

Einstein, Relativity and Absolute Simultaneity

Edited by William Lane Craig
and Quentin Smith



Routledge
Taylor & Francis Group

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2005 marked the centenary of one of the most remarkable publications in the history of science, Albert Einstein's "On the Electrodynamics of Moving Bodies," in which he presented a theory that later came to be known as the Special Theory of Relativity. This 1905 paper is widely regarded as having destroyed the classical conceptions of absolute time and space, along with absolute simultaneity and absolute length, which had reigned in physics from the times of Galileo and Newton to the dawn of the twentieth century. As we embark upon a new century, the Special Theory is now 100 years old, and a great deal has transpired in both philosophy and physics since its first publication. This volume is a timely reappraisal the theory's central claims, especially concerning the elimination of absolute time and absolute simultaneity.

This collection draws together essays by both philosophers and physicists, and reflects the cutting edge of research and thought on the question of absolute simultaneity. The issues discussed in the book include Aspect's confirm of Bell's theorem, De Broglie-Bohm's quantum mechanics, the privileged cosmic time series in a Friedman universe, Lorentz's ideas and neo-Lorentzian theory and other relevant issues. Almost all the contributors are convinced that the received view that simultaneity is not an absolute relation is not only unwarranted but false, and it is hoped that this collection will stimulate discussion among both philosophers and physicists concerning the warrant for and problems with assertions of the relativity of simultaneity on the basis of Einstein's theory.

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First published 2008
by Routledge
2 Park Square, Milton Park, Abingdon, OX14 4RN

Simultaneously published in the USA and Canada
by Routledge
270 Madison Avenue, New York, NY 10016

This edition published in the Taylor & Francis e-Library, 2007.

“To purchase your own copy of this or any of Taylor & Francis or Routledge’s collection of thousands of eBooks please go to www.eBookstore.tandf.co.uk.”

Routledge is an imprint of the Taylor & Francis Group, an informa business

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British Library Cataloging in Publication Data

A catalogue record for this book is available from the British Library

Library of Congress Cataloging in Publication Data

Einstein, relativity, and absolute simultaneity / edited by William Lane Craig and Quentin Smith.

p. cm.

1. Relativity (Physics) 2. Special relativity (Physics) 3. Absolute simultaneity. 4. Space and time. 5. Bell’s theorem. 6. Lorenz transformation. I. Craig, William Lane. II. Smith, Quentin, 1952-
QC173.585.E35 2006

530.11-dc22

2006015456

ISBN 0-203-70005-8 Master e-book ISBN

ISBN13: 978-0-415-70174-7 (hbk)

ISBN13: 978-0-203-70005-1 (ebk)

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Introduction

2005 marked the centenary of one of the most remarkable publications in the history of science, Albert Einstein's "On the Electrodynamics of Moving Bodies," in which he presented a theory that later came to be known as the Special Theory of Relativity (STR).

This 1905 paper is widely regarded as having destroyed the classical conceptions of absolute time and space, along with absolute simultaneity and absolute length, which had reigned in physics from the times of Galileo and Newton to the dawn of the twentieth century.

As we embark upon a new century, the Special Theory is now 100 years old, and a great deal has transpired in both philosophy and physics since its first publication. It therefore seems appropriate at this time to seek a fresh appraisal of the theory's central claims, especially concerning the elimination of absolute time and absolute simultaneity.

Part I

The classical concepts of time and space were codified by Isaac Newton in his epochal *Philosophiae Naturalis Principia Mathematica* (1687). In the Scholium to his definitions in the Principia Newton, in order to overcome certain prejudices of "the common people," who conceive of quantities such as time, space, place, and motion only in terms of "the relation they bear to sensible objects," drew a distinction with respect to these quantities between "absolute and relative, true and apparent, mathematical and common".¹ The most striking feature of this distinction is the independence of absolute time and space from the relative measures thereof. Absolute time or simple duration exists regardless of the sensible and external measurements which we try, more or less successfully, to make of it. Similarly, Newtonian space is absolute in the sense that it is distinct from the relatively moving spaces associated with inertial frames and, hence, also independent of the physical measures we apply to it. But Newtonian time and space are also absolute in an important and relevant second sense. Newtonian time is absolute in the sense that the simultaneity of two events e_1 and e_2 requires only a two-place relation of *simultaneous with* between e_1 and e_2 , rather than a three-place

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relation among e_1 , e_2 , and a reference frame (or a three-dimensional hypersurface of space-time), namely, e_1 's being *simultaneous with e_2 relative to a reference frame F* . Newtonian space is similarly absolute in the sense that length is a monadic property of physical objects, rather than a relational property of physical objects that includes a relation to a reference frame or hypersurface.

Relativity already governed Newtonian mechanics, that is to say, it was impossible for a hypothetical observer associated with an inertial frame to perform mechanical experiments which would disclose to him whether he was in motion or at rest. Newton's three laws of motion and his universal law of gravity applied strictly only to the frame of absolute space or to inertial frames which are at rest with respect to absolute space, but they could be transformed and expressed in any sensible and apparent inertial frame. This principle of relativity had already been enunciated by Galileo and comes to expression in the Galilean transformation equations relating the coordinates of an event in one reference frame to the coordinates assigned to that event relative to some other reference frame. Newton's mechanics assumed that the Galilean transformation equations were the appropriate means of transforming Newton's physics from one frame to another.

There was a loophole, however, in Galilean relativity that became apparent during the nineteenth century. Although mechanics had been relativised, electrodynamics had not. Maxwell's electromagnetic theory (1865) implied that electromagnetic waves propagate through a medium, an "aether" or field, at a constant velocity c , which is independent of the motion of the source of the waves. Consequently, by measuring the speed at which light waves in the luminiferous aether pass through one's measuring apparatus, one could determine what mechanics alone could not discover, namely, whether the inertial system in which the experiment was performed was at rest or in motion with respect to the aether. Since the aether was conceived to be at rest with respect to absolute space, any motion through it would be absolute, rather than merely relative. Detection of such motion on the part of any hypothetical observer would therefore provide him with what Newtonian mechanics alone could not, namely, knowledge of his situation with respect to absolute space and time.

