Special Relativity and the Future:

A Defense of the Point Present

Abstract

In this paper, I defend a theory of local temporality, sometimes referred to as a point-present theory. This theory has the great advantage that it allows for the possibility of an open future without requiring any alterations to our standard understanding of special relativity. Such theories, however, have regularly been rejected out of hand as metaphysically incoherent. After surveying the debate, I argue that such a transformation of temporal concepts (i) is suggested by the indexical semantics of tense in a relativistic universe, (ii) when properly understood easily withstands the usual accusations of metaphysical incoherence and (iii) leads naturally to a meta-philosophical position from which we can understand and escape the increasing sterility of debates between radical Parmenideans and radical Heracliteans in the philosophy of time.

§1 The Problem of Time in Special Relativity

> From without the World, though all things may be forethought in music or foreshown in vision from afar, to those who enter verily in Eä each in its own time shall be met at unawares as something new and unforetold.
>
> –J.R.R. Tolkien, *The Silmarillion,* p. 44

Among the many features that both classical physics and "common-sense" attribute to time are the openness of the future and the role of time as a global "metric." More precisely, those of us not in the grip of a particular theory tend to believe both of the following. First, in some sense, the question, “What is happening right *now* on the moon?” must have some determinate answer. Second, that the question “What will happen to me ten years from today?” does not. In this paper, I argue that, although the first of these beliefs is false, the second is true. Thus, I will defend a version of what has been called a “point-present” theory of time.

More precisely, I will argue that given special relativity, not both of these intuitions can be correct. Given special relativity then if time is global, the future is closed or, equivalently, determinate. This is not new; it dates back at least to the Putnam-Rietdijk-Stein debate of the late-1960’s. What is new is that I believe that we should retain only the second and deny the first assumption. I claim that special relativity provides us with good reasons for rejecting global time and points us towards an independently plausible theory of the open future. However, the resultant theory also requires a substantial re-evaluation of our temporal concepts in general and of those metaphysical concepts connected to them. After recapping some reasonably well-known history in the next section, I present the argument in three main stages. First, I introduce an indexical semantics for tense and argue that the most plausible transition from classical to relativistic concepts takes local or proper time along world-lines rather than global coordinate time as fundamental.

Second, in the next two sections, I develop my positive account of the openness of the future. The principle aim of §4 is to develop an account of *relational indeterminacy,* which will provide us with a plausible account of the openness of the future. One region of space-time P is relationally indeterminate relative to another region Q when the causal past of Q fails to determine the state of P. This account of indeterminacy, which is distinct both from indeterminism and from failure of predictability, provides a plausible account of the openness of the future in general. Most significantly, if we make certain plausible and quite weak assumptions, namely that the state of a region of space-time depends only on the past null-cone of that region plus its topological closure, then in Einstein-Minkowski space-time, only that causal past is determinate relative to any point of the space-time with the rest of the space-time being relationally indeterminate. Moreover, in Einstein-Minkowski space-time, the indeterminacy of the future does not depend on the deterministic or indeterministic structure of the particular causal relations.

From the perspective of contemporary debates in the philosophy of time, e.g. presentism vs. eternalism or 3-D vs. 4-D, this position most resembles an eternalist, 4-D perspective. I believe that the 4-dimensional space-time manifold is the basic spatio-temporal entity and that the entire space-time and its contents exist, in whatever sense space-times exist. However, perhaps the most fundamental philosophical consequence of this position is that it illustrates just how inappropriate the Platonic metaphysical structure of those debates is to questions about time. In the last section of the paper, I begin to develop this anti-Platonist perspective, which I call neo-Aristotelianism from its affinities to Aristotle's account of time in *Physics*.

§2 A new look at some old history

Until the late 1960's, even the advent of special relativity seems to have left these two core intuitions largely untouched. While all of those paying attention would certainly have admitted that global times, i.e., "planes of simultaneity," would have to be "relativized," they seem to have been confident that any fundamental temporal features of the world would be referred to these new, relativized times. The exception here is Kurt

Gödel who recognized fairly early that global time was incompatible with relativity theory(Gödel 1949). However, although Gödel recognized that relativity destroys the possibility of objective global time, he continued to demand that objective temporality must be global. Thus, Gödel argued that absence of global time in relativistic space-time is sufficient to disprove the existence of time itself. Gödel thus became the first, as far as I am aware, but not the last thinker to claim that relativity theory solves all philosophical problems about time by dissolving them.

The next fundamental move was made, apparently independently, by Hilary Putnam(Putnam 1967) and C. W. Rietdijk(Rietdijk 1966). Both argued that special relativity implies that there can be no objective distinction between past, present and future. Nicholas Maxwell resurrected this basic argument in the Eighties(Maxwell 1985). In response, Howard Stein(Stein 1968; 1991) twice claimed that the argument rested on a fundamental assumption which was itself inimical to, at least the spirit of, special relativity–that assumption being that the boundary between the "real"(Putnam) or "determined"(Rietdijk and Maxwell) past and present, and "unreal" or "undetermined" future must be a plane of simultaneity, a global time. More precisely, Stein proved the following theorem in his 1991 paper.

> Stein's Theorem: The only reflexive, transitive, and Lorentz invariant relations between world-points in Einstein-Minkowski space-time are *the trivial relation*, *the universal relation, and the relations of past time-like and past causal connection.*

The fundamental consequence of this theorem is that the openness of the future relative to the past for any region of space-time is, given special relativity, logically incompatible with objective global temporal structure.

Stein's theorem leaves us with three possible positions on time and temporality in Einstein-Minkowski space-time. First, a very strong block universe or Parmenidean position in which one insists on global times as a necessary condition for objective time and simply accepts that there simply is no such thing. This position tends to be popular with philosophers of physics and physics influenced metaphysicians who are often drawn to block universe positions for other reasons as well. While such positions may be the only remaining possibility, if the alternative defended below fails, they continue to have the problems of plausibility and relations to empirical reality that have plagued Parmenidean positions going back to, well, Parmenides. Second, one can insist on a strongly Heraclitean position with a commitment both to the openness of the future and to global times while denying standard special relativity and embracing, either some form of neo-Lorentzianism, as with Michael Tooley(Tooley 1997), or branching space-times, as with Storrs McCall(McCall 1976; 1994), as a replacement for special relativity. Such positions suffer from at least two severe methodological problems; they seem both to get the relationship between physics and philosophy backwards and to make it impossible to see how to get to *general relativity* without the space-time formulation of special relativity.

