Tense and Indeterminateness

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1 Preamble

Is tense real and objective? Can the fact that something is past, say, be wholly objective, consistent with modern physics? I believe that it can. But some hold that for tense to be real, then a certain ontological doctrine must also hold. There must be a fact of the matter as to what really, truly, exists at each time. For example, it is held that only what is *now* really exists. This is the doctrine of *presentism.* Alternatively, that only what is *now* or *past* really exists; following Savitt, I shall call this *possibilism.* But on either view there is a problem with special relativity.

There is another question that is closely related. Is the contrast between the determinate and the indeterminate real and objective, consistent with physics? I say that it is. But many will insist that it be ontologically grounded, taking us back to presentism or possibilism. If so, and if it is true that the latter are incompatible with relativity, then the contrast between the determinate and the indeterminate is incompatible with it too. It would follow that quantum theory, or at least relativistic quantum theory, cannot be interpreted in terms of this distinction.

The two questions have been considered before (Maxwell 1985); but I shall present them in a rather different light, and come to different conclusions.

2 The Problem With Presentism

I am construing presentism as an ontological doctrine; that all that is is what is now. I take it that "what is now" is a 3-dimensional space, along with sundry events; moments in the careers of objects. It is therefore a time-slice of spacetime. If we are to take the position seriously, as a philosophical thesis, it is a public space - for nothing else exists, this is the whole of reality; and I take it that solipsism is not a serious position in philosophy. So we had better all agree on how this public space is to be defined. The criterion will have to specify an instant of time; over and above that, it had better not make any special reference to a particular person, or a geographical location, or an everyday object. We are after a view of cosmology, of all that exists; it had better not be a view which is provincial.

From a 4-dimensional perspective, presentism is therefore saying that what is real is a particular time-slice. But from the 4-dimensional perspective, this is to single out a *family* of time-slices, a space-time foliation. It is a family and not a time-slice because the presentist does not deny that there is change, that one time is succeeded by another. In 4-dimensional terms, that can only mean that the one time-slice is later than another; and so on with all the rest. No wonder that the presentist position appears inconsequential; the clearest way of understanding it is by casting it in 4- dimensional terms, but when that is done it looks just like its rival.

Or so it does in the non-relativistic case. Given relativity theory, there is an important difference. For according to relativity, there are many inequivalent way of slicing space-time into a family of time-slices, with no one of them privileged. That is inconsistent with presentism. A single foliation is privileged, she will have to insist, because at each time there is a fact of the matter as to all that exists. In other words - again reverting to the 4-dimensional perspective - there is a fact of the matter as to what "an instant of time" really is; and likewise its successors. With that we have a preferred foliation.

How might this preference be made out? Not by appeal to a particular worldline, surely. The world-line of what, or of whom? In fact this is our normal procedure. We give special prominence to ourselves, specifically to the Solar System, in the case of Ephemeris Time; and to Planet Earth, in the case of the atomic clock standard (Temps Atomique International or TAI, the present standard of SI units)[1]. Neither, in fact, gives us a foliation of space-time, but in each case we do obtain a local system of time-slices. In the latter case, in effect we have dotted around a number of clocks, synchronized by the radar method, on the surface of the Earth; which itself is functioning as an approximately rigid body. Is it by reference to the Earth, or to the Solar System, that all that exists at each time is decided? Surely not; surely, in adopting these time standards, we do not suppose we are settling any grand metaphysical questions.

However far we might try to extend this local family of surfaces, in spacelike directions, the presentist can hardly embrace it as the arbiter of all that there is at each time. To do so would return us, not to Lorentz's position, but to Aristotle's. The Earth is no longer at the centre of the universe; so how do we define a foliation without this sort of provincialism? Not, evidently, using the radar method (Einstein synchrony). Einstein defined a natural relation between points belonging to timelike worldlines. Denote such points p_u for timelike worldline u and let $l(p_u, q_v)$ be the straight line connecting the point p_u to the point q_v . Given lines u, v, write $u \perp v_p$ iff u and v_p intersect orthogonally at the point p . Then the condition that q_u is Einstein simultaneous with p_v is:

$$\text{Ein}(q_u, p_v) \text{ iff } l(q_u, p_v) \perp u_{q_u}$$

Evidently Ein is not transitive. As pointed out by Putnam (1967), if we use this to build up to a time-slice, either *all* events will satisfy Ein, or, in accordance with Einstein's original operational procedure, *one* particular fiducial world-line u must be used throughout. The only remaining possibility is if all the world-lines considered happen to be parallel (in which case Ein is transitive). This is what happens for a system of inertial bodies which are all mutually at rest (an inertial frame). With that, if we look for a realistic, approximately inertial frame, we are back to TAI.