The failure of nineteenth century attempts to detect the earth's motion through the aether prompted a crisis in physics which compelled men like FitzGerald, Lorentz, Larmor, and Poincaré to reject the Newtonian assumption that the Galilean transformation equations were sufficient to obtain invariant laws about observed phenomena in electrodynamics and mechanics and to adopt instead the relativistic Lorentz transformations. In so doing, they had already sounded the death knell of Newtonian physics, for they had relativised the sensible measures of absolute time and space in a way undreamt of by Newton. Measures of simultaneity and of length will vary from frame to frame and so become relative to reference frames. But

since absolute time and space are independent of their sensible measures, the relativity of these measures did not lead these theorists to abandon the notion that there really exists absolute simultaneity and absolute length, even if these quantities remain undetectable to us.

Einstein inaugurated a “scientific revolution” in his 1905 paper by interrupting the research program of Lorentz and others with a radically different approach. Foundational to this approach was the denial of absolute space and the consequent redefinition of time and simultaneity so as to deny their absolute status as well. What Einstein did, in effect, was to eliminate Newton’s absolute time and space on the grounds that they were unobservable in principle, and along with them the aether, thus leaving behind only their sensible measures, so that sensible time became the only time there is and sensible space the only space there is. Since these had by now been relativised to inertial frames, one ends up with the relativity of simultaneity and of length.

Part II

How could Einstein “know” that absolute time and space do not exist? Most historians of science now recognize that Einstein’s rejection of Newtonian absolute time and space was predicated upon a positivist philosophy of science. It is now widely acknowledged that at the philosophical roots of Einstein’s theory lay an epistemological positivism of Machian provenance which issued in a verificationist analysis of the concepts of time and space. The introductory sections of Einstein’s 1905 paper are predicated squarely upon verificationist assumptions. Einstein takes it for granted that *all* our judgments in which time plays a role must have a “physical meaning,”² where physical meaning is given by operational definitions. Operationalism is already a strong form of verificationism, but there is more. Einstein goes on to say that “a mathematical description of this kind has no physical meaning unless we are quite clear as to what we will understand by ‘time’.” The meaning of “time” is made to depend upon the meaning of “simultaneity,” which is defined locally in terms of occurrence at the same local clock reading. When it comes to judgments concerning the simultaneity of distant events, the concern is to find a “practical arrangement” to compare clock times. In order to “define” a common time for spatially separated clocks, we adopt the convention that the time which light takes to travel between two relatively stationary observers *A* and *B* is the same from *A* to *B* as from *B* to *A* in a round trip journey – a definition which *presupposes* that absolute space does not exist. For that definition presupposes that *A* and *B* are not at relative rest but both moving in tandem absolutely, or in other words that neither absolute space nor a privileged rest frame exists. The only justification for that assumption is that it is observationally or sensibly impossible to distinguish uniform motion from rest relative to such a frame, and if absolute space and absolute motion or rest cannot be sensibly observed, they therefore

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do not exist (and may even be said to be meaningless). Such an inference is clearly verificationist and amounts to a variation on Berkeley: “To be is to be perceivable.” This sort of inference unjustifiably draws an ontological conclusion from a mere epistemological assumption.

Thus, in Einstein’s formulation time and space are reduced to sensible measures based on periodic motions (such as natural or constructed clock pointer movements) and rigid measuring rods, measures that are relative to local inertial frames. Simultaneity is defined in terms of clock synchronization via light signals. All of this is done by mere stipulation. Newton’s absolute time and space, which transcend operational definitions, are assumed to be mere figments of our imagination. Through Einstein’s operational definitions of time and space, Mach’s positivism triumphs in the STR. Reality is reduced to what our physical instruments say.

Unfortunately for Einstein’s Special Theory, however, its epistemological and ontological assumptions are now seen to be questionable, unjustified, false, perhaps even illogical. In a recent review, Tyler Burge remarked that “the central event” in philosophy during the second half of the twentieth century has been “the downfall of positivism and the re-opening of discussion of virtually all the traditional problems in philosophy”.³ In light of the collapse of positivism and in light of its essential role in the epistemological foundations of the STR, a reappraisal of the time concept in Relativity Theory is long overdue. For apart from a verificationist critique of some sort, it is no longer obvious why the received view is to be preferred to the views of Lorentz and Poincaré, which are consistent with the Newtonian ideas of absolute time and absolute simultaneity.

Certain contemporary theorists have attempted to free STR of its verificationist assumptions, but it is questionable whether such efforts have been successful. For example, the philosopher of physics Graham Nerlich has been most critical of Einstein’s original verificationism and develops a non-reductionistic “realist” theory of relativistic space-time. Such relativistic substantivalism remains verificationist, however, to the extent that it assumes that time and space, although not identical with observable clock movements and rigid rods, must possess only those properties that are measurable by observable clocks and rigid rods. This assumption underlies the views of all those who hold that the “essence” of Special Relativity is Lorentz invariance, since Lorentz invariance ultimately requires that law-like behavior is the behavior that would be measurable by light-clocks and rigid rods if such clocks and rods were present. Similarly, Eli Zahar, who attempts to provide a non-verificationist foundation for Special Relativity, in fact ends up relying on an implicit verificationism after all.⁴

Part III

It is remarkable that the Special Theory has thus far managed to survive largely unscathed the collapse of its essential epistemological underpinnings.

One wonders how this can be so. Undoubtedly a major part of the answer is the understandable one that physicists are not epistemologists; physicists typically know no more about epistemology, the philosophy of language (e.g. problems with the verificationist criterion of semantic meaning), and ontology than philosophers typically know about physics. The precise philosophical arguments for the illogicality, falsity, or unjustifiability of the epistemological, semantic, and ontological presuppositions of the Special Theory remain, with a few exceptions, unknown among physicists.

