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EXACTING A PHILOSOPHY OF BECOMING FROM MODERN PHYSICS

BY

RICHARD T. W. ARTHUR

It seems to me an extraordinary fact that, in the longstanding dispute over the objectivity of becoming, exact philosophers have, almost without exception, come down *against*. As far as Western philosophy is concerned, of course, this side-taking began at the beginning when Parmenides and Zeno of Elea sharpened their emerging analytical abilities at becoming's expense. McTaggart and the early Russell one might also place in this tradition. But one would hardly expect modern philosophers of physics, whose disposition, after all, is more Ionian than Eleatic, to be similarly opposed; yet ranged against the objectivity of becoming we can find quotations from Einstein, Minkowski and Weyl, and explicit opposition from Gödel, Grünbaum, Smart, Putnam and, in their wake, the majority of modern philosophers of science.[1]

But if I am right one of the main reasons for this opposition lies in the vagueness of the expositions of becoming given by its proponents, and it is this deficiency that I shall attempt to redress here.

Temporal Becoming

First it is necessary to relate our subject to the theory of time. Now becoming is usually conceived in the form of a *"tide"* sweeping from past to future: everything that has become is in the past, everything that is yet to come is in the future, and the set of things or events that is in the present marks the ever-changing border between the two.

But there are insuperable problems with this account. In the first place, as McTaggart, Russell, Grünbaum and others have argued,[2] the conception of a "moving present" is hopelessly flawed, and so would hardly provide us with a happy foundation for our construction. Furthermore the "tide" conception of becoming is firmly anchored to a theory of time which is absolute in two senses: (i) it depends on the existence of a well-defined absolute present moment, thus precluding its application to a relativistic universe; and (ii) it implies that "coming-to-be" is conferred on an event by the passing or transiency of an event-independent time, whereas we would prefer to conceive an event—literally, "something which comes about"—as the seat of becoming.

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We would therefore do much better to abandon the construal of becoming in terms of the moving present, and construe it directly as a *relation among events.* Let us then define the two-place relation B on the set of all possible events E as follows:

Definition 1

For any $a,b \in E$, $aBb =_{def}$ *a has come about for b.*

Now let us investigate the conditions such a relational construal of becoming should be expected to satisfy. As minimal conditions we should expect B to be both *transitive* and *asymmetric:*

Postulate of Transitivity

For any $a,b,c \in E$, aBb & $bBc \rightarrow aBc$. (If *a* has come about for *b* and *b* has come about for *c*, then *a* has come about for *c*.)

Postulate of Asymmetry

For any $a, b \in E$, $aBb \rightarrow \sim bBa$. (If *a* has come about for *b*, then *b* has not come about for *a*.)

Some comments are in order at this point.

These two properties of the relation B suffice to establish a *strict partial ordering* on the set of all possible events, which we may call the *order of becoming*. Clearly, given the relationship between time and becoming, we will want to identify this order of becoming with the *temporal order.*

Now there is a dominant school of thought which holds that the *time-reversal invariance of all physical laws* establishes either (a) that the temporal order is *intrinsically symmetric,*[3] or at least (b) that it would be in the absence of irreversible processes.[4] Evidently either of these positions would automatically rule out the above identification of the order of becoming as the temporal order. For if (a) is true, the temporal order cannot be asymmetric as our second postulate requires, and if (b) is true, the reversibility of physical processes cannot consist in a reversibility of the order in which the states comprising the process come about. But as I have argued elsewhere,[5] these are good grounds for *rejecting the alleged equivalence of T-invariance and the symmetry of the temporal order,* rather than arguments against asymmetric temporal becoming.

Becoming, after all, is a category that pertains to *individual* processes, pairs of states, or events etc. It is no argument against the asymmetry of the order of becoming that certain *types* of process may be ordered in either direction with respect to it: if the law governing a type of process with states A, B, and C, for instance, is *time-symmetric,* this means that—*de facto* conditions aside—the individual process with A coming about after B, and B coming about after C, is equally likely to occur as the process with C after B, and B after A. In either case the order of becoming of the states is asymmetric. Thus the asymmetry of becoming is completely independent from questions of reversibility and irreversibility, and is not contradicted by the existence of time-symmetric physical laws.