These objections are certainly not definitive, but they should be at least sufficient to lead us to take the third alternative seriously; no matter how implausible it seems at first glance. That third alternative is "point-presentism" or, as I prefer, local temporality.

As a first approximation *local time* is the claim that proper time along my world-line is the only and actual time that passes for me and that only my past null-cone and its interior is determinate for me. Moreover, I claim that these are actual and objective features of our existence as a spatio-temporal entity and not subjective features of our awareness. Where this position is mentioned at all, it is rarely considered in any detail or argued against. Instead, it is generally dismissed out of hand. The Introduction to (Oaklander and Smith 1994) is typical here.[1]

My defense of local time involves two distinct projects. First, I must respond to the specific objections to the theory. Those objections fall into two broad classes–semantic objections and metaphysical objections. The semantic objections are generally versions of Gödel's intuition that time *just is* global; the existence of a single time for entire universe *just is* a logical or semantic feature of what we mean by time. In Section 3 I introduce an indexical semantics for tense and show that there is no logical requirement that we retain global time when we replace the classical temporal order relations with the relativistic order relations and that there are very good physical and methodological reasons to avoid doing so. The metaphysical objections focus on the status of regions space-like separated from the present. Since any theory of local time must treat the space-like separated regions as indeterminate in much the same way as the future time-like separated region, objections generally focus on the claim that treating "merely spatially separated entities" as indeterminate would commit one either to profoundly bizarre solipsism, in which only my present self exists, or to a bizarre verificationism, in which the absence of an immediate causal connection to an entity provides grounds to deny that it exists. In sections 4 and 5, I consider the status of the space-like separated regions in some detail and conclude that on a reasonable statement of the distinction no such pernicious consequences hold.

However, I believe that these explicit objections are not the truly fundamental barriers to the fair consideration of a local theory of time and temporality. What actually drives the resistance is an implicit understanding that such a radical re-evaluation of the nature of time–as contingent rather than necessary, relational rather than absolute and local rather than universal- requires a nearly equally radical re-evaluation of cherished metaphysical assumptions about what it is to be real, and thus what it is to do metaphysics. The final section of the paper attempts to lay out the terms of such a re-evaluation and renewal of metaphysics.

§3 Tenseless Time and Local Time

In recent years, several slightly different versions of token-reflexive or indexical semantics for tenses have appeared in the literature. (See especially Mellor 1981; and 1986; Le Poidevin 1991; and Tooley 1997; in addition see the essays in Poidevin and MacBeath 1993; Oaklander and Smith 1994) Thus, my goal here is not a general defense of the new theory of time. Rather, I will introduce a particular schema for such a semantics and indicate briefly some of the reasons why I prefer it. I will then deploy that schema to the particular purposes of this paper: the nature of the transition from classical to relativistic temporality.

The fundamental semantical puzzle about tensed sentences is the difficulty of finding a schema that makes use only of the temporal order relations (earlier, later, at the same time as) to account for the context dependency of tenses. The schema that I prefer solves this problem by taking the truth of sentences in a context as the fundamental semantic feature of sentences, roughly following the treatment of demonstratives by David Kaplan(Kaplan 1989). Thus, the basic meta-language for giving the tenseless truth-conditions for tensed English sentences consists of a tenseless fragment of English with ability to refer to and quantify over arbitrary regions of space-time, **dates**, and to discuss the relevant geometrical relationships between **dates**, plus the following technical machinery.[2] Capital Greek letters will be used as names for tensed sentences of English.[3] For example, the meta-language sentence, "Σ= 'The first moon landing is today.'" says that 'Σ' is a name of 'The first moon landing is today.' In addition, the language contains both the function *date* from occupants of space-time to the region of space-time that they occupy and the function *ext*, from terms in the object language to their extension. Thus, consider the truth-conditions for:

Σ= 'The first moon landing is today.'

Intuitively, it is clear that Σ is true if and only if someone used it on July 20, 1969. More formally,

TC(Σ):

$$\forall c\left\{[\Sigma \text{ is true in } c] \leftrightarrow \left[\mathit{date}\left(\mathit{ext}(\text{' the first moon landing'})\right) \subseteq \mathit{day}(c)\right]\right\}$$

Where c ranges over contexts. Let me give one more example. Consider,

Γ= 'President Bush went to Iraq three weeks ago.'

The truth-conditions for Γ are given by:

TC(Γ)

$$\forall c\left\{[\Gamma \text{ is true in } c] \leftrightarrow \left[\begin{array}{l}\mathit{date}\left(\mathit{ext}(\text{'President Bush's trip to Iraq'})\right)\\ \text{is three weeks earlier than } c\end{array}\right]\right\}$$

While a full defense of this schema is beyond the immediate scope of this essay, it has three advantages worth pointing out.[4] First, even a quick glance at TC(Σ) or TC(Γ) should disabuse the reader of any sense that there is some illicit appeal to tensed notions at work. Both of them contain names for tensed sentences of English, but they certainly do not contain any uses of such a sentence.

Second, the examples make particularly clear the way in which the characteristic behavior of tenses results from changing relationships between the context of utterance or evaluation and the dates of the subjects of the sentences. This is particularly useful in clarifying the problems with a certain class of objections to tenseless accounts of time; a class best exemplified by A. N. Prior's "Thank Goodness That's Over"(Prior 1959). In this well-studied argument, Prior suggests that defenders of tenseless theories of time, *de-tensers,* should be puzzled by certain apparently reasonable human attitudes. In Prior's example, given that a de-tenser believes that there is no intrinsic difference between a headache at the time when we suffer from it and the same headache after it ends, he suggests that a reasonable person should not feel relief only after the end of the headache.