The price paid for the growth of knowledge is increased specialization, which, paradoxically, also prevents or reverses the growth of knowledge, since specialists in one field often base their work on premises that (unknownst to them) have been refuted or disconfirmed in another field. The only solution we can see for this problem is that the training or schooling of physicists ought to include schooling in philosophy (and, as we shall see, the converse should hold for philosophers). Perhaps this is most practicable in the form of there being thinkers who take as their specialization the intersection of physics and philosophy and the works of these thinkers, at least in “introductory formats”, being a part of the education of both physicists and philosophers. If this proves unfeasible and the situation remains as it presently stands, the unpalatable situation may result that neither physicists nor philosophers are in a position to have adequately justified beliefs about space and time but only philosophers of physics (or the few thinkers who are both philosophers and physicists, such as David Albert and Bas Van Fraassen, and, from the side of physics, Niels Bohr and David Bohm, who developed philosophical theories in addition to physically interpreted equations).

Apart from leaving unaddressed the epistemological and semantic presuppositions of STR, there is an even stronger factor behind physicists’ unwillingness to abandon the Special Theory. The Special Theory is a part of orthodox quantum field theory (QFT) (quantum electrodynamics and quantum chromodynamics), which aims to unify the Special Theory with quantum mechanics. Physicists would be at a loss as to how to proceed if they rejected the Special Theory as unjustified, since they (for the most part) believe that this would require them to reject QFT.

In the light of this dependence on Special Relativity, physicists are not likely to abandon it unless it is observationally disconfirmed and there is an observationally adequate theory available to replace it. In fact, there is a theory that is not merely observationally equivalent to the Special Theory, but also observationally superior to it, namely Lorentzian or neo-Lorentzian theory. Lorentz’s theory is regarded by many physicists who have studied Lorentzian theory, such as J.S. Bell, to be observationally equivalent to the Special Theory. However a Lorentzian or neo-Lorentzian theory is, in fact, observationally superior to the Special Theory (a fact that Bell, surprisingly, did not point out), since a Lorentzian theory, in contrast to the Special Theory, is consistent with the relations of absolute, instantaneous simultaneity

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implied by the EPR correlations that were observed in Aspect's confirmations of Bell's theorems. Special Relativistic QFT is no less disconfirmed by Aspect, *et al.* than is Special Relativity. Physicists do not appreciate the fact that a (non-orthodox) QFT can be formulated in terms of a Lorentzian theory, in which case it would avoid both disconfirmation by the Bell-Aspect observational data and the criticism of the untenability of the epistemological basis of the Special Theory.

One reason the Bell-Aspect experiments do not cause worry among most relativistic quantum field theorists is that the discussion of the Bell-Aspect experiments is isolated from the discussions of relativistic theories and is confined (for the most part) to discussions of non-relativistic quantum mechanics. There may be good reasons for this. But it may also reflect the worry that physicists do not know how to solve the problem of reconciling the Bell-Aspect experiments with relativistic QFT.

An even more "glaring" problem that a Lorentzian theory of absolute time can solve is that orthodox (special relativistic) QFT has not been fully or successfully "relativised". The absolute simultaneity implied by either collapse or non-collapse interpretations of QM, shows up in orthodox QFT as instantaneous relations (*e.g.* causal relations or correlations) among space-like separated regions associated with commuting or anti-commuting operators. Since the "special relativistic" ingredients in orthodox QFT are the same as those implied by a space-time formulation of Lorentzian theory, one can formulate a Lorentzian QFT that both explains and predicts the apparent Lorentz invariance and other "relativistic effects" that are observed, and yet is also theoretically and observationally consistent with instantaneous causal relations and correlations (see Chapter 3 for a discussion of the required Lorentzian formulation of QFT).

Physicists who work in the area of General Relativity know that the Special Theory has been supplanted by the General Theory of Relativity (GTR) and that simultaneity does not have the relativity attributed to it by the Special Theory but instead is absolute in the "cosmic time" which emerges through a cosmological application of GTR. However, QFT does not involve GTR and specialists in QFT do not address or take into account the absolute simultaneity relation that belongs to GTR-based cosmologies (which we discuss in the next section).

It may be concluded that the main reasons many physicists still hold to Special Relativity are (1) an insufficient awareness of the epistemological and other philosophical problems with Special Relativity; (2) the isolation of the discussion of the Bell-Aspect observations from relativistic QFT; (3) the neglect of GTR by specialists in QFT, since GTR is not a part of QFT; and (4) the lack of familiarity with Lorentzian theories and consequent unawareness of how a Lorentzian QFT would not be faced with the manifest problems of orthodox, relativistic QFT. We hope that the discussions in this volume of the epistemological problems with Special Relativity, the discussions of the disconfirmation of the Special Theory by Aspect's

confirmation of Bell's theorems, the discussion of the absolute simultaneity relation in GTR, and the discussion of Lorentzian theories, will help physicists who still adhere to the Special Theory to become more aware of these issues and to enable them to formulate more theoretically and observationally adequate theories.

Part IV

An explanation of why many philosophers of time remain wedded to the relativity of simultaneity could in part be that there has developed in twentieth century philosophy of time a habitual or even "orthodox" belief that absolute simultaneity and a tensed or (to borrow McTaggart's convenient nomenclature) A-Theory of time go hand in hand, and that relative simultaneity and the B-Theory go hand in hand. But this "habit of belief" originated with the lay-physicist's belief that the basic contrast in the theory of time is between "the flowing Newtonian time that contains relations of absolute simultaneity" and "the tenseless four-dimensional spacetime of Minkowski" and that physics presented one with a choice between one or the other. But while A-Theorists are arguably committed to a rejection of Einsteinian or Minkowskian relativity,⁵ the B-Theory does not in fact require relativity, since a space-time formulation of Lorentzian theory and even of Newtonian absolutism can be given, and there is nothing in positing a preferred foliation of space-time that commits one to objective tenses or temporal becoming. A-Theorists' commitment to tense and temporal becoming may make them more open to absolute simultaneity, but the B-Theory is consistent with either relative or absolute simultaneity. If this "habit of belief" remains operative among B-Theorists who reject absolute simultaneity, then the problem is the lack of a sufficient knowledge of contemporary physics.