Now let us look at what further structure it is reasonable to attribute to becoming. So far we have a strict partial ordering of possible events. There is, however, no intuitive conception of *connectedness* for the relation divorced from its connection with absolute time: if neither aBb nor bBa (neither comes first), we cannot deduce the identity of a and b, nor even that they belong to the *equivalence class* of events which happen at the same time. But of course we are free to *postulate* such connectedness, and it is interesting to see that to do so is equivalent to establishing the basis for an absolute time in the first of the senses alluded to above.

This, in effect, is what Leibniz did in his *Metaphysical Foundations of Mathematics* in 1715.[6] Construing the effective component of his relation "contains the ground for" as our relation B, his postulate of "the connection of all things" can be used to establish the relation of contemporaneity C as an equivalence relation on the set of all possible events. This is achieved as follows.

First contemporaneity is defined in a way whose form is familiar from the causal theory of time, but whose interpretation in terms of becoming appears to be intuitively more plausible:

Definition 2 (Contemporaneity)

For any $a,b \in E$, $aCb =_{def} \overline{aBb}$ & $\overline{bBa}$. (For any two possible events *a* and *b*, *a* is contemporaneous with *b* if and only if neither event has come about for the other.)

The reflexivity and symmetry of C now follow easily from this definition and the foregoing postulates. But for contemporaneity to be an equivalence relation, C must also be *transitive,* and this can only be effected by the addition of a further postulate. The following is sufficient, and approximates Leibniz's postulate of interconnectedness under this interpretation:

Leibniz's Postulate

For all $a,b,c \in E$, aCb & $aBc \rightarrow bBc$. (For any three possible events *a,b* and *c*, if *a* is contemporaneous with *b* and has come about for *c*, then *b* has also come about for *c*.)

With C thus established as an equivalence relation, its definition (Def. 2) above fulfills the role of a postulate of connectedness for the relation B. If we now pass to the quotient set $\overline{C}$ induced on E by this equivalence relation C, that is, the set of all such equivalence classes, we see that it is *totally ordered* by the relation B. That is, we have an *absolute time:*

Define an *instant* as the equivalence class of contemporaneous possible events. Then *absolute time* is the set of all such instants ordered by the relation B.

Now with the additional postulates of *denseness* and *denumerability* of possible events—both explictly posited by Leibniz—and, in addition, *Dedekind's cut postulate*—which was partially implicit in Eudoxus' treatment of the continuum which Leibniz followed[7]—we have Leibniz's complete concept of a temporal ordering which is isomorphic to the real numbers in their standard ordering.

We may call the time defined by the above postulates *Leibniz-absolute time.*[8] But this is quite different from absolute time in Newton's main sense of a time flowing independently of events. To investigate *Newtonian absolute time* we must turn to the context of *spatiotemporal becoming*.

Becoming in Newtonian Spacetime

Newton conceived the *transiency* of events as accruing from their occupation of points of absolute space at successive instants of a constantly flowing absolute time. Now apart from any Neoplatonistic bias he may have had, Newton had independent technical reasons for regarding time as a constantly flowing entity; these had to do with his theory of fluxions,[9] on the one hand, and the provision of a continuous kinematic connection between points of absolute space at different times, on the other. Now, as Howard Stein has explained, this latter concept of a kinematic connection amounts to the requirement of an *affine connection* among points of a *four-dimensional spacetime*.[10] Thus Newton's kinematics must be regarded as supplying, in effect, a theory of *spatiotemporal becoming*, rather than simply temporal becoming. For, unlike Leibniz's theory, Newton's is able to provide an adequate foundation for the paradigm instance of becoming, the *motion* of an object through space and time.