Apparently, Prior is deploying a principle that, roughly, it is reasonable to change our attitudes towards some entity only after detecting some change in the entity. Unfortunately, for Prior, that principle is clearly false. There is at least one situation, other than an actual change in an entity, in which it is rational to change our attitudes towards that entity – when there is a change in our knowledge of the entity. Consider our attitudes towards a political regime that we had supported because we believed that it exemplified certain closely held political beliefs. We later come to believe that it does not, and in fact never had, exemplified those beliefs, and we cease to support it. There is no change in the object under consideration, only in us, but it is certainly rational to change from support to non-support towards it.

The case is similar with respect to Prior's headache. For those of us for whom headaches are merely temporary facts of life, we know that our headache will end and so have a general feeling of relief for this fact, but we do not know when any particular headache will conclude in advance of its conclusion, and thus, it is not rational to feel relief for its ending until it has in fact ended. The case of the headache is actually stronger than that above because in the case of the headache, there is a change in the real objective relations that we bear to the headache, rather then a merely epistemic change in us. It is appropriate to feel relief for the end of a headache only at times later than the headache. Like all of our attitudes and feelings about something, the feeling of relief depends primarily not on the properties that the thing possesses but on our relations to the thing, and the change from the relation "is earlier than" to the relation "is later than" is a real change in our relation to the headache.

I take this argument to be neutral between two distinct classes of theories of the nature of temporally extended things, especially persons. One class of such theories takes objects as distinct from processes and temporally extended events in their not having any temporal parts. On these theories, a person, for example, is entirely at each "time" on her world-line, while an event is distributed over its temporal extent. On the other class of theories – *genidentity theories* – objects, like events, are distributed over their histories. However, both theories must, it seems to me, take some notion of an object's "being at" a succession of "times" as a primitive of their explanandum. This is all that I need stipulate for my account of the Headache Problem.

Third, and most importantly for my purposes here, it makes it particularly easy to see the advantages to restricting ourselves to local relativistic concepts, rather than their global coordinate counterparts, for a relativistic theory of tense. To make the issues as clear as possible, let us consider a simple present tense version of Σ:

Ω= "The first moon landing is happening now."

In a classical context, the truth conditions for Ω are fairly straightforward. Ω is true in all contexts, *c*, such that (some temporal part of) *c* is simultaneous with (some temporal part of) the first moon landing. When we move to special relativity, things are, of course, no longer so simple. The transition confronts us with two possible choices. We can parse "now" or "at the same time as" either according to relativistic definition of simultaneity and relativize the truth-conditions for Ω to frames of reference, or we can parse it as "here-now" and deny that *stricto sensu* Ω is true in any context that fails to intersect the spatio-temporal region occupied by the moon landing.

It is obvious that nothing in the logic of the situation requires the global reading. In a sense, this is sufficient to establish my point. If a theory has no logical or conceptual impediment and has the advantage of salvaging our intuitions about the openness of the future, it certainly seems to deserve a full and fair hearing, which it seems not to have received to this point. However, the situation is better than that. In addition to its advantage in allowing us to retain an indeterminate future in Einstein-Minkowski space-time, this choice has two principle advantages, and no substantial disadvantages. The first principle advantage is methodological. The local time reading of Ω transfers naturally to general relativity in a way that the global reading does not. In particular, this framework allows us to make good sense of debates about the nature of time and of timetravel in universes with closed time-like curves and without *any* global hyperplanes of simultaneity (cf. Gödel 1949; Earman 1995).

The second advantage is that once we embrace local time most of the interpretative problems of special relativity drop away. In special relativity, the only physically significant time is *proper time*. In a relativistic universe clocks measure only proper time, and only proper time provides any natural measurement of the rates of physical processes. These phenomena are as empirically well-confirmed as anything in physics.[5]

None of this is new. What appears to be new is an insistence that we "bite the bullet" so to speak. If proper time is the only kind of time that matters, then proper time *just is time*. Moreover, if that is correct, then we must truly and consistently embrace the consequences of that truth. Let me just briefly consider two of those consequences. First, the coordinate system and simultaneity relation associated with an inertial reference system is privileged only with respect to other coordinate systems. It may be geometrically handy, but using such a frame does not give us access to anything about the universe that we cannot equally well describe in any other coordinate system. Second, the temporal distance between events depends on the path one takes between those events. In the classic twin paradox case, neither twin's path through space-time is privileged. If it took Twin A 5 years and took Twin B 10, years, then that is what it took them. However, and here is the fundamental point, this does not make the passage of time for either or both of the twins a subjective rather than an objective matter. The fact of the time elapsed along the two paths has nothing at all to do with the existence of the twins as conscious beings; relativity theory says that we get the same result whether we send twin human beings, twin dogs, twin sets of atomic clocks or twin samples of radioactive material; and every experiment we can come up with confirms that, in this at least, relativity theory is correct and common sense is wrong.

§4 Relational Indeterminacy and the Open Future

Given the conclusion of the previous section, there is no logical or conceptual bar to local temporality. However, the argument so far provides no direct grounds for accepting that there is a substantive distinction between the past and the future relative to each temporal element, whether global instants or local events. In this section and the next, I argue that, given certain common and plausible assumptions and one plausible way of characterizing the distinction between a closed past and an open future, we have good grounds for believing in an open future in Einstein-Minkowski space-time. The argument of this section and of the next proceeds in three stages. First, I introduce and explicate a definition of the open-future vs. closed-past distinction. Second, I demonstrate that, given certain standard assumptions, the past null-cone and its interior of each point of Einstein-Minkowski space-time is closed and the rest of the space-time is open relative to that point. Finally, I argue that this particular way of understanding the distinction allows us to avoid the standard objections to point-present theories.

What would it be for some region of space-time to be *open*, as opposed to *closed*? Intuitively it seems reasonably straightforward that such an open region must be, in some sense, a locus of multiple possibilities. It must be the case that the region could be occupied by any one of a number of different things; be the site of any one of a number of different events; or, more generally, be in any one of a number of distinct states. Unfortunately, even given a theory that specifies what the possible states of space-time are, this does not get us very far. In particular, without more specifications of the relationships between regions of space-time, all of space-time is either trivially open or trivially closed. Given no additional information, the state of every region of space-time could be anything compatible with a consistent assignment to the remainder of the space-time; everything is open. Alternatively, a complete specification of the state of space-time clearly fixes the state of each region; everything is closed.