The problem here is, in a sense, the reverse of the first problem we mentioned above, namely, physicists' lack of awareness of the many arguments that philosophers have provided against the epistemology, philosophy of language, and ontology presupposed by the Special Theory. The most widespread belief among philosophers is that contemporary physics has proven that simultaneity is relative either in Einstein's sense that there exists no preferred reference frame or in Minkowski's sense that there is no preferred foliation of space-time.

In fact, by the early 1920s this claim had been undermined due to the cosmological application of Einstein's 1915 General Theory. Einstein's cosmological model of 1917, based on his GTR, and Alexander Friedman's cosmological model of 1922 (which is now recognized to be the sort of general relativistic cosmological model that is pertinent to our universe) imply a privileged or preferred foliation of space-time. Although the general relativistic space-time manifold can in theory be sliced up arbitrarily, there obtain *de facto* boundary conditions which determine a preferred foliation.

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The hypersurface of homogeneity and isotropy is the preferred hypersurface for the formulation of the laws of physics and the measurement of space and time. For example, the statement that the Big Bang occurred 13.7 billion years ago is not based on a measurement relative to any arbitrary reference frame, but to the privileged reference frame, the frame of homogeneity and isotropy, and is therefore absolute. It is regularly noted that a special relativistic or Minkowski metric can be defined infinitesimally close to any point in a universe with a Friedmann metric, even though only a Friedman metric applies to the universe itself. The metric that describes the universe determines its spatio-temporal structure, and Friedman's spatio-temporal structure includes an absolute reference frame, the frame of homogeneity and isotropy. It has often been commented by physicists that Einstein's GTR thus reintroduced the relations of absolute simultaneity that his STR had denied. In fact, the idea that the hypersurface of homogeneity is the privileged frame, which determines absolute temporal and spatial measurements, has been a part of graduate textbooks on General Relativity or cosmology going back to the 1920s.

Thus, philosophers who embrace relativity because they are under the impression that the evidence of physics implies it are quite mistaken; in fact the opposite is true. Similarly, philosophers who hold to a tenseless or B-Theory of time for the reason that it is implied by Einstein's 1905 theory or Minkowski's 1908 theory are unjustified in so doing because the evidence of physics does not in fact imply that those theories are true. Einstein's 1905 theory and Minkowski's 1908 theory are "vacuum solutions" to Einstein's GTR, that is, solutions that hold only if there is no matter in the universe.

The notion that a Friedman universe has an absolute hypersurface of simultaneity remains debatable only in the sense that our universe is not perfectly homogeneous, so that the concept of the hypersurface of simultaneity is the concept of an abstract hypersurface that results from averaging out the variations in the homogeneity of matter on very large scales. Whether or how one can derive a surface of absolute simultaneity in the strict (rather than "averaged out") sense is a matter that is up to debate. Some physicists adopt a "York slicing," but it is not evident that this resolves the problem of the surface of absolute simultaneity being a concept that relies on the "averaging out" of inhomogeneities.

General Relativity is not the only physical theory developed after 1905 or 1908 that falsifies or casts doubt on the relativistic concepts of simultaneity. Louis De Broglie in 1928 and David Bohm in 1952 developed an interpretation of quantum mechanics that implies that there is a strict plane of absolute simultaneity, in the same sense as Lorentz's and Newton's in respect of it being a unique, universal, instantaneous plane of simultaneity that is non-local and space-like. De Broglie's and Bohm's theories of absolute simultaneity were largely ignored until J. S. Bell wrote a series of essays about them in the 1960s, which were collected into his 1987 book *Speakable and Unsayable in Quantum Mechanics*. Since 1987, the number of adherents

to a de Broglie-Bohm interpretation of quantum mechanics has been increasing steadily, as one finds the number of articles about the de Broglie-Bohm theory in physics journals growing from year to year. Several contributors to this volume, Valentini, Maudlin, Smith, and Callender are adherents to the de Broglie-Bohm interpretation of quantum mechanics. Even some competing interpretations of quantum mechanics, namely, those that involve a collapse of the wave function, imply absolute simultaneity, since the collapse of the wave function is instantaneous. The experimental confirmation of Bell's theorem by Aspect and others implies that there is an instantaneous, non-local, space-like relation of simultaneity that coincides with EPR causal correlations (where "cause" is defined in a counterfactual sense, along lines such as suggested, *e.g.* by David Lewis). In this volume Maudlin's essay discusses the most recent experimental findings to date, which give us some idea of the price that must be paid by those who insist upon the relativity of simultaneity in quantum mechanics.

Accordingly, philosophers who believe that simultaneity has the relativistic nature described in Einstein's 1905 paper or Minkowski's 1908 paper make manifest the fact that more education is needed about contemporary physics. If physicists need more education in philosophy, philosophers, especially philosophers of time, need more education in contemporary physics.

Part V

The fact that many philosophers need to become more acquainted with the theories of current physics, theories that assert or imply that simultaneity is not relative in the sense of Einstein's 1905 paper or Minkowski's 1908 paper, makes a volume of essays such as this one useful for philosophers of time and philosophers in general. The same holds for physicists, even if for different reasons. It is appropriate (if coincidental) that the publication of a work that subjects the thesis of the relativity of simultaneity to a critical analysis should fall on the centennial anniversary of Einstein's 1905 essay.