It is unfortunate that Putnam did not make it clear that not only transitivity, but also symmetry, is required by the presentist. For Stein (1968) has responded that there is a perfectly satisfactory, invariant, transitive relation, namely past causal connectibility; and claimed, and has been widely thought to have proved, that Putnam was mistaken. This relation, denote Con, holds for events *simpliciter*, independent of world-lines:

$\text{Con}(p, q)$ iff q lies in or on the past light-cone to p

If we build up a foliation in this way, it will be a nested sequence of past light-cones. The tips of this sequence will lie on a time-like curve. Again we are back to TAI; time as referred to a particular time-like curve.

But nothing less than an equivalence relation will do for the presentist. An equivalence relation is distinguished from other kinds of relations precisely because it partitions a set into subsets, without distinguishing any particular element of each subset. But an equivalence relation is symmetric as well as transitive (reflexivity is trivial); we have as yet no candidate in sight.

Maxwell did no better when he restated Putnam's argument (Maxwell 1985); provoking Stein to give a proof that Con is the only relation which is transitive, defined in terms of the structure of Minkowski space (Stein 1991). Therefore there is no equivalence relation, proving Putnam's point. This is not to say that none can be defined, period; only that none can be defined independent of the matter distribution. Clifton and Hogarth (1995), thinking that they were proving Stein right, went on to prove that no transitive worldline-dependent relation could be defined, given an arbitrary collection of inertial lines. They have strengthened Putnam's point.

Of course, in a realistic model of a material system, there will be a lot of structure to the system of worldlines, none of which will be inertial. But the task of distinguishing a unique foliation, by any natural condition, seems increasingly hopeless. That is the problem with presentism: it goes against the grain of relativity theory. There was no such difficulty in classical mechanics[2].

3 Relationism

I began with the claim that tense is perfectly real and objective. According to presentism, that was supposed to require an ontological distinction between past and future; but as we have seen, that cannot be drawn in simple and intrinsic terms. Is there any alternative? Obviously possibilism fares no better; if possibilism is true, there is a boundary between what is past and what is not. Concerning this boundary, there must be intersubjective agreement; so we are back to the same difficulty that we met before.

The alternative is to deny that the distinction between the past, present, and future has to be drawn at all on the ontological level. Suppose that all events exist; they may all have objective relations with one another, among them spatio-temporal ones. On this view, Stein is exactly right to focus on Con; there is indeed a natural and non-arbitrary definition of a time-order (in

McTaggart's terms, of the B-series), so long as we allow it to be only a partial ordering. It is perfectly objective and real for all that. Let me call this position *relationism*[3].

Of course, once one does adopt this position, there is no harm in choosing a convenient foliation of space-time by reference to the matter distribution. By all means let it be Ephemeris Time, or TAI. Nothing weighty hangs on it, not in physics and not in metaphysics. The interesting metaphysical question has already been settled; the physical ones have not been asked.

4 The Problem With Indeterminateness

Consider now the distinction between the determinate and the indeterminate. I take it we have no very sharp pre-theoretical idea of what indeterminateness means. It is a state of potentiality, of indefiniteness, of what is as yet unformed; to be contrasted with what is actual, or what has become actual, or definite. But vague as it is, I take it that this means something more than that the future is in principle unpredictable; that is a necessary but not a sufficient condition for indeterminateness.

In quantum mechanics we have a more precise idea of what indeterminateness might mean. It is represented by a superposition of states each corresponding to a determinate outcome. Of course this is as yet only a mathematical expression of the idea; it does not interpret indeterminateness, it is interpreted in terms of it. But a precise language is worth something, and I will talk assume throughout in terms of quantum mechanics; specifically, in terms of one or another variants of quantum mechanics. I shall rule out deterministic hidden-variable theories - specifically, the pilot-wave theory - but there remain the indeterministic interpretations. These include stochastic state-reduction theories; this class of theories accords well with the neo-classical, stochastic notion of indeterminism (as in Brownian motion, for example). In other words, restricting ourselves to quantum mechanics, we lose nothing in generality, and gain in clarity.