But as we've already noted, Newton conceived his space and time as entities existing *independently* of events. This conception was eloquently refuted by Leibniz, who showed that the concepts of instant (and spacetime point) were incomplete unless they were interpreted as referring to the relative positions of possible events.[11] On such an interpretation, Newton's spacetime structure still has an absolute existence as the posited structure of spatiotemporal relations among all possible events, but it has no meaning independently of the existence of possible events which could individuate its points.

Consequently, if we now adopt this Leibnizian interpretation of Newtonian spacetime, we can no longer accept Newton's construal of transiency in terms of the flowing of time. Instead, we must construe it as before in terms of a relational property of *events*, in this case the set of possible events which satisfy the spatiotemporal relations implicit in the Newtonian spacetime structure.

Let us call this set N. We may now define a relation B_N on this set N, and require it to satisfy our minimal postulates of transitivity and asymmetry as before. But now our relation of becoming has considerably more structure than before, corresponding to the fact that certain lines in Newtonian 4-D spacetime are to be interpreted as paths of *possible spatiotemporal processes*. Indeed, all the requirements of the *continuity* of the temporal order, as well as its *connectedness*, follow directly from this interpretation of the Newtonian spacetime structure. Thus it is a property of the four-dimensional affine structure of Newtonian spacetime that it allows a decomposition into equivalence classes of events which form a family of parallel three-dimensional affine subspaces, each of which possesses a Euclidean metrical structure, such that every straight line transverse to these is a one-dimensional real affine space. The significance of these straight lines, which are called *timelike* straight lines, is that they represent possible paths of uniform rectilinear spatiotemporal becoming.[12] Now since this interpretation is generalizable to any timelike lines, straight or curved, we are led to the following principle:

Principle of Spatiotemporal Becoming

For any $a,b \in ST$, $aB_{ST}b =_{def}$ *the vector defined by (a,b) is* timelike
(where *ST* is the set of possible events of the spacetime in question, and B_{ST} is an asymmetric and transitive relation defined on it).

Now the condition $\sim aBb \;\&\; \sim bBa$ (neither comes first) may be used to define an equivalence relation of contemporaneity as before, and this relation will then give us a total ordering of instants of absolute time. Only in this case each instant (or equivalence class of events under contemporaneity) will possess a Euclidean metrical structure which must be identified as the *structure of spatial relations* among these contemporaneous events, and the total ordering of instants by the relation B_N will automatically have the structure of an affine real line. This is *Newtonian absolute time*.

For the sake of completeness, it should perhaps be remarked here that the structure of Newtonian time is left invariant by the introduction of the Principle of Invariance under Galilean Transformations. For although this principle has the effect of obliterating Newton's absolute space, its effect on the topology of time amounts only to the replacement of the single time-axis of absolute space by a family of parallel time-axes, each corresponding to a particular inertial frame of reference. But because the time axes are parallel, an instant of each time axis will consist in the same equivalence class of events (modulo a common origin and scale). We can therefore introduce an affine coordinate function that ranges over the instants of Newtonian time in the past-future direction which is unique up to a change of scale and zeropoint.

Becoming in Einstein-Minkowski Spacetime

Now let us turn to the context of Einstein-Minkowski spacetime. The most salient feature of this spacetime is the *relativity of the time coordinate function* to a particular inertial frame. Associated with each and every such reference frame there exists a well-defined *time-axis*, which runs orthogonal to a family of parallel 3-D affine subspaces of 4-D Einstein-Minkowski spacetime, just as in the Newtonian case. The difference is that the time axes of Lorentz frames in relative motion are not parallel to each other, as are the Galilean time axes. Consequently, the class of events which is simultaneous with a given event is different for each choice of reference frame.

