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## On the Passing of Time

Metaphysics is ontology. Ontology is the most generic study of what exists. Evidence for what exists, at least in the physical world, is provided solely by empirical research. Hence the proper object of most metaphysics is the careful analysis of our best scientific theories (and especially of fundamental physical theories) with the goal of determining what they imply about the constitution of the physical world.

The foregoing theses strike me as incontestable. If one accepts them, the project of metaphysics takes on a form rather different than that commonly practiced today. Long gone, of course, are logical empiricist attempts to reduce all meaningful assertions to claims about sense experience. The metaphysical irreducibles are to be provided by physics- quarks, electrons, and space-time, for example- rather than by ‘epistemological priority’. The horror inspired by ‘unverifiable’ propositions completely dissipates, an attitude nicely attested by the physicist J. S. Bell when discussing interpretations of the quantum theory:

The ‘microscopic’ aspect of the complementary variables is indeed hidden from us. But to admit things not visible to the gross creatures that we are is, in my opinion, to show a decent humility, and not just a lamentable addition to metaphysics. (Bell 1987, pp. 201–2)

Empiricists subordinated metaphysics to epistemology via the empiricist theory of meaning. For Hume, the simple elements of any idea had to be provided by experience, so talk of the in-principle unobservable must be empty of cognitive content. Similarly for the logical empiricists, albeit with the emphasis shifted first from ideas to sentences and then, with Hempel and Quine, to complete theoretical systems. Since the collapse of the empiricist

Thanks to David Albert, Frank Arntzenius, John Earman, Adam Elga, Shelly Goldstein, Ned Hall, Barry Loewer, Huw Price, and Brad Weslake for, in some cases, vigorous opposition, and in others, sympathetic support. You know who is who. The first section of this paper appeared as Maudlin 2001.

criteria of meaning, philosophers have no longer been trying to reduce the theoretical vocabulary of physics to middle-sized-thing-language, and there is no good reason to try to reinvigorate that moribund program.

But the ghost of the empiricist program still haunts metaphysics. It manifests itself most obviously in the thesis of Humean Supervenience, which animates the work of David Lewis. Lewis claims that his Humeanism springs exactly from a desire to protect physics from incursions by philosophers:

Is this [namely Humean Supervenience] materialism?—no and yes. I take it that materialism is metaphysics built to endorse the truth and descriptive completeness of physics more or less as we know it; and it just might be that Humean supervenience is true, but our best physics is dead wrong in its inventories of the qualities. Maybe, but I doubt it. Most likely, if Humean supervenience is true at all, it is true in more or less the way that present physics would suggest ...

Really, what I uphold is not so much the truth of Humean supervenience but the *tenability* of it. If physics itself were to teach me that it is false, I wouldn't grieve. (Lewis 1986a, p. xi)

But the practical results of embracing Humean Supervenience are not the same as turning to scientific practice for the raw materials from which clear ontology is refined. For example, Lewis's Humeanism impels him to search for a reductive analysis of laws of nature (the so-called Mill–Ramsey–Lewis best systems theory). But nothing in *scientific practice* suggests that one ought to try to reduce fundamental laws to anything else. Physicists simply postulate fundamental laws, then try to figure out how to test their theories; they nowhere even attempt to analyze those laws in terms of patterns of instantiation of physical quantities. The practice of science, I suggest, takes fundamental laws of nature as further unanalyzable primitives. As philosophers, I think we can do no better than to follow this lead.

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. To take a single example: one can try to eliminate fields from one's ontology by concocting an action-at-a-distance theory, but even if the concoction can be achieved, why think that the resulting theory is more likely to be true than the field theory one began with? Less is not always more, and certainly less is not always more justified. On the other hand, if every entity is to be allowed in as an

irreducible primitive, the metaphysician's work is quickly, and uninspiringly, done.<sup>1</sup>

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A general, abstract account of when ontological reductions should be pursued and when a bare posit should be made would no doubt be a Good Thing. I am unsure whether any such general account is possible, and am certainly unable to provide one here. In its stead, I can only offer a profession of what Nelson Goodman would call my 'philosophic conscience' (Goodman 1983, p. 32). I believe there is a fundamental physical state of the world. One may roughly think of that state as consisting of electrons and quarks and photons and so on distributed throughout space-time, but the work of understanding just what electrons and quarks and space-time are remains undone. (Part of that state appears to include a quantum wavefunction, which is not like electrons, or fields, or space-time, and deserves its own careful scrutiny.)<sup>2</sup> I am a substantialist about space-time insofar as I do not think that spatio-temporal facts can be reduced to relational facts about material bodies as more or less classically conceived. Since it likely will turn out that in our best theories neither electrons and quarks nor space-time can be more or less classically conceived, many current philosophical disputes about space and time are likely to need revisiting in the future.

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In addition to the physical state of the universe, I believe in fundamental physical laws.<sup>3</sup> Facts about what the laws are cannot be reduced to, or analyzed in terms of, other sorts of facts. My philosophical conscience dictates that ultimately the physical state and the fundamental physical laws are all there are in the inanimate realm: all astronomical or chemical or meteorological facts supervene on these. Insofar as counterfactual and causal claims have determinate truth conditions, the ontology that underwrites the truth values of these claims is just the physical state and the fundamental physical laws.<sup>4</sup> There are no ontologically additional biological or chemical or economic laws, there are no further brute facts about causation or counterfactuals or dispositions.

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<sup>1</sup> At least at one level. Inflating ontology can, in some contexts, pose severe questions of *choreography* among the entities. If one thought that, say, typewriters were not composite entities among whose parts are keys, it would be puzzling why one cannot manage to use a typewriter without also touching some keys.

<sup>2</sup> The wavefunction appears to be a section of a fiber bundle: see 'Suggestions from Physics for Deep Metaphysics', Chapter 3, this volume.

<sup>3</sup> See 'A Modest Proposal Concerning Laws, Counterfactuals and Explanation' Chapter 1, this volume.

<sup>4</sup> See 'Causation, Counterfactuals, and the Third Factor', Chapter 5, this volume.

The qualifier ‘inanimate’ appears above as a bow to the mind-body problem. I admit that the evident existence of subjective mental states is neither obviously part of, nor reducible to, physical state and physical law. But I do not think that all ontological analyses need be held hostage to this conundrum. In particular, investigation of the physical ontology can proceed so long as the physical world contains plausible *de facto* correlates of subjective mental states, such as the notorious firing of C-fibers for pain. Identifying *de facto* correlates leaves a lot of work to be done, such as identifying the generic features of these correlates in virtue of which they are correlated to mental states, explaining the connection between the third-person and first-person description, and so on. In this sense, the Newtonian (or Democritean) world-picture does not solve the mind-body problem but still can proceed without such a solution. In actual practice, the Newtonian need only derive from the theoretical apparatus states that correspond to what we take to be the manifest observable structure of the world: a Newtonian derivation of a parabolic trajectory for a thrown rock can be tested in obvious ways in the lab with no notice of conscious states at all. But a more fastidious Newtonian could, for example, trace a set of interactions between the rock and the firing of neurons in the brains of the experimenters that would suffice to underwrite the reliability of the laboratory investigation.

The general ontological picture just adumbrated is by no means popular. The notion that laws of nature are irreducible, for example, has few adherents. Furthermore, when considering the exact nature of the physical state of the universe, I find that I am strongly inclined to a view that strikes many of my colleagues as lunacy. I believe that it is a fundamental, irreducible fact about the spatio-temporal structure of the world that time passes.

Skepticism about the view that time passes (in the sense of that claim that I intend to defend) takes many forms. At its most radical, the skepticism appears as blank bewilderment about what I could possibly mean to say that time passes. Since I take the passage of time to be a fundamental, irreducible fact, there is some difficulty how to respond to this bewilderment. I cannot explain what I mean by paraphrasing or analyzing the notion of time’s passage in terms that do not already presuppose the notion. But the situation is not altogether desperate. I can indicate at least some features of the passage of time that serve to distinguish time from space, and that serve to distinguish this problem from other problems. Usually this is sufficient to convince my interlocutors that whatever it is I believe in, it is something that they do not.

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. Consider, for example, the sequence of events that makes up an asteroid traveling from the vicinity of Mars to the vicinity of the Earth, as opposed to the sequence that makes up an asteroid moving from the vicinity of Earth to that of Mars. These sequences might be ‘matched’, in the sense that to every event in the one there corresponds an event in the other which has the same bodies in the same spatial arrangement. The topological structure of the matched states would also be matched: if state B is between states A and C in one sequence, then the corresponding state B\* would be between A\* and C\* in the other. Still, going from Mars to Earth is not the same as going from Earth to Mars. The difference, if you will, is how these sequences of states are oriented with respect to the passage of time. If the asteroid gets closer to Earth as time passes, then the asteroid is going in one direction, if it gets further it is going in the other direction. So the passage of time provides an innate asymmetry to temporal structure.

In ‘An Attempt to Add a Little Direction to “The Problem of the Direction of Time”’, John Earman describes a view he calls *The Time Direction Heresy* as follows:

It states first of all that if it exists, a temporal orientation is an intrinsic feature of space-time which does not need to be and cannot be reduced to nontemporal features, and secondly that the existence of a temporal orientation does not hinge as crucially on irreversibility as the reductionist would have us believe. (Earman 1974, p. 20)

Earman himself does not unequivocally endorse the Heresy, but does argue that no convincing arguments against it could be found, at that time, in the very extensive literature on the direction of time. Over three decades later, I think that this is still the case, and I want to positively promote the Heresy. The arguments against it that I will consider are largely disjoint from those surveyed by Earman, so this essay can be seen as a somewhat more aggressive companion piece to his. The intrinsic, irreducible temporal orientation of the Heresy corresponds to a specification of the direction in which time passes.

The belief that time passes, in this sense, has no bearing on the question of the ‘reality’ of the past or of the future. I believe that the past is real: there are facts about what happened in the past that are independent of the present

state of the world and independent of all knowledge or beliefs about the past. I similarly believe that there is (i.e. will be) a single unique future. I know what it would be to believe that the past is unreal (i.e. nothing ever happened, everything was just created *ex nihilo*) and to believe that the future is unreal (i.e. all will end, I will not exist tomorrow, I have no future). I do not believe these things, and would act very differently if I did. Insofar as belief in the reality of the past and the future constitutes a belief in a 'block universe', I believe in a block universe. But I also believe that time passes, and see no contradiction or tension between these views.