This is the first collection of essays (of which we are aware) that is devoted, for the most part, to arguing that simultaneity is absolute. It is also a collection of essays that include writings in both philosophy and physics, perhaps erasing the distinction between them, at least in some cases. All of the chapters are original creations for this volume, some reflecting the cutting edge of research and reflection on the question of absolute simultaneity. Almost all are convinced that the received view that simultaneity is not an absolute relation is not only unwarranted but false. It is our hope, therefore, that this collection will lead to a better understanding among both philosophers and physicists of the problems inherent in making certain assertions about Einstein's theory of the relativity of simultaneity.

William Lane Craig
Quentin Smith

Notes

- 1 Isaac Newton (1966) *Sir Isaac Newton's "Mathematical Principles of Natural Philosophy" and his "System of the World,"* trans. Andrew Motte, rev. with an Appendix by Florian Cajori, 2 vols., Los Angeles: University of California Press, 1, p. 6.
- 2 A. Einstein (1981) 'On the Electrodynamics of Moving Bodies', trans. Arthur I. Miller, Appendix to Arthur I. Miller, *Albert Einstein's Special Theory of Relativity*, Reading, Mass.: Addison-Wesley, p. 393.
- 3 Tyler Burge (1992) 'Philosophy of Language and Mind', *Philosophical Review* 101, 49.
- 4 See Quentin Smith (1998) 'Absolute Simultaneity and the Infinity of the Past', in Robin Le Poidevin (ed.), *Questions of Time and Tense*, Oxford: Oxford University Press.
- 5 See William Lane Craig's chapter in this volume. Also see Quentin Smith (2000) 'The Inconsistency of STR and the Tensed Theory of Time', in L. Nathan Oaklander (ed.), *The Importance of Time*, Dordrecht, The Netherlands: Kluwer Academic Publishers, and Quentin Smith (1993) *Language and Time*, Oxford: Oxford University Press.

1 The metaphysics of special relativity: three views

William Lane Craig

Introduction

A physical theory is comprised of two components: a mathematical formalism and a physical interpretation of that formalism. Competing theories which differ only in virtue of their divergent physical interpretations can be extremely difficult to assess if they are empirically equivalent in their testable predictions. Considerations which are metaphysical in nature may then become paramount.

The Special Theory of Relativity (hereafter SR) provides a case in point. Herman Bondi has remarked that “there is perhaps no other part of physics that has been checked and tested and cross-checked quite as much as the Theory of Relativity” (Bondi 1964: 168). Indeed, muses J. G. Taylor, “as far as special relativity is concerned all has been worked out and tested;” the theory has enjoyed “remarkable successes, and absolutely no failures” (Taylor 1975, preface). The empirical success of SR’s testable predictions can, however, be misleading, dulling us to the truly controversial nature of the correct physical interpretation of the theory’s formalism. The fact is that the only version of SR which is experimentally verifiable, as Geoffrey Builder points out, “is the theory that the spatial and temporal coordinates of events, measured in any one inertial reference system, are related to the spatial and temporal coordinates of the same events, as measured in any other inertial reference system, by the Lorentz transformations” (Builder 1971: 422). But this verifiable statement is underdeterminative with regard to the radically different physical interpretations of the Lorentz transformations given, respectively, by Einstein, Minkowski, and Lorentz.

During the decades in which positivism dominated the philosophy of science these differences tended to be glossed over, since empirically equivalent physical interpretations of the same mathematical formalism were regarded as but different linguistic expressions of the same theory. But with the collapse of positivism – arguably the most important event in philosophy in the second half of the twentieth century (Burge 1992: 49) – such indifference toward the fundamentally different ontological structures of space, time, and space-time which appear in these three interpretations can no longer be

ignored. Unfortunately the articulation of a post-positivist philosophy of space and time has only scarcely begun. Minkowskians have issued critiques of Einsteinians in the effort to justify the former's space-time realism, and the largely marginalized neo-Lorentzians have criticized what we might call the received interpretation of SR (an Einsteinian-Minkowskian amalgam which fails to differentiate these viewpoints) for its denial of relations of absolute simultaneity; but I know of no critical appraisal in the literature which lays these three interpretations side by side and attempts to come to some adjudication of them. In this paper I propose to do just that.

Three relativistic interpretations

The Einsteinian interpretation

SR, as Einstein originally formulated it, postulates a 3+1-dimensional ontology, not a 4-dimensional ontology (Einstein 1981).¹ That is to say, it is a theory of familiar physical objects enduring through time. Space and time are relativised to reference frames, which serve to define distant simultaneity and along with it notions like rest, motion, speed, and velocity. Light is postulated to have the constant velocity c in every reference frame. Because physics is relativised to reference frames, clocks run at different rates and measuring rods have different lengths relative to different frames. Such an interpretation of SR implies an anti-realist or instrumentalist understanding of Minkowski space-time.² There is no tenselessly subsisting manifold of events; space-time is a theoretical construct only, a geometrical representation of a theory which is really about physical objects enduring through time. A Minkowski diagram will prove to be a helpful tool, but it neither depicts reality nor implies an ontology. A good representative of this original Einsteinian perspective is the French physicist Henri Arzeliès. In his *Relativistic Kinematics*, Arzeliès asserts, "The Minkowski continuum is an abstract space of four dimensions, the sole role of which is to interpret in geometrical language statements made in algebraic or tensor form. . . . The four-dimensional continuum should therefore be regarded as a useful tool, and not as a physical 'reality'" (Arzeliès 1966: 258). While it is true that relativity theory banishes the notions of absolute spatial and temporal intervals from physics, nonetheless "It is perfectly clear that in relativity, the ordinary three-dimensional space (which is Euclidian in special relativity) and the time of pre-relativistic physics is employed" (Ibid).