But we are concerned with the marriage of quantum mechanics to relativity - with relativistic quantum field theory (RQFT). The obvious difficulty, in extending state-reduction theories to the relativistic domain, is that it appears the process of reduction must pick out a unique frame of reference. This seems to be true even in the case of "effective" state-reduction, as it arises in the pilot-wave theory (where "empty waves" are thrown away, when their contribution to the quantum potential is negligible); in that theory too there is a problem with covariance (Bohm and Hiley 1993, Ch.12). The problem arises when one tries to define a Lorentz-covariant stochastic dynamics. On making a Lorentz boost, a transformation in velocity, one must transform data on one time-slice to data on another. This involves the dynamics, because points on these two surfaces are timelike separated; likewise the data. But given a stochastic dynamics, the data at one time is not determined by the data at an earlier time; so we cannot define the boosts.

I know of two ways of avoiding this conclusion. The first is due to Philip

Pearle, who supposes that one can incorporate, into the generators of the boosts, a white-noise function which effectively codes the entire history of the universe - including the future (Pearle 1990). In that case, insofar as in principle one can define a notion of Lorentz covariance - through possession of this white-noise function - in principle the future can be specified as well; so it is not in a state of indeterminacy. The second arises in the consistent-histories approach to quantum mechanics. Here one has a space of all possible histories, where each history is considered as a 4-dimensional whole, without any preferred foliation. A measure is defined on this space, and the histories are required to satisfy the consistency condition with respect to it (essentially that distinct histories do not interfere with one another). We suppose that one of these histories is ours, and that it is "typical", as defined by this measure. Conditional probabilities for A, conditional on B, can then be defined as the measure of all those histories which contain B and A, divided by the measure of all those which contain B. This is reminiscent of the situation in classical statistical mechanics; although we do not have equations, for these histories taken separately, the future is already fixed. As Grünbaum put it, responding to Reichenbach's proposal that indeterminacy can provide a criterion to distinguish the future from the past:

> Nor does indeterminacy make for any difference whatever at any time in regard to the attribute-specificity of the future events themselves. For in either kind of universe [deterministic or indeterministic], it is a fact of logic that what will be, will be! (Grünbaum 1973 p.324).

Indeterminacy - lack of predictability - is not to the point; indeterminateness is. To say that the future is indeterminate is precisely to say that it is not attribute-specific.

I come back to the more general argument. The contrast between the determinate and the indeterminate, between the definite and the indefinite, appears to be an ontological one; a matter of what exists, in a universal and unqualified sense. As such it is a matter of public record, the actually existent world which encompasses us all. It follows that its boundary is a spacelike hypersurface; and from this point on, we are familiar with all of the arguments from the case of tense.

It seems that the idea that the future is indeterminate, and not just unpredictable, is incompatible with relativity. Insofar as quantum mechanics has provided a mathematical expression of it, in terms of the superposition of states, it seems that this theory and relativity are pulling in diametrically opposite directions. In fact, properly understood, they are pulling in tandem.

5 The Everett Interpretation

The Everett approach involves a kind of modal realism; in some sense all physical possibilities are realized. The idea is fantastic, granted; but one should first see what it means, and whether it is consistent with physical principles. Alternative approaches to the problem of measurement call for their outright revision[4].

Consider first non-relativistic quantum mechanics. Suppose, from the outset, that a preferred basis is given once and for all (equivalently, that a preferred set of projections is given once and for all). We have the following parallel: corresponding to distinct times in non-relativistic classical theory, there are distinct possibilities, or components of state, in NRQM (all at a fixed time). Moreover, corresponding to the binary relation of simultaneity between local events $a, b, ...$ denote Sim, there is a binary relation between equal-time projections $\widehat{a}, \widehat{b}, ...$ denote Def, depending on the universal state[5], such that Def$(\widehat{a}, \widehat{b})$ if and only if $\widehat{b}$, is value-definite relative to $\widehat{a}$. In the non-relativistic case Sim is an equivalence relation; suppose that Def is too. One can then partition the set of all events, respectively the set of all projections, into equivalence classes corresponding to the different moments of time $A, B, ...$ in spacetime, and to different possible worlds $\widehat{A}, \widehat{B}, ...$ in the universal state. Call the view that only *one* of these possible worlds is real *actualism*. It is a natural extension of presentism[6]. Clearly, on this view, the distinction between the determinate (the actual) and the indeterminate (the non-actual) is drawn in terms of what exists.