The inexact use of the phrase 'block universe theory' can systematically distort and confuse discussions of the passage of time. Earman, for example, would cede pride of place to no one in his commitment to a single, four-dimensional relativistic space-time, but for all that he rightly considers that the Heresy could be correct. Here is Huw Price on the terminology:

Often this is called the *block universe view*, the point being that it regards reality as a single entity of which time is an ingredient, rather than as a changeable reality set *in time*. The block metaphor sometimes leads to confusion, however. In an attempt to highlight the contrast with the dynamic character of the 'moving present' view of time, people sometimes say that the block universe is *static*. This is rather misleading, however, as it suggests that there is a time frame in which the four-dimensional block universe stays the same. There isn't of course. Time is supposed to be included in the block, so it is just as wrong to call it static as it is to call it dynamic or changeable. It isn't *any* of these things, because it isn't the right sort of entity—it isn't an entity *in time*, in other words.

Defenders of the block universe deny that there is an objective present, and usually also deny that there is any objective flow of time. (Price 1996, pp. 12–13)

I am one of those unusual defenders of the block universe who does not deny that there is any objective flow of time. The four-dimensional universe is a single entity of which the *passage* of time, in one particular direction, is an ingredient. We will return to Price's objections to this doctrine presently.

The passage of time is deeply connected to the problem of the direction of time, or time's arrow. If all one means by a 'direction of time' is an irreducible intrinsic asymmetry in the temporal structure of the universe, then the passage of time implies a direction of time. But the passage of time connotes more than just an intrinsic asymmetry: not just any asymmetry would produce passing. Space, for example, could contain some sort of intrinsic asymmetry, but that alone would not justify the claim that there

is a ‘passage of space’ or that space passes. The passage of time underwrites claims about one state ‘coming out of’ or ‘being produced from’ another, while a generic spatial (or indeed a generic temporal) asymmetry would not underwrite such locutions.

Not infrequently, the notion of the passage of time is discussed under the rubric ‘time’s flow’, or ‘the moving now’. These locutions tend to be favored by authors intent on dismissing the notion, and certainly subserve that purpose. For time to literally ‘move’ or ‘flow’, they say, there must be some second-order time by means of which this movement or flow is defined, and off we go up an infinite hierarchy of times. Quite so. Except in a metaphorical sense, time does not move or flow. Rivers flow and locomotives move. But rivers only flow and locomotives only move because time passes. The flow of the Mississippi and the motion of a train consist in more than just the collections of instantaneous states that have different relative positions of the waters of the Mississippi to the banks, or different relative positions of the train to the tracks it runs on. The Mississippi flows from north to south, and the locomotive goes from, say, New York to Chicago. The direction of the flow or motion is dependent on the direction of the passage of time. Common locutions speak of time passing and things in time moving or flowing or changing. Given the essential role of the passage of time in understanding the notion of flow or motion or change, it is easy to see why one might be tempted to the metaphor that time itself flows. (Interestingly, there are few examples of extending the notion in the other way: time is the thing that passes. No doubt this is because the passage of time is not explicated by means of any other more primitive notion.) But in order to avoid such confusions, I will stick to saying only that time passes.

My primary aim in this essay is to clear the ground of objections to the notion that time, ‘of itself, and from its own nature, flows equably without relation to anything external’. The phrase, of course, is Newton’s characterization of ‘absolute, true, and mathematical time’ in the Scholium to Definition 8 of the *Principia*, and, properly understood and updated to fit Relativity, I fully endorse it. To forestall some bad objections, I would, myself, replace ‘flows equably’ with ‘passes’, but the basic claim is right on target.

There are three sorts of objections to the passage of time, which we may group as logical, scientific, and epistemological. Logical objections contend that there is something incoherent about the idea of the passage of time *per se*: conceptual analysis can show the idea to be untenable or

problematic. Scientific objections claim that the notion of the passage of time is incompatible with current scientific theory, and so would demand a radical revision of the account of temporal structure provided by physics itself. Epistemological objections contend that even if there were such a thing as the passage of time, we could not know that there was, or in which direction time passes. The second and third groups are not so distinct, and my discussion may run these sorts of arguments together.

For expository purposes, we are fortunate to have a text that touches on all of these sorts of objections. The passage occurs in Huw Price's book *Time's Arrow and Archimedes' Point*, under the heading 'The Stock Philosophical Objections about Time' (Price 1996, pp. 12–16). The heading is apt. These are, indeed, the very objections that arise spontaneously in any discussion of these matters, and, with one exception, they are not original to Price himself. He has, however, done us a service in collecting and presenting them in such a clear way, and I will use his exposition as a guide.

I should also clearly announce my disagreement with Price. It is not that Price thinks these arguments decisively refute the idea of the passage of time while I think that the case is not closed. Price does not consider these arguments decisive, but only relatively strong and plausible:

In making these assumptions [namely that there is a block universe *and* that there is no 'objective flow of time'] I don't mean to imply that I take the arguments for the block universe view sketched above to be conclusive. I do think that it is a very powerful case, by philosophical standards. (Price 1996, p. 15)

In contrast, I think that the arguments rehearsed have no force whatsoever against the existence of an 'objective flow of time', i.e. the view that time, of itself and by its own nature, passes.

## 1. LOGICAL ARGUMENTS

The stock logical objection is presented by Price as follows:

if it made sense to say that time flows then it would make sense to ask how fast it flows, which doesn't seem to be a sensible question. Some people reply that time flows at one second per second, but even if we could live with the lack of other possibilities, this answer misses the more basic aspect of the objection. A rate of seconds per second is not a rate at all in physical terms. It is a dimensionless quantity, rather than a rate of any sort. (We might just as well say that the ratio of the circumference of a circle to its diameter flows at  $\pi$  seconds per second!) (ibid. 13)



I think the ‘more basic’ aspect of this problem is indeed an original contribution of Price. It is, in any case, new to me. Let’s deal with the original objection first.

Let’s begin by considering the logic of rates of change. If something, e.g. a river, flows, then we can indeed ask how fast it flows (how many miles per hour, relative to the banks). To ask how fast a river flows is to ask how far the water in it will have gone when a certain period of time has passed.<sup>5</sup> If the Mississippi flows at 5 mph to the south (and maintains a constant rate), then after an hour each drop of water will be 5 miles further south. It will be 5 miles further from Canada and 5 miles closer to the equator.

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On this basis, if we ask how fast time flows, i.e. how fast time passes, we must mean to ask how the temporal state of things will have changed after a certain period of time has passed. In one hour’s time, for example, how will my temporal position have changed? Clearly, I will be one hour further into the future, one hour closer to my death, and one hour further from my birth. So time does indeed pass at the rate of one hour per hour, or one second per second, or 3,600 seconds per hour ...

What exactly is supposed to be objectionable about this answer? Price says we must ‘live with the lack of other possibilities’, which indeed we must: it is necessary and, I suppose, a priori that if time passes at all, it passes at one second per second. But that hardly makes the answer either unintelligible or meaningless. Consider the notion of a fair rate of exchange between currencies. If one selects a standard set of items to be purchased, and has the costs of the items in various currencies, then one may define a fair rate of exchange between the currencies by equality of purchasing power: a fair exchange of euros for dollars is however many euros will purchase exactly what the given amount of dollars will purchase, and similarly for yen and yuan and so on. What, then, is a fair rate of exchange of dollars for dollars? Obviously, and necessarily, and a priori, one dollar per dollar. If you think that this answer is meaningless, imagine your reaction to an offer of exchange at any other rate. We do not need to ‘live with’ the lack of other possibilities: no objectionable concession is required.<sup>6</sup>

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<sup>5</sup> One of course begins by defining rates of flow in terms of amount of change per unit time, assuming the flow to be constant. For objects whose rates change, like water in a river, the instantaneous flow is the limit as the relevant time approaches zero.

<sup>6</sup> For some reason I cannot quite comprehend, this rather trivial observation has preoccupied several of those who have read this essay. So to be absolutely clear: this is a comment about the concept *fair rate of exchange*. An exchange of dollars for euros such that the amount of dollars does

What of Price's 'more basic' objection? This, I fear, is just a confusion. A rate of one second per second is no more a dimensionless number than an exchange rate of one dollar per dollar is free of a specified currency. Price seems to suggest that the units in a rate can 'cancel out', like reducing a fraction to simplest terms. Any rate demands that one specify the quantities put in the ratio: without the same quantities, one no longer has the same ratio.

Suppose, for example, we are bartering floor tiles for licorice sticks. The agreed rate of exchange might be given in square feet (of tile) for feet (of licorice).<sup>7</sup> We are exchanging square feet of one thing for feet of another. It is simply a mistake to think we can 'cancel out' one of the feet in each quantity and say that the exchange is really in units of feet rather than square feet per foot. Of course, the rate will *transform* like a linear measure if we decide to change units: expressing our barter in terms of square inches of tile for inches of licorice, we multiply square feet by 144 and feet by 12. The real number used to express the ratio (i.e. the real number which stands in the same ratio to unity as the amount of tile stands to the amount of licorice, in the given units) will be multiplied by 12, just as if we were simply transforming a linear measure from feet to inches. But still the units of the barter are square feet per foot, not feet.

Similarly,  $\pi$  is defined as a ratio of a length (of the circumference of a Euclidean circle) to a length (of the diameter). The ratio is length to length: length does not 'cancel out'. There is, of course, also a real number (similarly called  $\pi$ , but don't get confused) that stands in the same ratio to unity as the circumference of a Euclidean circle stands to its diameter. That real number is dimensionless, but it plays no role in the definition of  $\pi$ .

$\pi$  itself is defined independently of any *unit* of length. If one introduces a unit of length, then one can form a fraction whose numerator is the number of units in the circumference of a circle and whose denominator is the number of units in the diameter. This fraction (equal to the real number  $\pi$ ) transforms like a dimensionless number when one changes units: it remains the same, so long as the same units are used for both measures. But still, length is involved in its definition, rather than weight or time or force. And the rate of passage

not have the same purchasing power as the amount of euros is not fair. Similarly, an exchange of some amount of dollars for another amount of dollars that does not have the same purchasing power is not fair. It follows analytically that the fair exchange rate of dollars for dollars is one for one.