Yet within the context of special relativity there is no principle by which one such frame-dependent time may be preferred over any other. From this fact, called by Hilary Putnam "The Principle That There Are No Privileged Observers,"[13] many authors have concluded with Gödel that "none of these various sytems of layers (i.e. simultaneity classes of events) can claim the prerogative of representing the objective lapse of time", and that therefore becoming is not an objective feature of the world.[14]

Let us put aside for the moment the question of the objectivity of these frame-dependent time functions and concentrate on the claim that the structure of Einstein-Minkowski spacetime precludes a viable concept of becoming—a claim that has recently been reiterated in articles by Putnam, Rietdijk and Fitzgerald.[15]

The first thing to notice about this claim from the viewpoint of this paper is that the concept of becoming which is being attacked is essentially the "tide" concept mentioned earlier in the paper. Becoming is associated by Gödel directly with the time-coordinate function, without a prior analysis of how spatiotemporal processes are represented in relativistic spacetime; it is simply assumed that the same relationship between simultaneity and becoming holds as in the case of Newtonian spacetime. That is, if we call the equivalence relation of simultaneity relative to a frame f 'Sim_f', the arguments of Gödel and company assume that, as before, we have

Connectedness

For any $a,b \in ST$, $\sim aBb \;\&\; \sim bBa \leftrightarrow a\,Sim_f\,b$.

Now it is a simple matter to show that this assumption gives rise to a situation where ~aBb and aBb both hold, thus precluding the existence of a self-consistent relation of becoming of this kind on Einstein-Minkowski spacetime. (See Figure 2, and the associated argument, below.)

But although this argument constitutes an adequate refutation of the "tide" conception of becoming in special relativity, it does not constitute a sound argument against our relation of becoming B. This is because the "tide" conception depends crucially on the above postulate of connectedness, and *the postulate is false in E-M spacetime.*

To see this it is necessary only to observe that spatiotemporal processes are represented in E-M spacetime just as they were in Newtonian spacetime, by *timelike lines,* so that the same principle of spatiotemporal becoming holds. But whereas in Newtonian spacetime the class of events not in timelike relation to a given event forms an equivalence class, so that B_N is connected, in Einstein-Minkowski spacetime it does not:

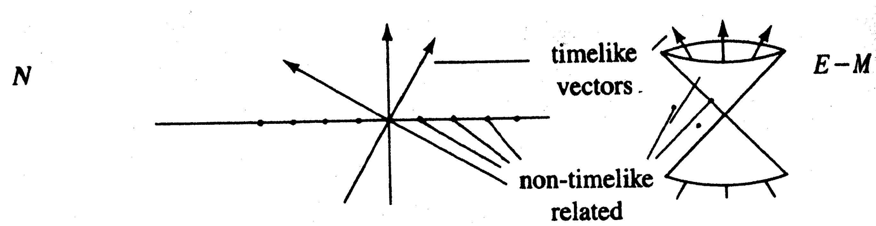
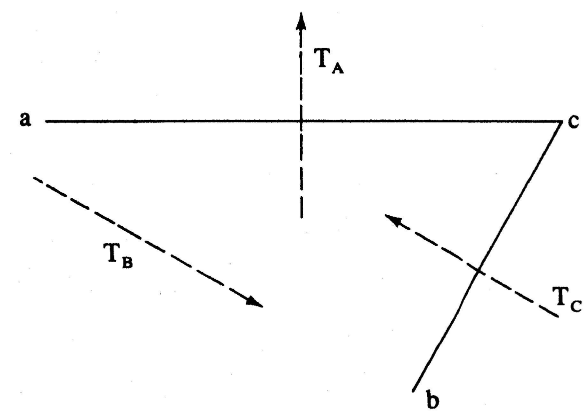


Figure 1

Consequently B_{EM} cannot be used to define a unique total ordering of instants, and there is no serial order of becoming. However there is still a perfectly valid *strict partial ordering*. This order is invariant under the orthochronous Lorentz transformations and is therefore *objective* ("the same for all possible physical observers"); it corresponds to the "*conical* time order" established by A. A. Robb in 1914.[16] (Intuitively it is readily conceived as a network of asymmetric timelike lines branching out in all future-pointing directions in spacetime.) The lack of a unique time-function for E-M spacetime can be construed as a result of the absence of a unique flow of becoming, due to the dependence of the rate of becoming of one process with respect to another on their relative velocities. Thus the states of the same process will follow one another at different rates with respect to the time-coordinate functions of different frames in relative motion. But the notion of the rate of becoming for a given process is saved from arbitrariness by the fact that it is a minimum in the rest frame of the object in question. This fact has the consequence that, once a scale has been chosen for one time-coordinate function, a unique scale is bestowed on all other possible frame times—each is perfectly objective, contrary to Gödel's claim. Moreover, this same fact allows the definition of a *proper time function,* associated with each *timelike line segment* of spacetime (of a sufficiently smooth nature). It is this proper time which is understood to measure *the* rate of becoming for the possible process following this timelike line (or *worldline*). *