The Minkowskian interpretation

There is no gainsaying Arzeliès insofar as Einstein's original formulation of SR is concerned. But it is also indisputable that once having encountered Minkowski's geometrical formulation of the theory, Einstein became an outspoken realist concerning space-time (Einstein and Infeld 1938: 219;

Einstein 1961: 150; Einstein and Besso 1979: 276–77).³ Minkowski took his space-time ontologically: it was not merely a geometrical representation of the world of space and time as described by Einstein's SR; rather it *was* the world. When he said, "A point of space at a point of time, that is, a system of values x, y, z, t , I will call a *world-point*. The Multiplicity of all thinkable x, y, z, t systems of values we will christen the *world*," (Minkowski 1952: 76) he was making self-consciously a metaphysical statement, proposing a new ontology. Heralding "a metamorphosis of our concept of nature," Minkowski declared, "Henceforth, space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality" (Ibid., 75, 76). On this second interpretation of SR, the notions of reference frames, invariant velocity of light, distant simultaneity, relative motion or rest, and so forth, so central to the Einsteinian interpretation, play no role.⁴ Rather the central feature of this interpretation is the light cone structure at any space-time point, which determines the geometrical properties of space-time. In 1911 A. A. Robb was able to recover all the geometric structure of Minkowski space-time on the basis of the single relation *after* among its points, conjoined with several conditions of that relation (Robb 1913). Taking Robb's relation to be extensionally equivalent to some sort of causal relation, recent theorists have defined causally the Lorentz group of transformation equations (Zeeman 1964: 490–93), orthogonality to a time-line in Minkowski space-time (Malament 1977: 293–300), and the metrical congruence of intervals in that space-time (Winnie 1977: 134–205). Space-time realists debate intramurally whether causality is truly constitutive of, rather than merely (at best) co-extensive with, Robb's fundamental relation,⁵ but the point remains that the familiar physical entities of the Einsteinian interpretation make no appearance in the space-time interpretation. These two interpretations of relativity theory thus present strikingly different metaphysical visions of reality; they are as radically divergent in their ontologies as is relativity theory itself in comparison with the Newtonian physics of absolute time and space. Minkowski's space-time approach to relativity theory, especially with the development of the General Theory of Relativity (GR), has come to be the dominant mode of presentation and discussion of relativity.

The Lorentzian interpretation

It is an interesting historical fact that neither of the giants of late nineteenth century physics to whom Einstein looked for inspiration in his work on SR, H. A. Lorentz and Henri Poincaré, was ever convinced, despite being fully apprised of the empirical facts, of the truth of the Einsteinian or Minkowskian interpretations of the Lorentz transformations. Well after Einstein had formulated his SR and as he struggled to craft a GR, Lorentz in particular continued to study and lecture on problems of relativity, often in connection with Einstein. By 1908 Lorentz had already realized the

incompatibility of his electron theory with Planck's quantum hypothesis, and by the 1911 Solvay Congress there was a general sense that the electron theory would have to be radically reformed in light of the advent of quantum physics (McCormach 1970: 486–88). Nonetheless, since Lorentz's attempted explanation of the phenomenon of length contraction in terms of the deformable electron was not essential to his basic physical interpretation of SR, Lorentz continued to adhere to an approach to relativity theory which preserved the classical notions of space and time. A theory may be classified as Lorentzian just in case it affirms that (i) physical objects are n -dimensional spatial entities which endure through time; (ii) the round trip vacuum propagation of light is isotropic in a preferred (absolute) reference frame R_0 (with speed $c = 1$) and independent of the velocity of the source; and (iii) lengths contract and time rates dilate in the customary special relativistic way only for systems in motion with respect to R_0 (Maciel and Tiomno 1989: 507–8).

Lorentz always spoke appreciatively of Einstein's alternate approach and lectured sympathetically on both SR and GR, while remaining finally unconvinced that Einstein had abolished the classical conceptions of time and space. Writing in 1910, he contrasted his view with Einstein's:

Assume there were an aether; then there would be among all systems x , y , z , t one singled out in that the coordinate axes as well as the clock is at rest in the aether. If one conjoins with this the idea . . . that space and time are something wholly different and that there is a 'true time' (simultaneity would then exist independently of location, in accord with the circumstance that it is possible for us to conceive of infinitely great velocities), then one easily sees that this true time would have to be indicated just by clocks which are at rest in the aether. If, then, the principle of relativity were generally valid in nature, then one would not be in a position to determine whether the coordinate system employed is that distinguished one. One thus comes to the same results as when one in agreement with Einstein and Minkowski denies the existence of the aether and the true time and treats all coordinate systems as equivalent. Which of the two modes of thought one may agree with is best left to the individual.

(Lorentz 1934: 211)⁶

Lorentz, realizing that his aether compensatory interpretation is empirically equivalent to the Einstein-Minkowski interpretations, leaves it up to the individual to choose which he shall adopt. But Lorentz preferred the classical conceptions of time and space on metaphysically intuitive grounds, as he made clear in his 1922 lectures at Cal Tech:

All our theories help us form pictures, or images, of the world around us, and we try to do this in such a way that the phenomena may be coordinated as well as possible, and that we may see clearly the way in

which they are connected. Now in forming these images we can use the notions of space and time that have always been familiar to us, and which I, for my part, consider as perfectly clear and, moreover, as distinct from one another. My notion of time is so definite that I clearly distinguish in my picture what is simultaneous and what is not.

(Lorentz 1927: 221)

Here Lorentz refuses to jettison what he took to be the intuitively obvious reality of absolute simultaneity among events in the world just because one cannot determine which spatially separated events are simultaneous or because Einstein's operationally re-defined notion of simultaneity is relative to reference frames. Moreover, he sees no good reason to scrap the intuitive distinctness of space and time in favor of Minkowski's unified reality, space-time.

A major reason that Lorentz remained unconvinced was that he was not a positivist. In 1913 he wrote,

According to Einstein it has no meaning to speak of motion relative to the aether. He likewise denies the existence of absolute simultaneity.

It is certainly remarkable that these relativity concepts, also those concerning time, have found such a rapid acceptance.