<sup>7</sup> The exchange rate might also be given without any standard units at all, as *this much* tile (holding up a tile) to *that much* licorice (holding up a strand).

of time at one second per second is still a rate: it, unlike  $\pi$ , is a measure of how much something changes *per unit time*.

Price also mentions a logical objection to the notion of the *direction* of the passage of time:

If time flowed, then—as with any flow—it would only make sense to assign that flow a *direction* with respect to a choice as to what is to count as a positive direction of time. In saying that the sun moves from east to west or that the hands of a clock move clockwise, we take for granted that the positive time axis lies toward what we call the future. But in the absence of some objective grounding for this convention, there isn't an objective fact as to which way the sun or the hands of the clock are 'really' moving. Of course, proponents of the view that there is an objective flow of time might see it as an advantage of their view that it does provide such an objective basis for the usual choice of temporal coordinate. The problem is that until we have such an objective basis we don't have an objective sense in which time is flowing one way rather than another. (ibid. 13)

This objection demands some untangling.

First, it will help greatly here to insist that properly speaking time passes, rather than flows, and that properly speaking anything that does flow only flows because time passes. The point about directionality of flow is then exactly correct: flows only have a direction because the asymmetry inherent in the passage of time provides temporal direction: from past to future. The natural thing is now to turn Price's Modus Tollens into a Modus Ponens: since there obviously is a fact about how the Mississippi flows (north to south) or how the hands of standard clocks turn (clockwise) there is equally a real distinction between the future direction in time and the past direction. The remark about choosing a convention for the 'positive direction of time' is a red herring: it is, of course, merely a convention that our clocks typically count up (i.e. indicate larger numbers as time passes) rather than count down. Nothing in the nature of the passage of time provides an 'objective basis' for that choice. A society that happens to build clocks that count down rather than up is not making any sort of mistake: attaching numbers to moments of time clearly requires purely arbitrary conventions. One who believes in the objective passage of time does not think there is an objective fact about which sort of clock is counting 'right' and which 'wrong', merely that there is an objective fact about which is counting up and which down. Up-counting clocks show higher numbers in the future direction, down-counting clocks lower numbers. To deny that there is an objective distinction between such

clocks is to deny that there *is* any objective distinction between the future direction and the past, and that is precisely to beg the question.

This exhausts our examination of the logical objections to the passage of time.

## 2. SCIENTIFIC OBJECTIONS

Scientific objections to the passage of time stem from two sources. One is the spatio-temporal structure postulated by the Special and General Theories of Relativity, and the other is the so-called Time Reversal Invariance of the fundamental laws of physics. Let's take these in turn.

Price does bring up the theory of Relativity in this section, but not in the context of discussing the passage of time. He rather brings it up in defense of the block universe view: the view that past, present, and future are all equally real. The opponent of this view wants to give some special ontological status to the present, as opposed to the past or future, and this is hard to reconcile with a Relativistic account of space-time. Since I believe that the past, present, and future are all equally real I have no quarrel with Price here. But there are others who have claimed that the passage of time requires some spatio-temporal structure forbidden by Relativity.

Kurt Gödel, after a description of the familiar 'relativity of simultaneity' in the Special Theory, writes:

Following up the consequences of this strange state of affairs, one is led to conclusions about the nature of time which are very far reaching indeed. In short, it seems that one obtains an unequivocal proof for the view of those philosophers who, like Parmenides, Kant, and the modern idealists, deny the objectivity of change and consider change as an illusion or an appearance due to our special mode of perception. The argument runs as follows: Change becomes possible only through the lapse of time. The existence of an objective lapse of time, however, means (or at least is equivalent to the fact) that reality consists of an infinity of layers of 'now' which come into existence successively. But, if simultaneity is something relative in the sense just explained, reality cannot be split up into such layers in an objectively determined way. Each observer has his own set of 'nows', and none of these various systems of layers can claim the prerogative of representing the objective lapse of time. (Gödel 1949, pp. 557–8)

Gödel then goes on to describe his famous solution to the Einstein field equations, which not only cannot be 'split up into layers' (i.e. foliated into

spacelike hypersurfaces) in a single objective way, it cannot be foliated into spacelike hypersurfaces at all (cf. Hawking and Ellis 1973, p. 170).

So we are left with two questions. First, does the passage of time imply a foliation of space-time, i.e. does it imply that the four-dimensional space-time structure is split into a stack of three-dimensional slices in an observer-independent way? Second, if it does, does this set the notion of passage of time in direct opposition to the account of space-time offered by our best scientific theories?

To the first question, I can find no justification for Gödel's blank assertion that the 'objective lapse of time' is 'equivalent' to the fact that reality is a stack of 'nows'. The passage of time provides, in the first instance, a fundamental objective distinction between two temporal *directions* in time: the direction from any event towards its future and the direction from any event towards its past. If we want to distinguish, for example, an asteroid going from Earth to Mars from an asteroid going from Mars to Earth, what do we need? We may focus completely on the world-line of the asteroid in question. Everyone agrees that one end of the world-line has Earth in the near vicinity of the asteroid, and the other end has Mars in the near vicinity: these facts do not require a foliation of the space-time. Does adding a foliation help *to any degree at all* in determining whether we have an Earth-to-Mars or a Mars-to-Earth trip? No. For even if we were to add the foliation, the crucial question of which events come first and which later would be unsettled. So the 'lapse of time' cannot be equivalent to the existence of a foliation.

Perhaps the 'lapse of time' is a foliation *plus* a specification of what the past-to-future direction is? This will certainly allow us to distinguish two trips from each other- but it is the direction, not the foliation, that is doing all the work. Give me the past-to-future direction and I'll tell you where the asteroid is going without reference to any foliation at all.

In a fully relativistic space-time, the obvious mathematical gadget one needs to distinguish one direction in time from another is not a foliation but an *orientation*. All relativistic models already employ orientable space-times: space-times in which the light-cones are divided into two classes, such that any continuous timelike vector field contains only vectors that lie in members of one of the classes. In order to account for the direction of flows or other motions, all we need to do is to identify one of these classes as the *future* light-cones and the other as the *past* light-cones. Once I know which set is which, I can easily distinguish a Mars-to-Earth asteroid from an Earth-to-Mars one. (See Earman 1974, section 2 for a more exact mathematical discussion.)

Having said that a foliation is not required for there to be a lapse of time, one should note that a foliation may well be forced upon us for purely physical reasons. In particular, although neither Special nor General Relativity posits a foliation of space-time, the only coherent, precise formulations of quantum theory we have seem to demand it, and the observed violations of Bell's inequality are very difficult to account for without the resources of such a foliation.<sup>8</sup>

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What then of an orientation? Is that something which physics alone can do without, which is being added to our account of space-time for merely 'philosophical' reasons? Is it, further, something that would sit uneasily with the spatio-temporal structure posited by physics alone?

The treatment of this question is one of the most peculiar in the philosophical literature. The usual approach sets the problem as follows: the fundamental physical laws have a feature called 'Time Reversal Invariance'. If the laws are time reversal invariant, then it is supposed to follow that physics itself recognizes no directionality of time: it does not distinguish, at the level of fundamental law, the future direction from the past direction, or future light-cones from past light-cones. Therefore, it is said, any such distinction must be grounded not in fundamental law, or in the intrinsic nature of the space-time itself, but in contingent facts about how matter is distributed through space-time. The direction of time, we are told, is nothing but (e.g.) the direction in which entropy increases. The philosophical puzzle is then how to relate various other sorts of temporal asymmetry (the asymmetry of knowledge, or of causation, or of control) to the entropic asymmetry. Paul Horwich's *Asymmetries in Time* (1987) provides an example of this form.

This problematic is peculiar because it fails at every step. To begin with, the laws of physics as we have them (even apart from worrying about a coherent understanding of quantum mechanics) are not Time Reversal Invariant. The discovery that physical processes are not, in *any* sense, indifferent to the direction of time is important and well known: it is the discovery of the violation of so-called CP invariance, as observed in the decay of the neutral K meson. These decays are *not* invariant if one changes a right-handed for a left-handed spatial orientation (parity) and changes positive for negative charge (charge conjugation). According to the CPT theorem, any plausible quantum theory will be invariant under parity-plus-charge-conjugation-plus-time-reversal, so the violation of CP implies a violation of T. In short, the fundamental laws of physics, as we have them, *do* require

<sup>8</sup> See my 1994 and 1996 for details.

a temporal orientation on the space-time manifold. So the argument given above collapses at the first step.

How do philosophers respond to this difficulty? Horwich, having noted the problem, writes:

However, this argument is far from airtight. First, the prediction has not been directly confirmed. And, even if it were true, it could turn out to be a merely *de facto* asymmetry, which does not involve time-asymmetrical laws of nature. Moreover neither the experimental nor the theoretical assumptions involved in the prediction are beyond question. For the frequency difference between the two forms of neutral K meson decay is not substantial and will perhaps be explained away. Anyway, the assumption that these processes are spatial mirror images may turn out to be false ... Finally, the so-called 'CPT theorem', though plausible, may be false. Since there are so many individually dubious assumptions in the argument, we may regard their conjunction as quite implausible. (Horwich 1987, p. 56)

There is a certain air of desperation about this passage. There is no dispute in the physics community about the reality or implications of this effect: Nobel prizes have been awarded both for the theoretical work and for the experimental verification of the effect. Insofar as philosophers of physics are looking for actual scientific results to base ontological conclusions on, this is a clear case of the science testifying in favor of a temporal orientation. The only plausible reason for Horwich suddenly to turn skeptical is that the failure of T invariance spoils his argument.

There is a somewhat better response available. That would be to admit that the laws of physics are not Time Reversal Invariant, and that there is, indeed, a physical orientation to space-time, but to insist that the physical processes sensitive to this orientation (like neutral kaon decay) are too infrequent and exotic to explain the widespread and manifest distinction between the past direction and the future direction that we began with. We will examine the plausibility of this response in due course. But we should at least acknowledge that the admission of an orientation to space-time is not, *per se*, wildly at odds with present physical theory since present physical theory already admits one.