It is not so clear that the alternative, that all possibly worlds (at a given time) are equally real, has anything to do with relationism. The relationist accounted for tense in terms of relations; nothing similar is so far on offer in the case of indeterminateness. Is it possible to adopt relationism when it comes to times, but actualism in the case of possibilities? Given determinism of course it is; that is the picture we have had in mind all along in the classical case. But it cannot be defined in terms of the relations available in quantum mechanics, assuming the branching of the universal state with respect to the preferred basis. It is a simple matter to extend Def to projections at different times. Doing this, one finds it is transitive[7]; but it cannot be symmetric in the presence of branching. Given bifurcation, with no recombination of branches, then from any world $\widehat{A}$ a unique path can be traced backwards in time to $\widehat{B}$; so Def$(\widehat{A}, \widehat{B})$. If Def$(\widehat{B}, \widehat{A})$ as well, then the transition amplitude for $\widehat{A}$ with respect to $\widehat{B}$ would be 1, and there could be no branching from world $\widehat{B}$, contrary to the hypothesis. So Def is not an equivalence relation, and one cannot end up with the classical relational picture of a 4-dimensional space-time without any distinguished present.

Neither, in that case, can one define Lewis's picture, where all possible 4-dimensional worlds are supposed to be equally real. We should not want to. According to Lewis, possible worlds bear no physical relations with one another. In that case, since we are considering a physical theory, it is hard to see why a single one of them, the actual world, is not enough. In any case Lewis has no place for indeterminateness; his theory of probability is just like the one already stated for the consistent histories approach (Lewis 1983).

But we can make sense of actualism combined with possibilism: a determinate past, up to a certain moment of time, is all that exists; the future does not exist, or is otherwise only potential. This is the view that will probably have the broadest appeal. It has long been favored by Shimony, and appears natural from the point of view of a state-reduction theory. Once again the distinction between the determinate and the indeterminate is drawn at the level of existence.

There is an alternative. We can suppose that at this moment in time all such possible worlds are equally real. It is still the case that in each the distinction between the determinate and the indeterminate is drawn at the level of ontology, along with the contrast between past and future; but the question of what the determinate reality is, and the range of future possibles, becomes indexical; it is the question of which world happens to be ours. This corresponds to the *many worlds* view, understanding tense in accordance with possibilism. As with Lewis's metaphysics, the important question is whether, and how, these worlds are related to each other; in the first instance, whether any parts of them which are qualitatively identical are numerically identical. One of the clearest exponents of this view is David Deutsch; according to him they are to be distinguished (Deutsch 1985). In that case, again one wonders why we need more than one of these worlds at each time.

More interesting is the case where one considers in addition all times. This is the view championed by Storrs McCall (1994). McCall represents the indeterminate future as a set of branches, one for each potentiality, fanning out from a trunk representing a unique and determinate past. The point of bifurcation is the present. All possible tree-diagrams exist for every time; it only remains to say which of them is ours. The distinction between past and future, and between the determinate and indeterminate, is wholly indexical. Again, as with the many-worlds view, there remains an ambiguity as to whether or not different tree-diagrams are physically related.

There is a natural way to combine them all. Suppose that the local parts of different diagrams are numerically identical if they are qualitatively identical. The trunks of two diagrams, if they share an initial segment, are there fused into one; yielding a new diagram, incorporating each of them as a branch, bifurcating from their common part. Continuing in this way, one obtains a single dendritic diagram, without any trunk[8]. Evidently the question of whether or not an event is indeterminate or determinate has become relational, depending on its status as future or past; as whether or not the question of whether an *incompatible* event is indeterminate or determinate. In other words, which of two mutually exclusive possibilities has happened, is likewise relational. This was Everett's original point of departure, his concept of the relative-state. This is the Everett interpretation; it is the natural extension of relationism in the case of tense.