Therefore, any non-trivial conception of openness, or *indeterminacy*, must be relational; a region must be indeterminate relative to the state of some other region of space-time. Can we make this concept any more precise? I believe we can. Let us assume that we have a theory with the following characteristics. First, it specifies the range of possible states for space-time. Second, it specifies or allows us to infer a probability structure on the theory so that we can specify the probability that any particular region of space-time is in a particular state as follows. Take Ω as the previously specified set of all possible states of space-time. $<\Omega, A, P>$ is a probability structure for the theory such that A is the power set of Ω, and P is a probability function satisfying the usual Kolmogorov axioms. We then read $P(a \in A)=x$ as the probability that space-time is in one of the states $s \in a$ being equal to x. Then, each region R determines a partition, Λ_R, of Ω such that $\Lambda_R=\{\lambda_r | \lambda_r$ are the elements of A where R is in the same state r.$\}$. Then, $P(\lambda_r)$ gives the probability that R is in state r, $r \equiv R$. Most importantly, for our purposes, we can specify the probability that any R is in state r given that another region S is in state s as the ordinary conditional probability $P(\lambda_r | \lambda_s)$. Hereafter, for clarity, I will normally write this $P(r \equiv R | s \equiv S)$.

Third, and finally, our theory must specify the relationships of causal connection between the various regions of space-time, *caus*(R, S) such that the state of S could causally influence the state of R. First, this allows us to define a partition of the space-time, relative to any given region R, into the causal past, C(R), the causal present, P(R), and causal future, F(R) as follows:

$$(4.1)\ \forall p,q\ (p\in R)\ \&\ (q\in C(R))\Leftrightarrow \mathbf{caus}qp\ \&\ {\sim}\mathbf{caus}pq$$

$$(4.2)\ \forall p,q\ (p\in R)\ \&\ (q\in P(R))\Leftrightarrow \mathbf{caus}qp\ \&\ \mathbf{caus}pq$$

$$(4.3)\ \forall p,q\ (p\in R)\ \&\ (q\in F(R))\Leftrightarrow \mathbf{caus}pq\ \&\ {\sim}\mathbf{caus}qp$$

It will also be useful to have a name for the entire region from which R is causally accessible, A(R), the union of C(R) and P(R). In order to avoid pre-judging certain apparently coherent positions such as the various version of neo-Lorentzianism in the literature, it is important to remember that these regions are independent physical notions, not the *geometric* ones that go by similar names. Secondly, we are now ready to say what it is for one region of space-time to determine the state of another region, to define a relation of *determination* between regions of space-time. We will say that:

(4.4) S determines R [*det*(R,S)] if and only if for all
possible states s of S, there exists a state r of R for
some region $Q\subseteq S\subseteq A(R)$, $P(r\equiv R|q\equiv Q)=1$

Finally, we can return to the question that opened this section, what would it be for the future to be open? Given the above it must be that the future is open if it is not determined, in the sense above, by the past. Which past? Given that, according to the previous section, the future is defined relative to our changing space-time location, it must be relative to *our* past. Thus, define the following two concepts *relational indeterminacy* and (relational) *determinacy*:

(4.5) **Relational Indeterminacy** (RI) =df. A point q_o is RI with respect to q_1 iff there is no R⊆A(q_1) such that ***det***q_oR.

(4.6) **Determinacy** =df. A point q is determinate with respect to a point q_o iff that point is not RI to q_o.

Therefore, we can finally state that the future is open, in the only sense that seems to matter, if and only if it is relationally indeterminate to our changing space-time location. In the next section, I will argue that given a standard and natural reading of special relativity, future regions of space-time are, in fact, relationally indeterminate.

However, first let us examine these concepts a bit more closely. In the first instance, we must distinguish relational indeterminacy from two other concepts with which it is often confused–*ontological indeterminacy* or *indeterminism,* and *predictive indeterminacy*.

(4.7) Ontological **Indeterminacy** (OI) =df. A point q_o is ontologically indeterminate if and only if there is no R⊆[A(q_O)-q_O] such that **det**q_oR.

This, or a closely related, notion of indeterminacy seems to be what Hans Reichenbach relied on for his conception of the openness of the future. However, critics quickly pointed out that this notion could not serve Reichenbach's purpose. A point that is **ontologically indeterminate** is always so. Thus, consider an indeterministic quantum measurement. Even if that measurement's outcome is now in our past, it remains true that the measurement's own causal past does not determine its outcome, and thus this relation cannot ground the difference between an open future and a closed past.[6] However, we will discover that the logical connections between relational and ontological indeterminacy show that Reichenbach was wrong only to the extent that he took ontological indeterminacy to be a logically necessary condition for becoming.

The second conception with which it is possible to confuse **relational indeterminacy** is an essentially epistemic notion. This variety of indeterminacy results from failures of information gathering or information utilization by particular observers:

> (4.8) **Predictive Indeterminacy** (PI) =df. A point q_o is PI with respect to an observer O having information I if and only if I is not sufficient for O to infer the state of q_o at q_1.

The reader should note that in this definition, the indeterminacy arises from two distinct kinds of failures on the part of the observer. First, **predictive indeterminacy** could arise from a failure to gather sufficient information about a particular event. This failure could be intrinsic to the kind of being that the observer is; for example, she gathers information only via causal processes and there are no causal processes from the event to her location. Alternatively, this failure could be accidental; for example, her eyes might not have been open when light from the event could have reached them.

Second, **predictive indeterminacy** could arise from a failure to carry out necessary inferences from information actually possessed. Again, this failure could arise either from intrinsic or accidental sources. An intrinsic inferential failure might arise if the necessary inferences require the calculation of formally incomputable functions by beings, apparently much like us, incapable of carrying out such inferences.[7] An accidental failure might arise from simple laziness.