But let's set aside the observed violations of CP invariance. Even apart from these, it is not at all clear that the accepted laws of physics are Time Reversal Invariant *in a way that suggests that there is no intrinsic direction of the passage of time*. This point has been well argued by David Albert in his *Time and Chance* (2000, chapter 1). Here's the problem. The way that time reversal has been understood since the advent of electromagnetic theory is not: for every physically allowed sequence of instantaneous states, the same

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set of states in the reverse time order is also physically allowed. This can plausibly be argued to hold for Newtonian mechanics,<sup>9</sup> but beyond that one needs to do more than simply reverse the time order of the states: one has to perform a ‘time reversal’ operation on the instantaneous states themselves. So the theorem is now: for every physically allowable sequence of states, the inverse sequence of *time-reversed* states is also physically allowable. More precisely: if states  $T_0, T_1, T_2, \dots, T_N$  are physically allowable *as time runs from  $T_0$  to  $T_N$  in some direction*, then the sequence  $T_N^*, \dots, T_2^*, T_1^*, T_0^*$  is also allowed, where the  $*$  represents the time reversal operation as applied to the states, and where time runs from  $T_N^*$  to  $T_0^*$  in the same direction as it runs from  $T_0$  to  $T_N$ . As stated, this result does not even suggest that time fails to have a direction at all. Indeed, the necessity of invoking the time reversal operation on instantaneous states suggests just the opposite: it suggests that even for an instantaneous state, there is a fact about *how it is oriented with respect to the direction of time*.

Given certain facts about the time reversal operator (in particular, given that particle positions or field values do not change under the operation), Time Reversal Invariance, as stated above, is still a very important feature of physical laws. For, as Albert insists, this sort of Time Reversal Invariance implies that *in a certain sense* anything that happens in the universe can, as a matter of physical principle, happen ‘in reverse’: if ice cubes can melt into puddles, then puddles can spontaneously freeze back into ice cubes, for example. But notice that this sense of ‘in reverse’, far from delegitimizing the passage of time, presupposes it: the melting of an ice cube ‘in reverse’ requires that the puddle stage *precede* the ice cube stage. So to get from Time Reversal Invariance of the laws (in this sense) to the objective *absence* of a direction of time would require some extensive philosophical argumentation in any case.

Finally, let’s even set Albert’s objections aside. That is, let’s suppose that we can understand the time reversal operation without there being an objective direction with respect to which the reversal occurs, let’s suppose that the fundamental laws of nature make no distinction between the past direction and the future direction of time. Would it even now follow unproblematically that, as far as physics is concerned, there is no direction of time, no distinction between the past-to-future and future-to-past directions?

<sup>9</sup> One has to be clear about what it means for a state to be instantaneous: instantaneous states, for example, do not include *velocities* of particles, or, more generally, the rate-of-change-with-time of any quantity. See Albert’s discussion.



If *all* that physics ever appealed to in providing accounts of physical phenomena were the dynamical laws, then we would seem to have a straightforward Ockham's Razor argument here. But the laws of nature *alone* suffice to explain almost nothing. After all, it is consistent with the laws of physics that the universe be a vacuum, or pass from the Big Bang to the Big Crunch in less time than it takes to form stars. The models of fundamental physical law are infinitely varied, and the only facts that those laws *alone* could account for are facts shared in common by all the models. In all practical cases, we explain things physically not merely by invoking the laws, but also by invoking *boundary conditions*. So to argue that the direction of time plays no ineliminable role in physics demands not only a demonstration that no such direction is needed to state the laws, but that no such direction plays any role in our treatment of boundary conditions either. But this latter is far from obvious. We will return to this point towards the end of this essay.

### 3. EPISTEMIC OBJECTIONS

Let's return for the moment to the violation of CP invariance displayed in neutral kaon decay. We noted above that this phenomenon seems to imply that the laws of nature are not Time Reversal Invariant in any sense, and hence that the laws themselves require an intrinsic asymmetry in time directions, and hence that space-time itself, in order to support such laws, must come equipped with an orientation. But one might still object that this orientation (let's call it Kaon Orientation) has nothing to do with the supposed large-scale and manifest asymmetry involved in the passage of time. For it is only in rather special and recondite circumstances that Kaon Orientation manifests itself, while the passage of time is evident and ubiquitous. More directly, even if there is an intrinsic Kaon Orientation to space-time, in most normal circumstances we would not be in a position to determine what it is.

We can call this sort of objection an epistemic objection: it does not directly deny the logical or physical acceptability of the existence of a fundamental temporal asymmetry, but insists that even if such an asymmetry is postulated, we would not be able to tell what it is. In the case of the Kaon Orientation, the objection is merely practical: kaon decay experiments (or other physical phenomena whose outcomes depend on the Kaon Orientation) are relatively rare and inaccessible. But the epistemic objection can be raised in an even

more thoroughgoing and radical manner, in a form which, if valid, would make the passage of time epistemically opaque even if physically real.

Price raises the objection in one way, D. C. Williams in another. Let's begin with Price's formulation:

In practice, the most influential argument in favor of the objective present and the objective flow of time rests on an appeal to psychology—to our own experience of time. It seems to us that time flows, the argument runs, and surely the most reasonable explanation of this is that there is some genuine movement of time which we experience, or in which we partake.

Arguments of this kind need to be treated with caution, however. After all, how would things seem if time didn't flow? If we suppose for the moment that there is an objective flow of time, we seem to be able to imagine a world which would be just like ours, except that it would be a four-dimensional block universe rather than a three-dimensional dynamic one. It is easy to see how to map events-at-times in the dynamic universe onto events-at-temporal-locations in the block universe. Among other things, our individual mental states get mapped over, moment by moment. But then surely our copies in the block universe would have the same experiences that we do—in which case they are not distinctive of a dynamical universe after all. Things would seem this way, even if we ourselves were elements of a block universe. (Price 1996, pp. 14–15)

The short diagnosis of the foregoing is that it is an argument by 'surely': Price simply asserts that the crucial conclusion follows from his premisses even though it is by no means evident that it does. The point can perhaps be made more clearly if we switch to the form that Williams uses.

That form begins by granting that there is a direction of time, so the past-to-future direction differs from the future-to-past direction. But now the observation is made that we also accept the Time Reversal Invariance (let's set aside the kaon interactions as irrelevant here) as stated above: for any physically possible sequence of states  $T_0, T_1, \dots, T_N$  running from past to future, there is a physically possible sequence  $T_N^*, \dots, T_1^*, T_0^*$  running from past to future. For example, given the actual sequence of physical states of your body over the last ten minutes, the time-reversed sequence of time-reversed states is also physically possible. Somewhere on some other planet (as far as the laws of physics go) some such sequence could exist, unproblematically time reversed relative to the sequence of states that make you up. Let's call this sequence of states your *time-reversed Doppelgänger*. But, the objection goes, there is an obvious one-to-one mapping from the Doppelgänger's states to yours. So the Doppelgänger would *surely* have qualitatively identical

experiences to yours, only with the whole process oppositely oriented in time. Here is Williams's description:

It is conceivable too then that a human life be twisted, not  $90^\circ$  but  $180^\circ$ , from the normal temporal grain of the world. F. Scott Fitzgerald tells the story of Benjamin Button who was born in the last stages of senility and got younger all his life till he dies a dwindling embryo. Fitzgerald imagines the reversal to be so imperfect that Benjamin's stream of consciousness ran, not backward with his body's gross development, but in the common clockwise manner. We might better conceive a reversal of every cell twitch and electron whirl, and hence suppose that he experienced his own life stages in the same order as we do ours, but that he observed everything around him moving backward from the grave to the cradle.<sup>10</sup> (Williams 1951, p. 113)

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If we accept that the relevant physics is Time Reversal Invariant, then we accept that your time-reversed Doppelgänger is physically possible. Let's suppose, then, that such a Doppelgänger exists somewhere in the universe. What should we conclude about its mental life?

The objector, of course, wants to conclude that the mental state of the Doppelgänger is, from a subjective viewpoint, just like ours. So just as we judge the 'direction of the passage to time' to go from our infant stage to our gray-haired, so too with the Doppelgänger. But that direction, for the Doppelgänger, is oppositely oriented to ours. So the Doppelgänger will judge that the temporal direction into the future points opposite to the way we judge it. And if we insist that there is a direction of time, and we know what

<sup>10</sup> This particular conceit, that a time-reversed person would *see* the world around him as if it were a movie shown backwards, is not supported by any physical considerations of time reversibility. Presumably, if your time-reversed Doppelgänger experiences anything at all, it will be a subjectively indistinguishable experience from your present one: the experience of things happening in their accustomed order. The question of whether it would even be physically possible for the Doppelgänger to interact with a non-time-reversed environment (or, equivalently, whether we could physically interact with a time-reversed environment which contained puddles constituting themselves into ice cubes) to allow for *perception* of that environment is a tricky technical question. The problem arises since the entropy gradient in the environment has to be oppositely oriented from the entropy gradient in the observer, and it is not clear whether these can be made to mesh, or, if they do, whether the meshing condition produces what would normally be called perception. Perception typically suggests a wide array of counterfactual dependence so that the mental state of the observer would track the state of the environment over a range of possible variations. The entropy meshing might require that the brain state of the observer and the state of the environment be exquisitely fine-tuned to each other, preventing such counterfactual resilience. In any case, the brain state of someone watching a movie being run backward is not the time reverse of the brain state of someone watching the original sequence of events, and the time reverse of the optical array produced by a melting ice cube is not the same as the optical array produced by the backward-running movie of the melting, so simple time reversal arguments cannot establish under what conditions one would be able to see a time-reversed melting ice cube.

it is, then we must say that the Doppelgänger is deceived, and has mistaken the direction of time. But now we become worried: the Doppelgänger seems to have exactly the same *evidence* about the direction of time as we do. So how do we know that (as it were) *we* are not the Doppelgängers, that *we* are not mistaken about the direction of time? If there *is* a direction of time, it would seem to become epistemically inaccessible. And at this point, it seems best to drop the idea of such a direction altogether. But is this correct?