Figure 2



Event c is in spacelike separation from both a and b; aBb.
Now $a\,Sim_A\,c$ entails that ~aBc & ~cBa.
$c\,Sim_C\,b$ entails that ~cBb & ~bBc.

Proof of ~aBb:

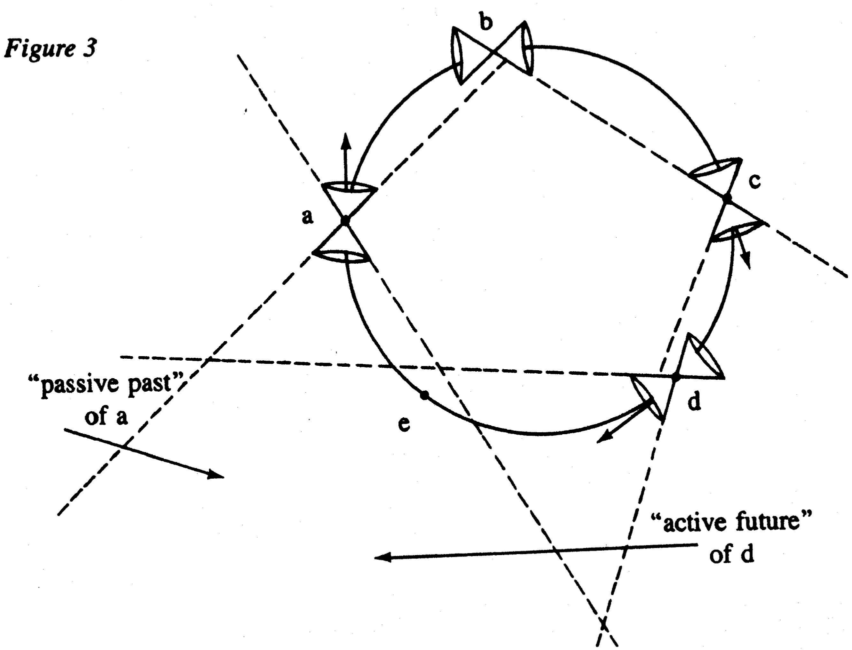
1	(1)	~(aBc)	Assumption
2	(2)	aBc & cBb	Assumption
2	(3)	aBc	2, Simp.
1,2	(4)	aBc & ~aBc	1,3 Conj.
1	(5)	~(aBc & cBb)	2,4 RAA
1	(6)	~(aBb)	5, transitivity of B.

Becoming in Curved Spacetimes

So far we have been dealing with flat spacetimes. But when we come to the context of the *curved* spacetime of Einstein's General Relativity we are again confronted with some apparently severe difficulties for our construal of becoming. For there exists a variety of solutions to the Einstein-Maxwell field equations which admit *closed timelike curves*,[17] allowing the possibility of an object's travelling through spacetime so as to return to its starting point *in time* as well as space. Now any such curve will contain a set of possible events a,b,c,d, etc. such that aBbBcBdB. . .Ba. (See Figure 3 below.) But by the transitivity of becoming we will obtain bBa as well as aBb, in contradiction to the asymmetry of B. According to Gödel, "This again shows that to assume an objective lapse of time would lose every justification in these worlds." (*op. cit.* p. 561)

But would it? First we should point out that the relation B has only been defined for the flat space that is *tangent* to the worldline of the object (say a spaceship) assumed to be making this cyclic journey into its own past. Thus even though the worldline is timelike and future-pointing throughout the spaceship's journey, the set of events which are in the spaceship's absolute past—that is, which have come about for the spaceship—are *constantly changing*, and the transitivity of B cannot be assumed to hold good *between* any two such tangent spacetimes. It must, however, hold good for a sufficiently small line segment of the timelike line, since it is on this condition that the definability of the proper time of the spaceship depends.