The confusion of **predictive indeterminacy** with **relational indeterminacy** generates much of the misunderstanding that leads to various charges that attempting to connect the causal structure of space-time with becoming confuses metaphysical with epistemological issues or invokes some form of verificationism.[8] This arises particularly because we are the kind of beings who do depend on causal processes for the information we possess, and thus **relational indeterminacy** does lead to **predictive indeterminacy**. Predictive indeterminacy serves in large part to explain our sense of becoming. Thus, as with **ontological indeterminacy**, **predictive indeterminacy** has a role to play in the explanation of becoming but a less central one than has sometimes been attributed to it.

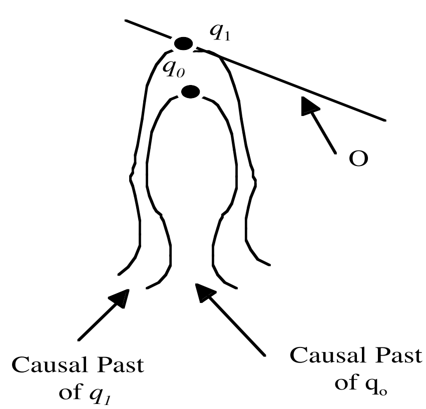


Figure 1

Applications of Definition to Arbitrary Space-time

In order to examine some of the consequences of the definitions, consider figure 1 above. The curves intersecting q_o and q_1 mark off their respective (and arbitrary) causal pasts. The arbitrary shape of those regions indicates the independence of the definitions from any substantive assumptions about causal connection. Note that C(q_1) contains C(q_o). This allows us to make the following inferences from the definitions. First, q_o is determinate with respect to q_1 since q_o is in the causal past of q_1. We can see that the state of q_o must be determinate with respect to q_1, because a complete specification of the state of the causal past of q_1 includes a specification of the state of q_o. Intuitively, even if q_o is ontologically indeterminate, q_1 has direct causal access to the state of q_o since by definition causal processes can propagate from q_o to q_1. Next, consider the observer O, whose world line is represented by the straight line in the figure. Even though q_o is determinate with respect to q_1, q_o can be predictively indeterminate with respect to O on the assumption that all of O's information results from the detection of causal processes at q_1 if, for example, no actual causal process propagates from q_o to q_1; or O is unable to detect those processes; or O is unable to make use of knowledge about the state of q_o obtained from detection of those processes. Finally, if we assume for the moment that only the complete causal past of a point *could* suffice to determine the state of that point independently of the direct specification of the state of that point, then q_1 is relationally indeterminate with respect to q_o, since C(q_o) contains only a proper subset of C(q_1)

These conclusions are instances of more general logical connections between the definitions. First, we should note that any point, q_o, relationally indeterminate to another point, q_1, is also predictively indeterminate for causally obtained information with respect to that point. Given that a complete specification of the state of the causal past of a point exhausts the possible knowledge of, or possible information possessed by, an observer at that point, it is clear that no observer could possess sufficient information to infer the state of a point relationally indeterminate with respect to that observer's here and now. Similarly, an ontologically indeterminate point, q_1, is relationally indeterminate with respect to all points, q_1, such that $q_1 \notin C(q_i)$. Clearly, if no specification of $C(q_1)$ is sufficient to determine the state of q_1, then neither will the specification of any subset of $C(q_i)$ that does not contain q_1.

Finally, it is worth saying something about how relational indeterminacy connects with the classical problem of future contingents: the problem of the status of tautologies of the form A∨~A, where A is a proposition about the future.[9] In brief, I believe that indeterminacy reveals itself semantically not at the first-order but at the second-order. More specifically, A∨~A is a tautology and is true for the usual reason that one of the components is true. However, I claim that not all English statements of this apparent form are tautologies. Consider an entity, *r,* that could possess any one of a number of incompatible properties, in the simplest case the property P and anti-P, which we can represent, using polish notation, as NP.[10] I claim that *r* is indeterminate with respect to P in a particular model when the union of the extensions of P and NP is not the entire domain of the model and *r* falls into the gap between P and NP. This allows us to retain a classical semantics of propositions since in this case both ~P(*r*) and ~NP(*r*) are true. In addition, this conception makes explicit the concept of "attribute indefiniteness," as the most straightforward understanding of indeterminacy.[11]

§5. Application of the definitions to Neo-Newtonian and Einstein-Minkowski space-time

By themselves, the above definitions seem to add very little to these debates. Almost all parties to the debate over the force of Stein's theorem seem to agree that different relations of causation are appropriate for differing space-times.[12] The disagreements seem to be about the metaphysical cost and implications of varying the causal connectibility relation in various ways. However, I claim that these definitions allow me to show that we can have univocal concepts of determinacy and indeterminacy whose extensions vary when we vary the relation of causal connection; that these concepts have the expected and desired consequences given natural neo-Newtonian and Minkowskian relations of causal connection, respectively; and, finally, that they can ground a significant distinction between past and future in at least some space-times.

The first step in this process is to show how to apply these definitions in classical space-time. To that end, we need a definition of the causal past in neo-Newtonian space-time. Two aspects of neo-Newtonian space-time have natural and immediate interpretations in terms of classical physics, the simultaneity structure and the affine structure. The presence of instantaneous action at a distance determines the simultaneity structure; all and only those time-slices of objects (or objects at a time)[13] that can exert gravitational force on a given object at a time are simultaneous with it. Newton's first law of motion, that force-free objects follow *straight lines* or *affine geodesics* in the space-time, determines the affine structure. These two principles exhaust the physical interpretation of neo-Newtonian space-time since they allow us to define in principle methods for the measurement of the intrinsic metric features of the space-time, absolute temporal intervals and absolute instantaneous spatial separation.[14]

Next, given the definitions 4.1-4.3, the simultaneity slices constitute the causal present for each point on them. Given this, we can determine which points are causally earlier or later than each simultaneity slice yielding a definition of the causal past as the shaded region in Figure 2. Given these assumptions it follows, first, that causal effects can reach q_o from all points below the plane of simultaneity, and no causal effects can reach q_o from points above the plane of simultaneity. Therefore, the results of the previous section tell us that all points beneath the current plane of simultaneity are determinate.