In order to facilitate the discussion, I will refer to corresponding bits of the Doppelgänger with a simple modification of the terms for parts of the original person. For example, I will speak of the Doppelgänger's neuron\*s: these are just the bits of the Doppelgänger that correspond, under the obvious mapping, to the original's neurons. We can unproblematically say that the Doppelgänger's neuron\*s fire\*, meaning that they undergo the time reverse of the process of a normal neuron firing. It *may* be that neuron\*s can be properly called neurons and the firing\* may be properly called firing, but we do not want to presuppose that at the outset, so one must remain alert to the asterisks.

So the first question is: given the physical description of the Doppelgänger that we have, what can we conclude about its mental state? The answer, I think, is that we would have no reason whatsoever to believe that the Doppelgänger has a mental state at all. After all, the physical processes going on in the Doppelgänger's brain\* are quite unlike the processes going on in a normal brain. Nerve impulse\*s do not travel along dendrites to the cell body, which then fires a pulse out along the axon. Rather, pulses travel up the axon\* to the cell body\*, which (in a rather unpredictable way) sends pulses out along the dendrite\*s. The visual system\* of the Doppelgänger is also quite unusual: rather than absorbing light from the environment, the retina\*s emit light out into the environment. (The emitted light is correlated with the environment in a way that would seem miraculous if we did not know how the physical state of the Doppelgänger was fixed: by time-reversing a normal person.) There is no reason to belabor the point: in every detail, the physical processes going on in the Doppelgänger are completely unlike any physical processes we have ever encountered or studied in a laboratory, quite unlike any biological processes we have ever met. We have *no reason whatsoever* to suppose that any mental state at all would be associated with the physical processes in the Doppelgänger. Given that the Doppelgänger anti-metabolizes, etc., it is doubtful that it could even properly be called a living organism (rather than a living\* organism\*), much less a conscious living organism.

Now the response is likely to chime in: the Doppelgänger's physical state is not unfamiliar: it is *just like ours* save for the direction of time. That is so: but the difference is no minor one. It turns emission into absorption, normal metabolic processes into weird and unexampled anti-thermodynamic ones.

No, no, the response insists: since the gradient of the entropy (or whatever) has been reversed, *the direction of time itself has been reversed*, and, oriented to the thus-defined direction of time, the physical processes are just like normal ones. This response, of course, has a name: *petitio principii*. The aim of the argument is to *show* that there is no intrinsic direction to time, but only, say, an entropy gradient. But it achieves its aim only if we are convinced that the Doppelgänger has a mental state 'just like ours', and the only way to make that claim even vaguely plausible is to assert that the Doppelgänger's *physical* state is not, in any significant sense, time reversed (relative to any physically significant direction of time) at all. And that is precisely to beg the question.

Having worked through the response to Williams, the response to Price is even starker. He imagines a Doppelgänger that is not just reversed in time, but a Doppelgänger in a world *with no passage of time at all*, i.e. (according to his opponent) in a world in which there is no time at all, perhaps a purely spatial four-dimensional world. So it is not just that the nerve pulse\*s of this Doppelgänger go the wrong way (compared to normal nerve pulses), these nerve pulse\*s don't go anywhere at all. *Nothing* happens in this world. True, there is a mapping from bits of this world to bits of our own, but (unless one already has begged the central question) the state of this world is so unlike the physical state of anything in our universe that to suppose that there are mental states at all is completely unfounded. (Even pure functionalists, who suppose that mental states can supervene on all manner of physical substrate, use temporal notions in defining the relevant functional characterizations. Even pure functionalists would discern no mental states here.)

All the participants in this debate accept the supervenience of the mental on the physical. If you believe in the passing of time, then that is among the relevant physical characteristics of the subvenience base. To simply suppose that it is not, that the character of mental states cannot possibly depend on how time is passing for the brain states, and to disguise this critical assumption with no more than an offhand 'surely', is to miss the nature of the dispute altogether.

Up to now, we have been considering only the following question: given that we regard the time-reversed Doppelgänger as physically possible, what should we conclude about the mental state (if any) that such a Doppelgänger

would have. There is, however, another slightly different argument in the neighborhood that needs to be carefully distinguished from this one. This argument goes as follows: suppose you were to *actually find* or have *strong evidence for the existence of* some such Doppelgänger (on a distant planet, say), then would that not change your view about the objective passing of time?

This is quite a different matter. It is perhaps too flippantly posed: it might not even be *physically possible* to ‘find’ (i.e. observe or encounter) such a Doppelgänger if there were one (see footnote 5 above): the *light* that would enter our eyes from such a Doppelgänger would not, for example, be correlated with the shape or movements of the Doppelgänger, and it is unclear what other sort of evidence could convince us of its existence. But if we *were* somehow convinced of its existence, what would we conclude?

If we stick to the idea that time passes, and that the Doppelgänger really is a time-reversed copy of a normal person, then, as argued above, we would have no reason to suppose it conscious, or to speculate on the content of its mental states if it were conscious. But quite apart from its mental states, the Doppelgänger would behave in a radically anti-thermodynamic way (relative to our time direction), and there would be correlations between the Doppelgänger and its environment which we would judge, although physically possible, to be wildly unlikely and conspiratorial. That is, physics as we presently practice it would regard the Doppelgänger as a physical possibility of a sort almost unmeasurably unlikely ever to occur. So if we were to actually *find* or to *come to believe in the reality* of such a thing, we would have very good reason to *revisit* our physical theory, including any views we might have about the passage of time. Perhaps (but who knows?) I would abandon my views about the passage of time in favor of a different view, according to which the existence of such a Doppelgänger is not so unlikely. But just because I regard the Doppelgänger as physically possible, and think that the existence of such a Doppelgänger would provide good reason to revise my views on the nature of time, it does not follow that I have reason to regard my views *now* (in the absence of evidence of a Doppelgänger) as impeached. Nor is this a good inference: I regard the Doppelgänger as physically possible, and I would regard a Doppelgänger as good reason to reject an absolute passage of time, therefore I regard the absence of absolute passage as *physically possible*. If there is passage, a Doppelgänger may be possible- a physically possible but *evidentially misleading* object. An analog: even given a purely local stochastic physics, it is possible to observe violations

of Bell's inequality in a laboratory (because of an objectively *very unlikely* set of outcomes). Were those outcomes to occur, it would be rational to reject the purely local physics. But it does not follow that the purely local physics underwrites the *physical possibility* of non-locality, just the physical possibility of evidence that rationally leads us incorrectly to accept non-locality.

So none of the arguments for the epistemic inaccessibility of the direction of the passage of time goes through without already begging the question at hand. And having exhausted the logical, the scientific, and the epistemic arguments, there are no stock arguments left. The usual philosophical arguments, which have induced Price and Williams and many others to reject an objective passage of time, have no force whatsoever.<sup>11</sup>

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#### 4. THE CASE IN FAVOR OF THE PASSING OF TIME

The failure of the stock arguments against the passing of time does not *per se* constitute a positive argument in favor of the claim that time passes. What, then, can be said in defense of the claim that time, in its own nature, passes?

I do not have much that is original to offer here, so presenting the positive case is mostly an organizational task. It will be helpful in presenting the case to divide the opponents of the passing of time into two camps, and to deal with them in turn. We may denominate the two camps the *conciliatory* opponents and the *in-your-face* opponents.

Gödel, as cited above, is an archetypal in-your-face opponent. The absence of an objective passing of time, according to Gödel, means that Parmenides, Kant, and the modern idealists were right when they considered 'change as an illusion or an appearance due to our special mode of perception'. Physical

<sup>11</sup> There is one famous source of arguments against the passage of time that I have not mentioned: that of J. M. E. McTaggart (1927, chapter 33). The reason is that this argument is a mare's nest of confusions, the proper use of which is to give to students with instructions like 'Find the fallacy of composition' and 'Explain why McTaggart's response to Russell is question-begging'. But since the terminology *A series theory of time* and *B series theory of time* have crept into the literature, let me make some comments. The theory of time's passage I defend focuses on the *B* series: all events are ordered by a transitive, asymmetrical relation of earlier and later. Given events ordered in a *B* series, one can define an infinitude of *different A* series that correspond to taking different events as 'now' or 'present'. McTaggart's argument is marred throughout by his use of the phrase 'the *A* series' when there are, in fact, an infinitude of such. Any theory that denies a fundamental asymmetric relation of earlier than (or later than), and hence denies an intrinsic direction of time, ought not to be called a *B* series theory but rather a *C* series theory. So I am not arguing for an *A* series theory over a *B* series theory, I am arguing for a *B* series theory over a *C* series theory, and get the many *A* series for free.

reality, as it is apart from conscious beings, contains no change at all. Rivers, in themselves and apart from our representations of them, do not flow; stars, in themselves and apart from our representations of them, do not collapse; atoms do not radiate; and so on. Change is an illusion in the same way that the apparent comparative size of the moon at different positions in the sky is an illusion: not even an optical trick, like the apparent bending of a stick in water (which has an explanation in terms of the behavior of light), but a product solely of the cognitive machinery of humans. According to the in-your-face opponent, outside of human (or other conscious) beings, there is nothing that corresponds to change at all. And in a world without change, there is surely no need for the passage of time.

The response to the in-your-face opponent is straightforward. We ought to believe that there is objective change because (1) the world is everywhere and always presented to us as a world in which things change, (2) change appears to affect all physical things and (unlike, say, pain) not to be a feature of only a small, select group of objects, and (3) there are no good arguments to suggest that this change is illusory. That is, the basic approach to ontology is always to start with the world as given (the manifest image), and then adjust or adapt or modify or complicate that picture as needed, under the pressure of argument and observation. But neither argument nor observation suggests that things do not change in the mind-independent world, so we ought to think that they do.

Another way to put the response is this: why should we think that the physical world has temporal extension (apart from the ‘direction of time’) at all? Why think that it has a spatial aspect, or spatial extension? Kant, of course, denied these as well, as did Parmenides and the modern idealists. But no contemporary ‘analytical’ philosopher, people like Price or Horwich or Sklar or Albert or Williams or Earman—in short, no one who takes modern physics as the touchstone for ontology—denies that the physical world, in itself, has spatio-temporal extension. But why believe *that*? Presumably because that is how the world is, in the first place, presented to us and because our further investigations—both logical and scientific—have not given us any grounds to question it. So too for the reality of change.