Figure 3



"The cone of the active future encroaches upon that of the passive past", Hermann Weyl, *Raum Zeit Materie*, p. 249.

In fact, of course, the very counterintuitiveness of such closed timelike worldlines, far from contradicting becoming in our sense, *depends* on the interpretation of proper time as measuring the objective lapse of time for the spaceship. It is after a lapse of a certain period of its proper time that the spaceship encounters events such as 'e' that were *previously* (with respect to its proper time!) in its own *past* (with respect to a given spacetime point).

Thus, on this analysis, becoming is an essentially *local* phenomenon, and would not be impugned at all by the existence in the actual world of closed timelike worldliness. Our principle of spatiotemporal becoming stated above may therefore be retained, provided only that we restrict our asymmetric, transitive relation B to the *tangent space* of the curved spacetime at any point on a timelike curve.

Becoming in Quantum Theory

Perhaps the most interesting implications for the concept of becoming, though, are to be found in quantum theory. But my time is running out, so I shall just restrict myself to a few remarks.

First, it is apparent that insofar as any quantal processes manifest themselves in space and time, they do so in accordance with the above principles. A quantal event, such as the mutual annihilation of an electron-positron pair, may only come about provided the electron and positron follow continuous curves in spacetime to the point of their collision.

At a more fundamental level, however, we know that there are no precise trajectories; a given timelike curve represents only *the most probable path* of a given quantal process. Events actually localized in spacetime, such as the detection of an electron by a Geiger counter appear to be *discrete*. Yet, on the other hand, the probabilities of localization themselves propagate in a continuous fashion, so that the states in the state space of a given quantal process form an ordered set which is continuous, linear, transitive and asymmetric. This suggests that quantal time must be defined on the state space, leaving us with the interesting problem of demonstrating its *compatibility* with the spacetime description of becoming given above.

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NOTES

[1]Milič Čapek gives a useful summary of positions in his article "The Inclusion of Becoming in the Physical World", in his *Concepts of Space and Time*, D. Reidel, Boston, 1976.

[2]See J.M.E. McTaggart, *The Nature of Existence* Vol. II, Cambridge, 1927, pp. 9–31; Bertrand Russell, *The Principles of Mathematics*, (esp. Ch. 13), 2nd edn., N.Y., W.W. Norton & Co. Inc., 1943; Adolf Grünbaum, "Relativity and the Atomicity of Becoming", *Review of Metaphysics* IV, Dec. 1956, pp. 143–186; and George Schlesinger, "The Structure of McTaggart's Argument", *Review of Metaphysics* 24, pp. 668–677.

[3]Cf. Henryk Mehlberg, "Physical Laws and Time's Arrow", pp. 105–138 in H. Feigl and G. Maxwell (eds.), *Current Issues in the Philosophy of Science*, Holt, Rinehart and Winston, N.Y. 1961.

[4]Cf. Adolf Grünbaum, *Philosophical Problems of Space and Time*, (esp. Ch. 8), D. Reidel, Dordrecht/Boston, 1973.

[5]"A New Slant on the Direction of Time", Address to the *Canadian Philosophical Association Congress*, Dalhousie, June 1981.

[6]G.W.F. von Leibniz, "Metaphysical Foundations of Mathematics", (1715), pp. 201 & ff. in P.P. Wiener (ed.), *Leibniz: Selections*, Charles Scribner's Sons, N.Y. 1951.

[7]Consult Hermann Weyl, *Philosophy of Mathematics and Natural Science*, Princeton University Press 1949, Athenum, N.Y. 1963: pp. 38–46.

[8]Compare John Winnie's treatment in "The Causal Theory of Spacetime", Minnesota Studies Vol. VIII, *Foundations of Space-Time Theories*, Earman, Glymour and Stachel (eds.), University of Minnesota Press, Minneapolis, 1977: pp.134–205.