The acceptance of these concepts belongs mainly to epistemology . . . It is certain, however, that it depends to a large extent on the way one is accustomed to think whether one is attracted to one or another interpretation. As far as this lecturer is concerned, he finds a certain satisfaction in the older interpretations, according to which the aether possesses at least some substantiality, space and time can be sharply separated, and simultaneity without further specification can be spoken of. In regard to this last point, one may perhaps appeal to our ability of imagining arbitrarily large velocities. In that way, one comes very close to the concept of absolute simultaneity.

Finally, it should be noted that the daring assertion that one can never observe velocities larger than the velocity of light contains a hypothetical restriction of what is accessible to us, [a restriction] which cannot be accepted without some reservation.

(Lorentz 1920a: 23)

Here Lorentz clearly discerns the foundational role played by Einstein's verificationist theory of meaning in his formulation of SR and rejects it. In defense of absolute simultaneity, Lorentz appeals to the use of arbitrarily fast signals, even though they are not presently observable. He disregards the assumption that it is meaningless to speak of such unobservables. Elsewhere Lorentz affirms that it makes sense, if there is an aether, to speak of motion relative to it even if observers could not detect such motion (Lorentz 1914: 26).⁷ He writes,

But it needs to be clearly recognized that **A** could never assure himself of the immobility in the ether which we have attributed to him by supposition and that physicist **B** could with the same right, or rather with the same absence of right, claim that it is he who finds himself in these privileged circumstances. This incertitude, this impossibility of even disclosing a movement in relation to the aether, led Einstein and numerous other modern physicists to abandon completely the notion of an aether.

There, it seems to me, is a question toward which each physicist must take a position which best accords with the manner of thinking to which he is accustomed.

(Lorentz 1934: 7: 165)

Lorentz's conception of the aether was virtually equivalent to space itself. His aether was so dematerialized that Einstein, lecturing at the University of Leiden in 1920, could tease the Dutch physicist by declaring, "As regards the mechanical nature of Lorentz's aether one might say of it, with a touch of humor, that immobility was the only mechanical property which H. A. Lorentz left it" (Einstein 1920: 7). For Lorentz the aether is just the privileged spatial frame.

Lorentz thus accepts a 3+1 ontology of spatial objects enduring through a privileged time, a metaphysic which he felt no obligation to abandon out of deference to a verificationist epistemology.

Assessment of the interpretations

Metaphysical underpinnings of the classical concept of time

In another place I have argued that the collapse of positivism during the second half of the twentieth century has re-opened the discussion of the metaphysical foundations of the classical concept of time and that only Lorentz's approach to problems of space and time, in contrast to Einstein and Minkowski's, has remained unshaken by this epistemological revolution (see Craig 2002: 129–52). Specifically, I sought to expose the theological foundations of the classical concept of time as enunciated by Isaac Newton in his epochal *Philosophiae naturalis principia mathematica*.

By way of review, the *locus classicus* of Newton's exposition of his concepts of time and space is the *Scholium* to his Definitions in the *Principia*. In order to overcome "common prejudices" concerning such quantities as time, space, place, and motion, Newton draws a dichotomy with respect to these quantities between "absolute and relative, true and apparent, mathematical and common." With regard to time he asserts:

Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by

another name is called duration: relative, apparent, and common time, is some sensible and external (whether accurate or unequal) measure of duration by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year.

(Newton 1966 1:6)

Newton's much misunderstood and greatly maligned distinction between absolute and relative time deserves our thoughtful consideration.

The most evident feature of this distinction is the independence of absolute time from the relative measures thereof. Absolute time, or simple duration, exists regardless of the sensible and external measurements which we try, more or less successfully, to make of it. Newtonian time is thus first of all absolute in the sense that time itself is distinct from our measures of time.

But, of course, Newton also conceived time as absolute in a more profound sense, namely, he held that time is absolute in the sense that it exists independently of any physical objects whatsoever. Usually, this is interpreted to mean that time would exist even if nothing else existed, that there exists a possible world which is completely empty except for the container of absolute space and the flow of absolute time. But here we must be very careful. Modern scholars tend frequently to forget how ardent a theist Newton was and how central a role this theism played in his metaphysical outlook. Noting that Newton considered God to be temporal and therefore time to be everlasting, David Griffin observes that "Most commentators have ignored Newton's heterodox theology, and his talk of 'absolute time' has been generally misunderstood to mean that time is not in any sense a relation and hence can exist apart from actual events" (Griffin 1986: 6–7).

In fact, Newton makes quite clear in the *General Scholium* to the *Principia*, which he added in 1713, that absolute time and space are constituted by the divine attributes of eternity and omnipresence:

He is eternal and infinite . . .; that is, his duration reaches from eternity to eternity; his presence from infinity to infinity He is not eternity and infinity, but eternal and infinite; he is not duration or space, but he endures and is present. He endures forever, and is everywhere present; and, by existing always and everywhere, he constitutes duration and space. Since every particle of space is *always*, and every indivisible moment of duration is *everywhere*, certainly the Maker and Lord of all things cannot be *never* and *nowhere*.

(Newton 1966: 2: 545)

Because God is eternal, there exists an everlasting duration, and because He is omnipresent, there exists an infinite space. Absolute time and space are therefore relational in that they are contingent upon the existence of God.

In his treatise *De gravitatione* (Newton 1962: 89–156), Newton declares explicitly that space is *not* in itself absolute (*non absoluta per se*) and therefore not a substance. Rather it is an eminent – or emanative – effect of God (*Dei effectus emanativus*). It is uncreated and co-existent with God and yet ontologically dependent upon him for its being. God’s infinite being has as its consequence infinite time and space, which represent the quantity of his duration and presence. In the Neo-Platonic tradition the doctrine of emanation is associated with pantheism or panentheism. But, as Newton makes clear, he does not conceive of space or time as in any way aspects of God himself, but rather, as he says, concomitant effects of God.