Given this we can consider the various ways that a point q_1 could be RI to a point q_o (see figure 2). There are essentially three ways in which q_1 could fail to be

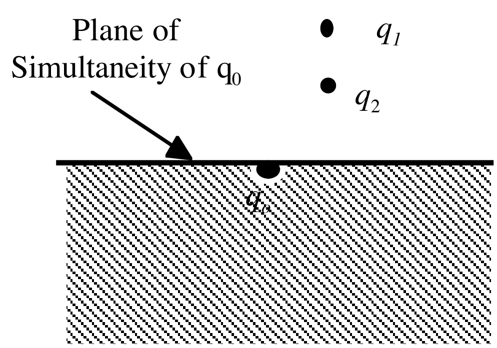


Figure 2

Relational Indeterminacy in Classical Space-time

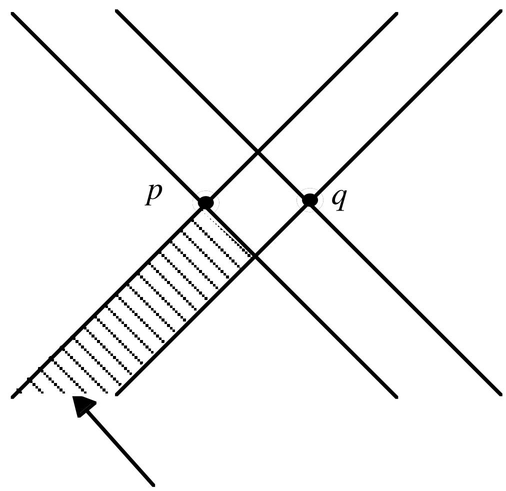
determinate with respect to q_o. First, there could be a causal influence on q_1 that fails to intersect C(q_o). Such a causal process would have to originate at infinity at a time later than that of q_o and reach q_1 in a finite time. This is essentially the so-called "space invaders problem" that bedevils all attempts to formulate determinism in the context of classical space-time. Here I point out only that the problem disappears in special relativistic contexts where we tend to postulate explicit limits on the rate of propagation of causal influences.

The second way in which q_1 could fail to be determinate is if there is some point (e.g., q_2 in Figure 2) to the future of q_o which is ontologically indeterminate and that has a causal influence on the state of q_1. Thus even if q_1 is itself ontologically determinate, there is no subset of C(q_o) sufficient to specify the state of q_1. Third, q_1 could itself be ontologically indeterminate. What this demonstrates is that barring "space invaders," indeterminacy can enter a classical space-time only through the existence of ontological indeterminacy, and only to the future of some point.

This fact about classical space-time combined with the supposed determinism of classical physics has extremely important consequences in the philosophy of time. Here I will focus on two of them. First, at least as far back as Laplace and Kant, this fact has driven philosophers seeking to ground the apparent openness of the future away from the physics of space and time and towards more radically metaphysical ways of approaching the problem. Thus, since classical physics seems to bar any access to an account of indeterminacy in terms of "failures" of causation, this has pushed philosophers to attempt to account for the openness of the future by appeals, for example, to existence as the relevant criterion. This also shows what was right about Reichenbach's conception of becoming. If we are committed to a classical picture of causal structure, then ontological indeterminacy seems to be the only way to generate relational indeterminacy in the universe and open up the future. However, since Augustine apparently defended such a view 1300 years before the advent of classical physics, the apparent lack of alternatives that seems to result from classical physics is certainly not the only reason philosophers have had for defending an ontological conception of becoming. The implicit reasoning seems to run as follows. If the future is both necessary and determined, then the only way in which it can be distinct from the past is in virtue either of existence, the ontological view, or some uniquely temporal features of the world, the pure tense view. The problem is, as we shall continue to see, that neither of these conceptions extends naturally to Minkowski space-time.

We can now consider how the definitions of Section 3 apply to Einstein-Minkowski space-time and provide a ground for real becoming. What we will discover is that with a definition of the causal past appropriate for special relativity, Einstein-Minkowski space-time comes equipped with a natural distinction between past and future in terms of Relational Indeterminacy. Next, we will consider the connection between Relational and Ontological Indeterminacy. I will argue that, given another source of relational indeterminacy, becoming is independent of the existence of ontological indeterminacy in the space-time. I then consider two objections to connecting this kind of a theory to temporal becoming. The first objection, directed by Adolf Grünbaum against Hans Reichenbach, is that failures of causal determination cannot ground becoming because they do not allow for the necessary "flow of time." The second objection, which will be one of the topics of the next section, is the solipsism objection mentioned above.

All standard physical interpretations of Einstein-Minkowski space-time take the causal past of each point as the past light-cone of that point and its interior (Fig. 4.3).



Region of the causal past of *p* not causally
accessible to *q*

Figure 3
Relational Indeterminacy in Einstein-Minkowski space-time

Given this definition of C(*q*), we can determine by inspection that any point not itself contained in C(*q*) has points in its causal past not in C(*q*). The problem of the relational indeterminacy of such points depends on the problem of how much of their causal past must be contained in C(*q*) to determine them. Thus, consider a point, $p \notin C(q)$. If *p* is ontologically indeterminate, then as above *p* is RI to *q*. If even the entire C(*q*) is insufficient to determine *p*, then clearly no subset is. Next, we need to consider the status of points that are not ontologically indeterminate. If C(*p*) does not itself contain any ontologically indeterminate points, then any cross-section of C(*p*) will serve to determine *p*, as long as all of the causal processes leading to *p* are Markov processes. In probability theory, a discretely ordered process is a Markov process if, and only if, the probability of the (n)-th element of the process conditioned on the (n-1) element is the same as the probability of the (n)-th element conditioned on all previous elements. Equivalently, we can say that the (n-1) element *screens off* (n) from all other elements of the process. For continuous space-time processes, this translates into the dependence of *p* only on points infinitesimally close to p. However, C(q) does not contain even a complete cross-section of C(p), and therefore, there are points in C(p) not determined by C(q). From this we can see that all such $p$are relationally indeterminate to q.

This conception incorporates the space-like regions relative to each point into the indeterminate future. However, this assimilation is not complete; only the causal future (the future light-cone and its interior) can be affected. What happens in special relativity is that two different ways of thinking about the present that tend to run together in classical space-times become forced apart. One way of thinking about the present is as the region just now becoming determinate; in this way of thinking, we treat it as the boundary of the future and like the future, still changing or becoming. This aspect of the present has been emphasized in the previous paragraphs. However, the present has another aspect that tends to assimilate it to the past. From this perspective, because it is becoming right now, it is too late to do anything about it, just as it is with the past. The space-like regions retain this aspect of the present, and it distinguishes them from the true future. As the boundary between past and future, this expanded present shares some features with both regions.