[9]For details, consult my address to the CSHPS, "The Theory of Fluxions and Newton's Theory of Time", May 1981.

[10]Howard Stein, "Newtonian Space-Time", *The Texas Quarterly*, Autumn 1967, pp. 174–200. My treatment of spacetime theory here is much indebted to this article of Stein's, as well as to his "On Einstein-Minkowski Space-Time", *Journal of Philosophy*, Vol. LXV, No. 1, Jan. 11, 1968.

[11]See especially Leibniz's 3rd paper §6 in his celebrated correspondence with Samuel Clarke: P.P. Wiener, *op. cit.*, p. 224.

[12]As Howard Stein has emphasized, a *timelike vector* can be defined *intrinsically*, (i.e. without dependence on coordinate systems) in Einstein-Minkowski as well as Newtonian spacetime. For details and a lucid discussion, see Stein (1968), p. 7.

[13]Hilary Putnam, "Time and Physical Geometry", *Journal of Philosophy* LXIV, 8, April 27, 1967, pp. 240–247: p. 241.

[14]Kurt Gödel, "A Remark About the Relationship Between Relativity Theory and Idealistic Philosophy", pp. 555–562 in Paul A. Schilpp (ed.), *Albert Einstein: Philosopher-Scientist*, Open Court, La Salle, Illinois, 1949.

[15]Putnam, *op. cit.*; C.W. Rietdijk, "A Rigorous Proof of Determinism Derived From the Special Theory of Relativity", *Philosophy of Science* 33, 4, Dec. 1966, pp. 341–4. Paul Fitzgerald, in his "The Truth About Tomorrow's Sea Flight", *Journal of Philosophy* LXVI, No. 11, June 5, 1969, takes a neutral stand on this claim.

[16]A.A. Robb, *A Theory of Time and Space*, 1914. A more accessible and lucid account of his theory is given by Robb in his *The Absolute Relations of Time and Space*, Cambridge University Press, 1921. See also the article by Winnie cited above.

[17]For instance, the Gödel solution, Taub-NUT space, de Sitter and anti-de Sitter spacetimes, and the Kerr solutions.

WHY ARE NOVEL PREDICTIONS IMPORTANT?

BY

RICHMOND CAMPBELL AND THOMAS VINCI

Introduction

Novel predictions, when they are successful, confirm a theoretical hypothesis much more strongly than the data already at hand that may have inspired it. The contrast appears stark and intuitively irresistible. It takes only imagination to invent a hypothesis tailor-made to fit known data. But to predict with accuracy experimental outcomes that would be unexpected otherwise requires a hypothesis that is at least approximately true, or else an astounding coincidence. Because such coincidence is very improbable, the success of novel predictions leads us inductively to have confidence in the hypothesis that implied them. It is no wonder that novel predictions provide strong confirmation.

But this easy view of the matter masks two fundamental problems: What makes novel predictions novel, and what general approach to the theory of confirmation will explain the importance of this kind of novelty? Our opening paragraph suggests a simple, rough and ready answer to the first question. A theoretical hypothesis provides novel predictions in the relevant sense *when it predicts results that would be unexpected otherwise*, i.e., unexpected, apart from the hypothesis in question, relative to our general background knowledge. This answer is initially plausible and gives the usual view of the matter.[1] For the sake of a convenient label, we shall call this kind of novelty *epistemic*. In this paper we shall argue to the contrary that epistemic novelty is not what makes novel predictions novel and cannot be used to explain the importance of novel predictions in the confirmation of theoretical hypotheses.

1. *Epistemic Novelty and Bayes' Theorem*

Whether epistemic novelty is the sense of novelty that is relevant for the purpose of analyzing the logic of confirmation remains to be seen. For the moment let us assume that it is and consider what role epistemic novelty might play in an application of Bayes' Theorem. A simple version of this theorem that follows directly from the standard definition of conditional probability is given in the following equation:

$$pr(h/e) = \frac{pr(h) \times pr(e/h)}{pr(e)}$$

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