The conciliatory opponent, on the other hand, does not claim that change is mere illusion or appearance. The conciliatory opponent is happy to say that things change, that rivers flow, that stars collapse, and that their doing so does not depend in any way on human modes of perception or consciousness. The conciliatory opponent simply wants to insist that such objective,



mind-independent change does not require that there be any objective, mind-independent, *intrinsic* passage of time. The attempt to analyze change without the passage of time proceeds in two steps.

The first step is exemplified in this passage from Williams:

Motion is already defined and explained in the dimensional manifold as consisting of the presence of the same individual in different places at different times. It consists of bends or quirks in the world line, or the space-time worm, which is the four-dimensional totality of the individual's existence. (Williams 1951, pp. 104–5)

According to Williams, the motion of the asteroid from Earth to Mars is just a matter of the asteroid being differently situated with respect to those planets at different times or, to take an easier case of change, my losing weight is just a matter of my space-time worm being thicker at one end than at another. Since these are objective, mind-independent facts about space-time worms, the changes are equally objective and mind-independent.

The rub, of course, is that the asteroid being differently situated at different times is consistent both with a motion from Earth to Mars and with a motion from Mars to Earth, and my space-time worm being thicker at one end than at another is as likely to indicate my gaining weight as my losing it. Motions and changes are not merely a matter of things being different at different times, but also critically a matter of which of these times are *earlier* and which *later*. To preserve a form of 'change' that cannot distinguish losing weight from gaining it is not to preserve change at all, so this attempt at reconciliation fails.

The conciliatory opponent is not done. The next step is to admit that some objective correlate to *earlier* and *later* must be found, so weight loss can be distinguished from weight gain, but to deny that this 'direction of time' need be a matter of the passage of time itself. An arrow must be provided, but the resources exist without adding anything intrinsic to the (undirected) spatio-temporal structure. Rather, the direction from earlier to later is nothing but, e.g., the direction of increasing entropy. You are losing weight if the universe at the thin end of your space-time worm has a higher entropy than the universe at the thick end, and the asteroid is traveling from Earth to Mars if the entropy at the Mars end of the trip is higher than the entropy at the Earth end. If there is no difference in the entropy (e.g. if the universe is in thermal equilibrium), then there is no longer a distinction between Earth-to-Mars and Mars-to-Earth trips. But we have never had any acquaintance with situations in complete thermal equilibrium, and there may

never be such situations, and even if there were, we could not experience them (since our own operation demands an entropy gradient), so the account is adequate to everything we ever have experienced or will experience.

This sort of conciliatory opponent seems to have Ockham's Razor as a weapon. After all, the Second Law of Thermodynamics says that entropy never decreases. As stated, this appears to be a contingent rule relating the entropy gradient to the direction of time (as implicit in the word 'decrease'). But why not turn the 'law' instead into an implicit *definition* of the direction of time: entropy never decreases because if the entropy gradient is not zero, then the forward direction of time *just is* the direction in which entropy gets larger! Our fundamental ontology is reduced (we no longer have *both* an entropy gradient *and* a direction of time), and the resulting definition of the direction of time is materially adequate, since we *do* think that entropy never decreases.

There are, however, several objections to this procedure. First, the reinterpreted 'Second Law' no longer has the *content* of the original. The original supposed that there is a direction of time- represented by an orientation on the space-time manifold- and that entropy never decreases *relative to that orientation*. That is, the original implied that the direction of entropy increase would always be the same, that entropy would ever increase (or at least not decrease) in a given, globally defined, direction. The new 'Law', as an implicit definition, puts no constraints on the shape of the global entropy curve at all. Entropy could go up and down like the stock market, but since the 'direction of time' would obligingly flip along with the entropy changes, entropy would still never decrease. And since we *don't* think that the entropy curve fluctuates in this way, the original has explanatory power that the reinterpreted version lacks.

(There is an interesting parallel here to those practitioners of analytical mechanics who want to take  $\mathbf{F} = m\mathbf{A}$  to be a definition of force rather than a law of nature, as Newton had it. This too reduces one's ontology, but at the price of seriously distorting the content of the scientific theory. Newton certainly did not take his law to be a definition, and nor do we- since we no longer accept it. Further, under some very mild assumptions (e.g. that the masses of bricks do not change when different springs are attached to them, and the forces produced by springs do not change when they are attached to different bricks) Newton's Second Law has testable implications, and could be experimentally refuted.)

The situation gets even worse once thermodynamics is subsumed under statistical mechanics, for then the Second Law is no longer taken to be

nominally guaranteed. Global entropy *could* decrease, and even has a calculable chance of doing so, and certainly will do so if we wait long enough; and local entropy, due to random fluctuations, decreases (if briefly) all the time. So the original Ockham's Razor argument—since the anisotropy of entropy increase and the anisotropy of the passage of time always coincide, why not be economical and identify them?—loses all of its force.

But let's put all that aside. Let's grant, for the moment, that entropy strictly increases monotonically throughout the history of the universe. And let's further grant (setting aside actual physics) that the fundamental laws of nature are completely Time Reversal Invariant, and can be stated without reference to any directionality in time. Would all that suffice to rationally compel us to *identify* the passage of time with the increase in entropy?

I do not think so. For simplicity, let's assume that the Time Reversal Invariant laws are deterministic, like Newtonian mechanics or classical electromagnetic theory. Then, as noted above, the total state of the world is accounted for not merely by reference to the laws, but by reference to the laws and the boundary conditions (let's not yet say *initial* conditions) of the universe. And the mathematical character of these boundary conditions, relative to the laws, is very particular. Let's assume that there are boundary conditions in the past (the Big Bang), in the future (the Big Crunch), and at the spatial limits (if the universe is not spatially closed). Now one is not free to arbitrarily specify boundary conditions along *all* of these boundaries and then to expect there to be a solution that respects the laws everywhere in the interior. Rather (leaving the problem of the spatial boundaries out for a moment), one is (relatively<sup>12</sup>) free to specify whatever conditions one likes on one of the boundaries, and then there will typically be a unique global solution to the laws that determines the conditions on the other boundary. And of course, when providing explanations and accounts of things, what we actually do is specify the state on the *initial* (i.e. earliest) boundary, and regard the state in the interior and on the final boundary to be *explained* or *produced* from the initial conditions and the operation of the laws through time.

The world might not have been this way. We could imagine deterministic laws of such a form that one could freely specify boundary conditions on all the boundaries of a system and be assured of a unique global solution

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<sup>12</sup> There may be certain constraints on the initial boundary conditions, having to do with charges and divergences of fields and so on, but these are of a different character than the problem we are presently discussing.

consistent with those conditions. It is a stunning, and contingent, fact that the laws- or the best approximations to the laws that we have been able to discover so far- have the mathematical form just described. And all this holds *even if the laws themselves are completely time reversible in whatever sense one might choose.*

This particular form of the laws of nature leads us into an asymmetrical treatment of the boundary conditions of the universe. It seems that given one set of boundary conditions together with the laws of nature we are able to adequately account for the other set of boundary conditions as well as the complete contents of the universe. Among the contents so explained is, of course, the global increase of entropy (insofar as it holds). So we have the following situation: if the asymmetrical treatment of the ‘initial’ and ‘final’ boundary conditions of the universe is a reflection of the fact that time passes *from* the initial *to* the final, then the entropy gradient, instead of explaining the direction of time, is explained by it.

The asymmetrical treatment of the boundary conditions of the universe is well known: we think that the universe started off in a macroscopically atypical but microscopically typical state (relative to a natural measure on the phase space of the universe), and that it will end in a macroscopically typical (or more typical) but microscopically atypical state. The ‘initial’ state is macroscopically atypical in that it has extraordinarily low entropy, but microscopically typical in that temporal evolution from it leads to higher entropy. The ‘final’ state is macroscopically typical, in that it has high entropy, but microscopically atypical in that temporal evolution from it (‘backwards in time’ as we would say) leads immediately and monotonically to lower entropy. Now one could try to deny that this sort of asymmetry in boundary conditions actually obtains (Price approvingly flirts with the idea of a ‘Gold universe’ which has low entropy at both ends), but every result we have from empirical enquiry suggests that this is how the universe is.

Since we cannot explain any of the actual contents of the universe by reference to the laws alone, we either have to abandon any such explanation or try to bring boundary conditions into such an explanation. But, as we have seen, if we are to posit constraints on boundary conditions, we had best not apply those constraints to *all* the boundaries, since it is typically not the case that the laws are consistent with constraints on all the boundaries. Rather, we seem to need only constraints on *one* boundary, together with the laws, to get us the universe. So the only question left is: which boundary should be subject to constraints, and what, if anything, does the selection of that boundary suggest about the passage of time?

One might think that although the two boundaries are treated differently, there is still a sort of explanatory symmetry between them. That is: postulate a macroscopically atypical but microscopically typical state, plus the laws, and one can explain the macroscopically typical but microscopically atypical state from them: the latter was generated from the former by means of the operation of the laws. But equally: postulate a macroscopically typical but microscopically atypical state at one end, plus the laws, and one can ‘generate’ a macroscopically atypical but microscopically typical state from them. Pick one end, add the laws, and you can explain the other end: which end you pick as *explanans* and which as *explanandum* is up to you.

But this supposed symmetry is illusory. The problem is this: in order to account for the universe as we see it, we need more than the laws: we need a constraint on one of the boundaries. That constraint, together with the operations of the laws, then suffices to account for the nature of the other boundary. But in order for this to work *the constraint must itself be specifiable independently of what will result from the operation of the laws*. A homely example: we want to explain the occurrence of an earthquake in terms of the preceding state of the underlying geology and the dynamics that governs them. This works fine so long as the precedent state is described in terms like pressures and fissures and plate movements and so on, terms that can be plugged into the laws to determine how the system will evolve. It does *not* work as an explanation if the only characterization one provides of the underlying geology is ‘in a state such as to lead to an earthquake in the near future’. Explaining the occurrence of the earthquake in these terms is clearly empty.

