewed as another (notably speculative) reductive proposal: there is a sense in which the directionality of time is reduced to an asymmetric causal precedence relation. However, depending on how this asymmetric relation is interpreted, that is, whether the causal or the precedence aspect is emphasized, causal set theory may as well be classified as a primitivist proposal. In this paper, we will not assess this any further.
[8] The same holds for Reichenbach's (1956) assumption that the universe is on a slope at present.
[9] For discussion, see, e.g., Winsberg (2004), Frigg & Hoefer (2015), and Loewer (2020) for thermodynamic approaches and Castagnino et al. (2009), Bartels & Wohlfarth (2014b), and (2025) for GR approaches.
[10] Some may disagree and insist that the postulation of primitives is a common explanatory strategy in the sciences, think of the introduction of new fundamental fields in particle physics. Still, in the case of the arrow of time, the reductive approaches appear to do more explanatory work than the postulation of a primitive, since they integrate the explanandum in the rest of physics.
[11] Arguably, any asymmetry that reveals itself as purely epistemic does not pose a problem anymore: in virtue of being epistemic, it is either discarded from our scientific image tout court or exempt from any non-integrable features.