Just as one combines all moments of time into space-time - obtaining a relational account of what is past and what is future - one combines all possible tree-diagrams, obtaining a relational account of what is determinate and what is indeterminate. The single diagram that results represents the unitary orbit of the universal state, expressed as a system of correlations; a certain network of relations. There are, of course, arbitrarily many other networks of relations; just as, in classical spacetime, there are arbitrarily many distinct foliations. But in both cases it is the local structure of the state, or of spacetime, that we are interested in, that is better or worse exhibited by the choice of projections, the dynamical variables; and better or worse by the choice of foliation, the coordinates.

This point is worth emphasizing. If one chooses a different set of projections at each time, one obtains a different system of correlations; just as with a different choice of coordinates on classical spacetime. But in both cases one has exactly the same object: the universal state and spacetime, respectively. Such different choices may be better or worse suited to describing the physics; our understanding of it, using projections which are related in accordance with quasiclassical equations of motion, is particularly suited to certain regions of the universal state - those in which we are to be found. And they are particularly suited to describing what we in fact observe - because we, our form of life, is built up from just those kinds of correlations. Both the dynamical variables, in quantum mechanics, and the coordinates, in relativity, used to describe these sorts of patterns, are more or less approximately defined; for nothing fundamental, at the ontological level, hangs on them.

But all of this is something of a fairy-tale, because, except for very special choices of the universal state - or for special regions within it - Def will not be symmetric at equal-times. It will be if the preferred basis at each time, the local projections $\widehat{a}, \widehat{b}, ...$ are defined by the criterion of environmental decoherence[9]. This does yield approximately classical histories, in favorable circumstances (Diósi *et al*, 1994); but it does so only in an approximate sense, and only in those favorable circumstances. In this sense the preferred basis may be defined only *locally.* From it we cannot in general build up to global projections $\widehat{A}, \widehat{B}$,....without privileging a particular sub-system, or locality, in each. All the strategies just discussed are still available, but the worlds all have a privileged place, or a privileged sub-system. With that, actualism, as applied to presentism and possibilism, is no longer credible.

There remain only the various forms of realism about possible worlds. When we consider the relativistic case, we lose the symmetry of Sim as well, viewed as an intrinsic geometrical relation. Deutsch's approach is no longer available, and nor is McCall's, as he intended it. We cannot partition space-time into times, on the basis of any intrinsic relation in the space- time metric; and we cannot partition the universal state into worlds, using intrinsic relations in the Hilbert-space norm. What one does have is a local version of McCall's view: many possible events, at different places and times, each with a locally-defined determinate past and indeterminate future. But better is the relationist view, where they are combined into a natural totality, and where our pre-theoretic notions of tense and indeterminateness can be made out in terms of relations within it.

6 Indeterminateness According to Everett

We learn better what form the Everett approach must take in RQFT. It is an intrinsically local theory, supposing that the preferred basis is defined by purely local criteria of decoherence; locally, in such decohering regions of the universal state, Def will be approximately symmetric as well as transitive[10]. But there will be no global extension of it. This point is important if we are to understand how stochasticity can be reconciled with relativity; and, indeed, the sense in which the Everett approach operates with Minkowski spacetime. Callender (this volume) is right to call this in question; if spacetime points are individuated by physical criteria, but referring to different branches, it follows that spacetime cannot be Hausdorf[11]. It is of no use to point out that the universal state is defined on Minkowski spacetime: whatever else relativity is, it is a phenomenological theory; the universal state is not what is observed, but only the relations which it codifies. In what sense - at the observable level - is our theory relativistic?

We should first verify that on the relational view Everett's approach is indeterministic - at the same, phenomenological level. It surely is, because one cannot solve the Cauchy problem, using data which concerns ordinary macroscopic events; not even if supplemented with data at the microscopic level, and not even given the universal state. Knowing everything there is to know, one cannot predict data of this sort for any future time-slice. One can predict *all possible* data of this sort, with all the associated transition-amplitudes; but nothing less.