Perhaps the most important aspect of this situation to note is that once we treat space-time as Minkowskian, the existence of real becoming no longer depends on the existence of ontological indeterminacy. Once we add a causal arrow, the necessary indeterminacy falls naturally out of the space-time structure. This is important because it allows us to respond to one strand of Adolf Grünbaum's objections to this kind of a picture. In *Philosophical Problems of Space and Time*, Grünbaum presents an argument intended to show that the failure of determinism cannot ground becoming. I take the argument to be as follows: for any given event, either that event is or is not determined by its own causal past. Whether to event is or is not so determined does not depend on what the here and now happen to be. That is, what I have called ontological indeterminacy is a paradigmatically tenseless fact about events and thus cannot ground becoming.

As we saw above, Grünbaum is correct as far as he goes. Ontological indeterminacy cannot fill the role into which philosophers such as Reichenbach have tried to force it. However, Relational Indeterminacy can. Relational Indeterminacy allows a unique specification of the past and future relative to each point. Again, Grünbaum complains that even so, such a distinction does not serve to pick out a unique now. Again, I agree. However, I do not think that such a unique now is necessary for objective becoming. The now is defined only relative to particular occupants of the space-time, including human beings. However, it is an entirely objective, if contingent, fact about those objects that they are where they are. Similarly, it is an entirely objective and physical fact that a human life consists of a sequence of events ordered from earlier to later. It is exactly the change from relationally indeterminate to determinate that is the objective counterpart to the subjective sense of temporal passage noted by, e.g., Henri Bergson(Bergson 1949) and Richard Taylor(Taylor 1992).[15] Nevertheless, is this really a theory of objective becoming? This is the topic of our final section.

§6 Conclusion: Towards a Neo-Aristotelian Metaphysics of Time

Let me recap the conclusions so far. I have argued (§3) that the semantics of tense combined with the physics of relativity provide us with good reasons for adopting local rather than global temporal concepts. Then, in §§4 and 5 I have argued that once we adopt this local conception, we have a perfectly natural sense in which Einstein-

Minkowski space-time supports a distinction between a closed or determinate past and an open or indeterminate future. However, this claim has been subject to two principle objections; objections which on the surface pull in different directions, but which I believe actually flow from a common, but deep, philosophical mistake. Pulling in one direction is a claim that I have not proved enough. On this objection, I have not provided an account of an objective past-future distinction; I have merely accounted for the mistaken belief in such a distinction. From the other direction comes the claim that I have proved too much. In searching for the indeterminate future, so it is claimed, I have made everything indeterminate and committed myself to some form of radical skepticism or solipsism.

While it is relatively easy to see *what* is wrong with these particular objections, it is more difficult to see what the problem is with the motivations behind them. This is because these objections really flow from a meta-philosophical position so common as to be largely invisible; this is the commitment to a conception of reality, call it the *Platonic* conception, such that anything real must be real all the way up (or down, pick your metaphor). Until we have a clear picture of how this commitment infects the philosophy of time and of its pernicious consequences, we will never have clear understanding of the nature or metaphysical role of time and temporality.

Let us first consider the two specific objections. Have I not simply proved that becoming depends on the existence of human beings and human language and thus is not a real feature of the universe? However, nothing in my account of the past-future distinction depends on human subjectivity. Certainly if there are no human language users, then there are no tensed statements in human languages. Nevertheless, the truthmakers for those statements might very well still exist. Tenses depend not on anything about human subjectivity, but merely on our existence as a certain kind of spatio-temporal entity. On this account it is just as true that my chair has a determinate past and an indeterminate future as it is that I do. The only difference is that I can state that I do and know that I do, but this is simply the tautology that only language users and knowers can state or know anything. It may well be true that from some eternal non-spatiotemporal perspective, a perspective that I can only just glimpse through mathematical physics, the past-future distinction dissolves. But, until I can occupy that perspective, not merely glimpse its existence, I am still here and now a being with a past and a future.

However, the fact that I can glimpse that perspective and that this plays a role in my account of temporality is important for understanding what my precise claims are and avoiding the charge that I fall into radical solipsism or skepticism. The problem of event solipsism is the most easily addressed. There are two aspects to the response. First, once we are committed to the space-time perspective, we are committed to the existence of the entire space-time, including the space-like separated regions. In whatever way the past light-cone exists, so do the space-like wings at each point. However, this does nothing to address the problem of the reality of the supposed occupants of the space-like wings. First, our own past commits us to there being *something* going on in the regions space-like separated from our here and now. Causal processes exist that intersect our own causal process and pass out of our region of causal accessibility. We reasonably believe that such processes continue to have effects in those regions just as we would expect. The only difference is that the exact nature of those effects is not yet determined for us.

As far as I can see, there is nothing strange about this. We should probably expect from the discussion at the end of the previous section that statements about the space-like regions relative to any particular here and now are assimilated to the kinds of claims that we can make about the future, that is, to predictions. Moreover, we should be used to the failure of our predictions at this point, to falliblism. What special relativity does is take our fallibility usually attributed merely to our own subjective epistemic failures – to Predictive Indeterminacy – and show us that sometimes that failure is not subjective but objective, built into the world and not into us, and arises from true Relational Indeterminacy.

This leads into the charge of skepticism. First, if philosophers have not yet learned to distinguish falliblism from skepticism, it will take a better epistemologist than I am to teach them. Second, if this is skepticism, it is of a rather atypical variety. The classical skeptical arguments begin with our failures; we cannot distinguish dreaming from waking; our perceptions can be in error and thus should never be trusted; and so on. That makes this position a strange variety of skepticism because it begins with *a claim about the external world*. It is based on a theory that starts with all of the things that a classical skeptic mistrusts and invokes a sketch of a theory about causation that a Humean skeptic would find entirely unjustifiable. That is, it is a positive claim about the nature of the external world, not a negative claim about our capacities to know things about that world. This indeterminacy is a fact about the world that tends to manifest itself to us in terms of our epistemic failure, but the fact about the world and not the epistemic failure is primary.