But exactly this sort of thing occurs if we take one of the boundary constraints as the basis (together with the laws) of the explanation of the other. For despite the surface similarity, the terms ‘macroscopically atypical’ and ‘microscopically atypical’ as used above have a completely different logic.

The initial state of the universe is macroscopically atypical in a way that can be completely characterized without any mention of the details of its dynamical evolution. The initial macrostate is atypical because it has low entropy, i.e. because it occupies (relative to the natural measure) a very very very small volume of phase space. One can characterize this atypicality without any mention at all of how such a state will evolve. The final state, however, is microscopically atypical in a way that can *only be characterized in terms of how the state will ‘evolve’ though time*. It is microscopically atypical because temporal evolution in one direction from it will lead, over a very

long period of time, to monotonically lower entropy. A generic microstate (relative to the natural measure over phase space) leads to higher (or constant) entropy whichever way one time evolves from it in accordance with the laws. The initial state is unusual in what it *is*, while the final state is unusual only in what it will *become* (in a generic sense of 'become' which covers backward evolution).

So if we want to explain the world as we see it- including the ubiquitous entropy gradient around us- this seems like a viable strategy: postulate in addition to the dynamical laws of nature a logically independent constraint on the initial state of the universe- that it have low entropy- and nothing else. On the assumption (and it is a big assumption, but one that we constantly make) that typical conditions (relative to the natural measure) require no further explanation, we would then expect a world of constantly increasing entropy, as we see. The world should evolve towards ever higher entropy, with the states always retaining the following peculiarity: their time reverses lead to lower, rather than higher entropy. But the 'peculiarity' is completely accounted for: time reverses of the states lead to lower entropy because the states themselves arose out of lower entropy. In particular, the microscopic atypicality of the final state is completely accounted for by *how it was generated or produced*.

But we cannot run this trick in reverse. Even though the laws themselves might run perfectly well in reverse, even though the time reverse of the final state might give rise to the time reverse of the initial state, we cannot specify an independent, generic constraint on the final state that will yield (granting the final macrostate is typical) ever decreasing entropy in one direction. The 'atypical' microstates are miscellaneous and scattered: they have *nothing* in common that can be described independently of the detailed temporal evolution to which they give rise. (Thus: a slight modification of the dynamical laws would lead to essentially no change in which initial states are macroscopically atypical, in that they have low entropy, but would completely alter the set of atypical high-entropy states whose time evolution in either direction leads to low entropy.) This asymmetry in the way that the initial and final boundary states are atypical forces an asymmetry in the explanatory scheme. And the explanatory scheme then uses the direction of time in accounting for the universe, even when using time-symmetric laws. The atypical final state is accounted for as the *product of an evolution from a generically characterized initial state* in a way that the initial state cannot be explained as a product of evolution from a generically characterized final state.

The basic structure of the explanatory situation can be seen as follows. On the one hand, this sort of explanation makes essential use of a notion of *typicality*: having granted that the state on one boundary is low entropy, we show that the vast majority of microstates compatible with that macrostate lead to higher entropy. This is taken to provide an *explanation* of the entropy increase in that evolution. And it appears that we can repeat the strategy: the state of the universe after a billion years is still low entropy, so we can expect the entropy to continue to rise. But when considering the state after a billion years, a puzzle arises: not only is entropy increase typical for evolution in the direction away from the low-entropy boundary, entropy increase is typical- in exactly the same sense- for evolution *towards* the low-entropy boundary. So either the typicality arguments do not really give explanations, or the expectations that arise from the typicality analysis must somehow be *trumped* when projecting backward in time. For any but the initial state, typical behavior is actual behavior only in one direction of time: behavior in the other direction is (in the *mathematically defined sense*) always atypical. That is, when looking backward in time, 'typical' behavior- behavior exhibited by almost all microstates compatible with the macrostate- is not *usual*: in fact, it never occurs!

If we are to maintain that typicality arguments have any explanatory force- and it is very hard to 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. That is provided by a direction of time: earlier states produce later ones. Absent such a direction, there is no account of one global state being a cause and another an effect, and so no account of which evolutions from states should be expected to be atypical and typical in which directions. If one only gets the direction of causation from the distribution of matter in the space-time, but needs the direction of causation to distinguish when appeals to typicality are and are not acceptable, then I don't see how one could *appeal* to typicality considerations to *explain* the distribution of matter, which is what we want to do.

So even apart from the (actual) lack of time reversal invariance of the laws of nature, we would have reason to accept an intrinsic asymmetry in time

itself: an asymmetry that plays a role in explaining both the nature of the final state of the universe and the constant increase in entropy that connects the initial to the final state.

Above and beyond and before all of these considerations, of course, is the manifest fact that the world is given to us as changing, and time as passing, and everyone takes for granted that their situation is importantly different before and after a visit to the dentist (even if they are at equal temporal removes), and importantly different toward the beginning and end of their lives (even though there may, in each case, be a long stretch of life lying to one side or the other) and that all the philosophizing in the world will not convince us that these facts are mere illusions. Even Descartes at his most skeptical, willing to question the existence of the external world, never questions the passage of time. Nor is there any evidential reason to suggest that such passage is ‘only in our minds’: it is the passage of time (in the right conditions) that leads iron to rust and fires to burn down. But to insist on these observations is somehow not to engage in philosophy, so I will desist.

## 5. HOW SHOULD THE PASSAGE OF TIME BE REPRESENTED MATHEMATICALLY?

If we accept that it is an intrinsic, objective feature of time that it passes (or that there is an intrinsic, objective, distinction between future-directed timelike vectors and past-directed vectors), then that feature ought to be incorporated into our mathematical representation of space-time. Granting that a Relativistic metric already represents objective spatio-temporal structure, but that such a metric includes no intrinsic asymmetry between the timelike directions, what needs to be added to the math?

As already mentioned above, all that seems to be required, from a mathematical point of view, is an orientation: an indication of which of the two globally definable timelike directions is to the future and which is to the past. Furthermore, as has also been mentioned, the violation of CP invariance observed in nature already appears to demand an orientation, which we have called the Kaon Orientation (or, more generically, the Weak Interaction Orientation). But now the Ockhamist siren song may be heard: why add *two* orientations to our ontology? Why not assume that the Kaon Orientation *just is* the passage-of-time orientation? Such an assumption would reduce our ontology at no cost to empirical adequacy.



The identification of the two orientations appears not to be a mere matter of semantics: if the orientations are ontologically distinct, then on the surface it seems that they could have been oppositely oriented to the way they are, while if there is only one, they could not. But this is a rather intricate question, since the violation of CP already requires specification of the spatial parity orientation. Let's leave these complications aside.

But there is another worry about identifying the two orientations. The passage of time is ubiquitous and manifest. Violation of CP is rare and subtle. If the orientation of time's passage were just the orientation that the Weak Interaction is attuned to, wouldn't we have trouble explaining how we can be so surely and easily aware of the direction of the passage of time?

A possible analogy: we naively begin with the idea that there is a manifest intrinsic anisotropy of *space*, which we denominate 'up' and 'down'. There then ensues a debate: is the distinction reflective of some innate structure of *space itself*, or merely a matter of how some material substance is distributed in an intrinsically isotropic space. The Newtonian takes the latter approach: 'up' and 'down' are determined not by space itself, but by the gradient of the gravitational potential. But notice: for this account to be acceptable, it had better be that the phenomena around us, and indeed our own bodies, are strongly coupled to the gravitational field. For we can easily distinguish up from down in everyday life, and if we ever become dizzy or disoriented (as occasionally happens) we can quickly regain our bearings. The explanation for this latter ability depends on the effect of gravitation on the semicircular canals in the inner ear. If the direction of time were only manifest in things like kaon decay, wouldn't we need a similar (and much more sophisticated) physical organ in the brain to orient ourselves to the passage of time?

But once we have proposed the analogy, its absurdity becomes manifest. We can indeed become disoriented and lose track of the directionality of space (whether this directionality is intrinsic to space itself or due to its contents is immaterial). But what would it even mean to be 'disoriented with respect to time', not to be sure, as it were, which way time is passing? This is certainly not a familiar or imaginable psychological state. And what would it mean to have a device (like the semicircular canals) that could serve to 'orient us in time'? After all, the *definition* of a good detector of something (whether it be gravitational fields or magnetic fields or cosmic rays) is already given in time-oriented terms: a good magnetic field detector (like a compass) is a device that, if *started* in a ready state (well oiled, level, and with the needle pointing in any direction at all), will *end* in a state in which some internal

pointer (the needle) is pointing in the direction of the local magnetic field. To say that a compass is working as a good indicator of the local magnetic field requires knowing the direction of time: the time reverse of the behavior of a good compass (needle going from an arbitrary direction to parallel with the local field) is the behavior of a bad magnetic field detector (going from pointing in the direction of the field to pointing in an arbitrary direction). Furthermore, *reacting* to the output of such a device and *basing* our further behavior on that outcome (e.g. deciding which way to go) are time-oriented behaviors, so if we could react to the reading of a 'time orientation' device and adjust our behavior to it, we would already have to be functioning in a time-oriented way.

Of course, this situation is perfectly general- it has nothing to do with any particular account of the direction of time. If one believes that the direction of time is just the direction of the local entropy gradient, still one does not think that we 'orient ourselves in time' by measuring the entropy at different times and figuring out in which direction it is increasing (not least because such measuring and figuring out already require increasing entropy). Entropy, after all, is not a first-order physical magnitude (like an electric field) for which one could even build a measuring apparatus. Rather, anyone who thinks that time direction is the direction of increasing entropy will say that we experience time as passing in a certain direction *simply because our entropy is increasing in that direction*, without the need for any further apparatus to determine the increase. In short, we experience the direction of time in a certain way because we simply are, as physical objects, time directed (even if 'time direction' is a matter of entropy gradient). The chain of observing-one-thing-by-means-of-another must come to an end somewhere: there must be elements of our experience that are determined directly by our physical constitution rather than by mediation through detectors.