For many that is not enough to ensure that the theory makes sense of probability; but I do not want to dispute that point here[12]. Let me grant that one must be able to define an *effective* stochastic process, to govern this phenomenology (some will insist that is not enough either; but again I defer discussion of that point). But we are agreed that the principles of relativity theory had better apply to what is observed. So this effective process had better be Lorentz covariant; how are we to square this circle?

I come back to my opening remark: the approach is fundamentally a local one. The process is to be defined at each space-time point, as an effective state reduction on a certain 3-dimensional surface in space-time. But this surface is not a time-slice, a space-like hypersurface. It is the surface of the forward light-cone of each point. As such, on making a Lorentz- transformation, this surface, and the associated data, is *invariant*. We do not have to transform between data at one space-time point, to data at another. Just as important, these stochastic processes at these space-time points are all *independent* of each other.

Of course, if we attempted to consider all of these operating in tandem, on a space-like hypersurface, and thereby attempted to define a stochastic process for a global 3-dimensional world, we could never in this way obtain any EPR-type correlations: the independence of the local processes implies factorizability, and that in turn the Bell inequalities (which we know to be violated). But that is only to say once again: the Everett relational approach is fundamentally local; it is consistent with relativity, as goes the observed phenomenology, only in this light. These correlations between measured outcomes are incorporated into *local* records; and the amplitudes for such records, in which the correlations do not obtain, are vanishingly small.

Is the Everett approach believable? But I know of no other that is. We can do no better than seek a coherent and systematic interpretation of physical theory. It should respect our pre-theoretical opinions that we are firmly attached to; and it should respect hard-won theoretical principles as well. Among our pre-philosophical opinions I count the sense that the future is indeterminate, in contrast to the present and past; and among theoretical principles I prize the relativity principle, and the principles of quantum mechanics. Everett's ideas hold out a radical and austere way of combining them; that is reason to pursue them. Revisionary approaches to the problem of measurement may yet yield dividends in the laboratory; and they may yet theoretical dividends too, if they further a theory of quantum gravity. But in the latter case, they will surely have to be conservative with respect to particle physics - to RQFT. Therein is the difficulty.

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Endnotes

1 The two techniques are in fact very different. For philosophical and historical background, see my (1998a).
2 One can locally define a foliation by reference to the cosmological microwave background; but that there is no guarantee that it be extended globally, and as COBE showed us, it is not perfectly isotropic. (See also my 1996a.) The conclusion may be different on certain approaches to quantum gravity, however; particularly the canonical approach. I have shall have nothing to say on that here.
3 Since it is of the essence to this thesis that tense is perfectly objective and real, albeit relational, the expressions "fatalism", "eternalism", and "the tenseless view" are clearly inappropriate.
4 The point is widely acknowledged in the case of state-reduction theories. For the pilot-wave theory, see my (1999); for the consistent histories approach, see Dowker and Kent 1996).
5 If ρ is the universal state, Def$(\widehat{a},\widehat{b})$ iff $Tr(\widehat{b}\widehat{a}\rho\widehat{a})/Tr(\widehat{a}\rho) = 1$; this is just Everett’s relativization, written in terms of projections (see my 1995 for further background).
6 Compare Hinchliff (this volume): ‘other times are like other possible worlds, they are not real. As there is something special about what is *actual* - it is all there is - so there is something special about the *present* - it is all there is.’
7 So long as the histories are consistent. See my (1996b).
8 I put to one side questions of the early history of the universe, and of an absolute origin.
9 Partition space S at time t into volumes S_k, $k \in I$, for a suitable index set I. Let local projections $\widehat{a}_k, \widehat{b}_k$,.. be associated with S_k . Choose any $j \in I$; take the partial trace of the state over degrees of freedom external to S_j , and then take the spectral decomposition of the reduced density matrix. If the basis that results diagonalizes the projections $\widehat{a}_j, \widehat{b}_j$, and this is so for every $j \in I$, then Def will be symmetric. (If $I = \{1, 2\}$, this requirement is: local projections are diagonal in the basis defined by the biorthogonal form.)
10 Stein has made a similar point in connection with Ein, in the classical case (Stein 1991 p.161-2).
11 It is worth remarking that the Hausdorf property is a non-local topological property. See Douglas (1995), who concludes it is suspect in consequence.

12 See my (1998b), and references therein, for detailed discussion.