Alternatively, we can think about the situation as follows. We believe that skepticism is problematic because it seems to have certain pernicious consequences. Philosophers search for ways around skeptical arguments because they prohibit us from having something that we in fact seem to have, i.e. objective knowledge about the external world. However, while I do not want to legislate language, calling the position developed here a variety of skepticism seems misleading at best. This is because my position does not have the kind of pernicious consequences usually attributed to skepticism. It cannot prevent us from having objective knowledge of the external world because it *begins* with such knowledge.

Note that nothing here contradicts my response to the previous objection. I can glimpse the existence of this eternal four-dimensional perspective, and the power of the formal geometric representation of this perspective provides powerful reasons for accepting it as the best available account of the fundamental nature and structure of space and time. However, I am still a being within space-time and as such, I have a determinate past and an indeterminate future, given that I exist within an appropriate space-time. To really see what is going on here we need to move up at least one level of abstraction.

I suggested above (§2) that the alternative to the theory of temporality developed here is a radical Parmenidean or neo-Eleatic conception. Moreover, in the second objection above, we can almost hear the shade of Parmenides or Zeno pointing out that if we try to fudge, we only end up with nonsense. However, the first objection has almost the same structure; here the defenders of radical becoming, the neo-Heracliteans, are pushing an equally strong objection to compromise from the other direction. If the neo-

Eleatics refuse to admit anything temporal to the universe, the neo-Heracliteans are equally adamant in refusing admittance to anything atemporal.

However, it is perfectly clear, going back to the responses to the original Eleatics that compromise is possible. Formally, the move advocated here is precisely the response of the neo-Ionian physicists, the ancient Atomists and, most importantly, Aristotle in response to the original Eleatic arguments of Parmenides and Melissus. Loosely, a neo-Ionian four element physicist, such as Anaximander, accepts as equally real both a chair's coming into existence through changes in the relationship between the essentially changeless and atemporal elements and the changeless and atemporal nature of those elements.[16]

For our purposes, though, Aristotle made the crucial move when he engaged directly with the problem of temporality, distinguishing it from the related problem of change that had preoccupied earlier Greek philosopher-scientists. As is well known, Aristotle defines time as "the quantity associated with change." This definition hardly bears repeating except for an important aspect of Aristotle's theory of change regularly overlooked in this context. Change, for Aristotle, is fundamentally the combination of Forms, themselves essentially timeless and changeless, with Matter, itself incapable of change, to generate substances. Thus, Aristotle is a realist about time although he does not believe that the universe is temporal all the way down. More picturesquely but not too inaccurately, given Aristotle's natural teleology, we can envision an Aristotelian universe as the essentially temporal expression of the underlying atemporal reality in matter.

Of course, no contemporary theory of temporality which claims grounding in modern physics, as this one does, can simply take over Aristotle's account of change and temporality: our physics is not Aristotle's. However, the theory presented above deserves to be called neo-Aristotelian in the following sense. The modern description of space-time, and thus the universe, as fields distributed on a four-dimensional differential manifold, provides a so-called “God's Eye view,” a glimpse of being *qua* being *sub specie aeternitas*. In this, it provides a perspective not dissimilar to that of *theoria* in Aristotle’s philosophy. But it is equally true, whether on Aristotle’s account or mine, we and the things around us are not eternal. To particular beings within space-time, including but not limited to human beings, certain other beings are causally accessible and others are not; are determinate or indeterminate; are past, future or neither

Notes

[1] Mauro Dorato (Dorato 1995) is almost the sole exception here.

[2] On one level, it might seem simpler here to speak simply of points and regions of space-time. However, part of the point of the section is that this space-time perspective slots quite nicely into a schema, which allows for other types of contexts and dates. The terminology of dates is comes from D. H. Mellor's work although I use it here differently than he does.

[3] In the remainder of this section, quotation marks are used according to usual use-mention distinction.

[4] For a more complete discussion of the issues here see Chapter 3 of (Harrington 1998).

[5] For clocks see the classic studies published as (Hafele 1972; Hafele and Keating 1972; 1972). On particle decay see (Rossi and Hall 1941).

[6] This objection parallels that in Grünbaum and in earlier responses to Reichenbach's program.

[7] For a discussion of the connection between problems of computability and predictive determinism see (Earman 1986).

[8] Perhaps the clearest example of the failure to distinguish predictive determinacy from other forms is Karl Popper's *The Open Universe* (Popper 1991).

[9] I would like to thank an anonymous referee from *The British Journal for the Philosophy of Science* for encouraging me to discuss this here.

[10] This distinction between sentence-operators and predicate-operators comes from (Prior and Fine 1977). Prior, however, assumes that sentence and predicate operators track each

other, e.g. $\sim P \Leftrightarrow NP$. There does not seem to be any particular reason not to waive this requirement when it is useful.

[11] I develop this in somewhat more detail in (Harrington 1998) and plan to develop this in more detail in the future.

[12] But, see (Tooley 1997)

[13] For this particular purpose these two formulations are equivalent. The point here does not depend, as far as I can tell, on ones metaphysical commitments on the nature of temporally extended things.

[14] The fact that classical gravitation is not only instantaneous, but also universal has serious consequences for the actual application of these methods since this implies that all actual affine geodesics are empty since there is no actual inertial motion. See (Torretti 1996) especially Chapter 1, for a careful discussion of this subtle problem.

[15] The only philosopher I am aware of who has come close to making this point is Sir Karl Popper in his book *The Open Universe*(1991). However, Popper formulates his conception of indeterminism in terms of predictability, which camouflages the objective character of the distinction. It also does not allow him to make the critical distinction between ontological and relational indeterminacy.

[16] For the Eleatics and the Ionian and Atomist response see especially (Barnes 1982). This interpretation of this important moment in the history of philosophy is certainly not without its problems. It is, however, clearly plausible, and more importantly serves to illustrate a theoretical move which I am making. Whether or not, the relevant pre-Socratics actually made it.

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