So if we experience the passage of time simply because we are (as physical objects) things in time, and time passes, then the other ways that the orientation of time appears in physics are not important. The rarity of phenomena like kaon decay would not stand in the way of identifying the Kaon Orientation with the orientation of the passage of time. But since I am suspicious of the Ockhamist position that such identifications are always desirable *per se* I find myself simply agnostic about whether the orientations ought to be identified.

There is one final issue that needs to be addressed. I have claimed that the only mathematical gadget one needs to add to represent the passage of

time is an orientation. But surely, it will be urged, this is hardly sufficient to adequately represent the metaphysical nature of passage. After all, one might have to add some intrinsic, anisotropic structure to space (a structure that would induce a partial ordering of events), but that would surely not justify the claim that space ‘passes’. Similarly, the fan of entropy increase can admit violation of CP invariance, and hence the need for a physical orientation in space-time, without thereby being forced to admit that the orientation has anything to do with the problem of ‘the passage of time’. So isn’t the mathematical structure used to represent the passage of time inadequate to its representational task; doesn’t it leave the ‘intrinsic nature of time’s passage’ completely obscure?

Yes, it does. There is nothing intrinsic about an orientation that makes it particularly suited to represent the passage of time (as opposed to, say, the Kaon Orientation, if it is distinct), just as there is nothing intrinsic about a (mathematical) scalar field that makes it particularly suited to represent a gravitational potential as opposed to, say, a Higgs field. We often use the very same mathematical objects to represent very different things, and what they represent is a matter not of their mathematical structure *per se* but how we are using the mathematics to represent the world. *This* orientation represents the passage of time simply because we have decided to so use it, and another (mathematically identical) orientation can be used to represent something quite distinct.

Mathematical physics is a field that uses mathematical objects as *representations* of physical states of affairs. And as with all representations, the content of the representations depends on certain representational *conventions*: particular mathematical objects are stipulated to represent particular physical items. One cannot recover these conventions by simply examining the representations themselves: one must have additional knowledge of the conventions. If one overlooks this basic fact, all sorts of confusions will arise.

To begin with a simple example: the physicist uses purely mathematical objects such as manifolds with Lorentzian metrics, to represent physical spatio-temporal structure. This requires a choice of conventions, such as whether Minkowski space-time is represented by a metric whose signature is  $(+, -, -, -)$  or  $(-, +, +, +)$ , i.e. whether timelike directions are to be represented by vectors whose norms are positive or negative. This is clearly a matter of pure conventional choice. Of course, if one *knows* already that it is Minkowski space-time that is being represented, one can tell which convention has been chosen by examining the mathematical structure, but the convention is still

in play. This is sometimes forgotten when dealing with two-dimensional space-times, where the metric will be of signature  $(+,-)$ . It is tempting to conclude that in such a space-time the spacelike and timelike directions have become somehow inherently indistinguishable because one cannot read off the convention from the mathematical object. But this is not to be expected: if a survey result is reported by using columns headed 'P' and 'Q' rather than 'Yes' and 'No', that does not mean that the *answers* are somehow indistinguishable: one simply has to know the convention being used in reporting the results. Similarly, when using a two-dimensional mathematical object to represent a two-dimensional relativistic space-time, one simply has to know what representational conventions are being used to distinguish the spacelike from the timelike directions.

Matters can get even more confusing when one uses *space-time diagrams* to represent relativistic spatial-temporal structure. The paper on which the diagram is drawn is typically an isotropic material. Cut into rectangles, the edges of the paper pick out directions as horizontal and vertical. Clearly, if some directions of lines on the paper are to represent timelike directions in space-time, others spacelike directions, and yet others null directions, conventions must be adopted. Knowing those conventions, it is not hard to interpret the diagrams. But there is no reason to suppose- as is sometimes done- that one ought to be able to recover those conventions from a close inspection of the diagrams themselves. For example, Brad Skow, in the course of asking 'What Makes Time Different from Space?' (forthcoming), presents us with a space-time diagram stating 'Let's take a look at a particular world with a two-dimensional spacetime and see if we agree that the laws distinguish space from time even though the geometry of spacetime does not' (section 6). But of course what we are presented with is not a particular world, but a space-time *diagram*. The geometry of the *diagram*, which is essentially Euclidean, surely does not tell us which directions on *it* represent space like directions and which time like. But the requisite information is not to be sought in further details of the diagram, it is to be sought in the representational conventions. The geometry of the *space-time represented* does distinguish the space like and time like directions, even apart from the material contents of the space-time.

But there seems to be a deeper problem. The proper mathematical representation of the direction of the passage of time (i.e. the direction from past to future) may be an orientation on the mathematical manifold representing the space-time. This orientation does provide a temporal anisotropy, but,

one might say, there is nothing about it that suggests movement or change or flow at all. It is completely static.

The obvious answer to this worry is that orientations on mathematical manifolds are static and unchanging exactly because all mathematical objects are, in their own nature, 'static' in the sense of being outside of time and unchanging. And because of this, one will always have the feeling that mathematical objects are, in their own nature, not adequate to represent the intrinsic nature of time. This is presumably the reason that we commonly talk of attempts to 'spatialize' time when we do mathematical physics, but never hear about attempts to 'temporalize' space. This arises, I think, simply from the choice of mathematical objects as representations. (Of course, mathematical objects are no more really spatial than they are temporal, but we are so accustomed to think about mathematical objects by contemplating *diagrams* that we can't shake the notion that they have something like spatial structure.) We could, of course, choose to use temporally structured *physical* objects to represent purely spatial structures, and so 'temporalize' space. It might be therapeutic to consider how this could be done.

Suppose our physics, instead of using mathematical objects to represent physical reality, used instead some intrinsically time-directed representational medium. For example, suppose one used musical tunes to represent things. A collapsing star would be indicated by a falling tone (under the convention that the lower the pitch, the smaller the radius of the star), while a supernova would be represented by a suddenly rising one. Such a scheme would have some obvious advantages when used to represent processes: since the representations themselves are time directed, the representations of any sequence and its time reverse would be obviously different. Using a spatial chart to track, e.g., one's weight through time needs something extra to indicate time direction: one might know that one axis represents weight and the other time, but still not know if the chart represents weight gain or weight loss. (The problem is worse if the charts are kept on panes of glass, with no indication of which side is 'front': then a weight-loss chart can exactly coincide with a weight-gain chart if the time direction arrow is omitted.) If we used tunes, then the two charts could never be confused with one another.

But, of course, this representational scheme would have corresponding difficulties when it comes to representing purely spatial facts. Suppose, for example, one wanted to record the elevation profile of the Rocky Mountain chain. Looking at the chain, one might, as it were, sing the profile as a tune of rising and falling pitch. But the nature of the tune- the way it

sounds- would differ greatly depending on which direction one scans the chain: left to right or right to left, or whether one sees the chain from the east or the west. (It helps to imagine that this culture has developed no musical notation, so a convention for ‘reading notes’ does not exist, and to imagine that written records are read up to down. We are so accustomed to spatialized representations of temporal sequences that we have internalized the conventions which relate spatial characteristics of the representations to temporal aspects of the thing represented.) So suppose some early Lewis and Clark come back from an expedition and are asked to describe the mountain chain they have seen. Lewis whistles one tune, and Clark the same tune in retrograde motion.<sup>13</sup> These tunes might well, to the untrained ear, sound as if they have nothing at all in common. But Lewis and Clark would insist that the profile of the mountain chain is that non-temporal object that is equally well represented by either of these two quite different-sounding tunes.

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One might say that there is something *infelicitous* about this way of representing spatial facts: representations that would strike one as radically different are supposed to have the same content, and it might even be quite difficult to tell when two representations represent the same spatial facts (again, suppose they have no musical notation). Furthermore, consider how someone who felt perfectly at home with tunes might raise philosophical problems about the idea of space: ‘You tell me that spatial facts are the sort of facts that can with equal fidelity be represented by either of a pair of completely different-sounding tunes. But I hear nothing at all in common between the tunes: they sound completely different. The idea of something they have in common is abstract and unintuitive, unlike the tunes themselves, which I can hear. So I just don’t understand what this “thing in common” is supposed to be, or how there could be something that is indifferently represented by two such distinct representations.’ The problem, of course, is that we are being asked to ignore the temporal-directedness of a representation whose temporal-directedness is quite salient, so we feel that the representation does not really fit to its object, even though the representational scheme can be described precisely.

Similarly, I think, we can have the lingering feeling that mathematical objects *per se* are not fit to represent the passage of time, even when the

<sup>13</sup> It is notable that the one tune would be the other in retrograde motion: we can easily ‘hear’ that one tune is the *inversion* of another, but it is much more difficult to recognize a tune played backwards.

convention relating the passage to the mathematics has been completely fixed. We are given an orientation, and told which set of light-cones are the future light-cones and which the past, so we can now distinguish representations of Earth-to-Mars asteroids from Mars-to-Earth asteroids, and distinguish representations of weight losses from representations of weight gains, and can distinguish representations of normally functioning humans from bizarre anti-metabolizing, anti-thermodynamic things. Perhaps a mere orientation seems somehow inadequate to capture the difference between these, but the apparent inadequacy must be an illusion. Of course, we could not use the pure mathematics to get someone who did not understand what the passage of time is to understand it, any more than we could use tunes to get someone who did not understand what space is to understand it. But everyone is perfectly familiar with the passage of time, and we would not really know what to make of someone who claimed not to comprehend the idea that some events lie to the future and some are in the past, or that there is a difference between losing and gaining weight, or traveling north as opposed to south. If such 'time blindness' really could exist, we probably could not remedy it by trying to teach the person physics. But none of that gives us any reason to question the passage of time.

In sum then, it is a central aspect of our basic picture of the world that time passes, and that in virtue of that passage things change. And there are no good logical or scientific or philosophical arguments that cast doubt on the passing of time, and there are no impediments to representing, in our present physical theories, that time passes. I draw what ought to be a most uninteresting conclusion, but one that has somehow managed to become philosophically bold: time does pass. Its passage is not an 'illusion' or 'merely the product of our viewpoint' or 'an appearance due to our special mode of perception'. Its passage is not a myth. The passing of time may be correlated with, but does not consist in, the positive gradient of entropy in the universe. It is the foundation of our asymmetrical treatment of the initial and final states of the universe. And it is not to be reduced to, or analyzed in terms of, anything else.