It is evident that when Newton speaks of divine eternity, he does not, like scholastic theologians in the Augustinian tradition, mean a state of timelessness, but rather infinite and everlasting temporal duration. In a preliminary draft of the *General Scholium*, Newton had explicitly rejected the conception of God’s eternity as an eternal now: “His duration is not a *nunc stans* without duration, nor is his presence nowhere” (cited in McGuire 1990: 93). Far from being atemporal, God’s now or present is the present of absolute time. Since God is not “a dwarf-god” located at a place in space (Newton 1978: 114–29) but is omnipresent, every indivisible moment of duration is everywhere, as Newton states in the *General Scholium*. There is thus a worldwide moment which is absolutely present. Newton’s temporalism thus provides the foundation for both absolute simultaneity and absolute becoming. These are features first and foremost of God’s time or metaphysical time and derivatively of measured or physical time.

Now Newton provides virtually no argument to think that God is temporal; he simply asserts it. But I have argued elsewhere that on a tensed or (to borrow McTaggart’s convenient terminology) an A-Theory of time, according to which tense and temporal becoming are objective features of reality, God must be temporal in virtue of His knowledge of tensed facts and His causal relation to the world (Craig 1998b: 221–50). Hence, if God exists and an A-theory of time is correct, Newton is justified so far forth in holding that there is absolute time in the sense of a metaphysical time which is independent of physical time.

Newton freely grants that although absolute time exists it may well be the case that due to the inaccuracies of our measures the true time is not disclosed to us (Newton 1966: 1:7–8). What Newton did not realize, nor could he have suspected, is that physical time is not only *relative*, but also *relativistic*, that the approximation of physical time to absolute time depends not merely upon the regularity of one’s clock, but also upon its motion. Unless a clock were at absolute rest, it would not accurately register the passage of absolute time. A clock moving relatively to oneself runs slowly. This truth, unknown to Newton, only intimated by Larmor and Lorentz in the concept of “local time,” was finally grasped by Einstein.

Where Newton fell short, then, was not in his analysis of absolute or metaphysical time – he had theological grounds for positing such a time –

but in his incomplete understanding of physical time. He assumed too readily that an ideal clock would give an accurate measure of time independently of its motion. If confronted with relativistic evidence, Newton would no doubt have welcomed this correction and seen therein no threat at all to his doctrine of absolute time. In short, relativity corrects Newton's concept of physical time, not his concept of absolute time.

Of course, it hardly needs to be said that there is a great deal of antipathy in modern physics and philosophy of science toward such metaphysical realities as Newtonian space and time, primarily because they are not physically detectable. But Newton would have been singularly unimpressed with this positivistic equation between physical undetectability and non-existence. The grounds for metaphysical space and time were not physical, but philosophical, or more precisely, theological. Epistemological objections fail to worry Newton because, as Lucas nicely puts it, "He is thinking of an omniscient, omnipresent Deity whose characteristic relation with things and with space is expressed in the imperative mood" (Lucas 1973: 143). Modern physical theories say nothing against the existence of such a God or the metaphysical time constituted, in Newton's thinking, by His eternity. What Einstein's relativity theory did, in effect, was simply to remove God from the picture and to substitute in His place a finite observer. "Thus," according to Holton, "the *RT* [Relativity Theory] merely shifted the focus of space-time from the sensorium of Newton's God to the sensorium of Einstein's abstract *Gedanken* experimenter – as it were, the final secularization of physics" (Holton 1973: 171). But for a man like Newton such a secular outlook impedes rather than advances our understanding of the nature of reality.

Unfortunately in our secular age physicists and philosophers of space and time rarely, if ever, give careful consideration to the difference God's existence would make for our conceptions of time and space. But in a fascinating passage in his essay "*La mesure de temps*," Poincaré does briefly entertain the hypothesis of "*une intelligence infinie*" and considers the implications of such a hypothesis. Poincaré is reflecting on the problem of temporal succession. In consciousness, the temporal order of mental events is clear. But going outside consciousness, we confront various difficulties. One of these concerns is how we can apply one and the same measure of time to events which transpire in "different worlds," that is, to spatially distant events. What does it mean to say that two psychological phenomena in two consciousnesses happen simultaneously? Or what does it mean to say a supernova occurred before Columbus saw the isle of Espanola? "All these affirmations," says Poincaré, "have by themselves no meaning" (Poincaré 1982: 228). Then he remarks,

We should first ask ourselves how one could have had the idea of putting into the same frame so many worlds impenetrable to one another. We should like to represent to ourselves the external universe, and only by so doing could we feel that we understood it. We know we can never

attain this representation: our weakness is too great. But at least we desire the ability to conceive an infinite intelligence for which this representation could be possible, a sort of great consciousness which should see all, and which should classify all *in its time*, as we classify, *in our time*, the little we see.

This hypothesis is indeed crude and incomplete, because this supreme intelligence would be only a demigod; infinite in one sense, it would be limited in another, since it would have only an imperfect recollection of the past; it could have no other, since otherwise all recollections would be equally present to it and for it there would be no time. And yet when we speak of time, for all which happens outside of us, do we not unconsciously adopt this hypothesis; do we not put ourselves in the place of this imperfect god; and do not even the atheists put themselves in the place where God would be if he existed?

What I have just said shows us, perhaps, why we have tried to put all physical phenomena into the same frame. But that cannot pass for a definition of simultaneity, since this hypothetical intelligence, even if it existed, would be for us impenetrable. It is therefore necessary to seek something else.

(Ibid. 228–29)

Poincaré here suggests that, in considering the notion of simultaneity, we instinctively put ourselves in the place of God and classify events as past, present, or future according to His time. Poincaré does not deny that such a perspective would disclose to us true relations of simultaneity. But he rejects the hypothesis as yielding a definition of simultaneity because *we* could not know such relations; such knowledge would remain the exclusive possession of God Himself.

But clearly, Poincaré's misgivings are relevant to a definition of simultaneity only if one is presupposing some sort of verificationist theory of meaning, as he undoubtedly was. The fact remains that God would know the absolute simultaneity of events even if we grope in total darkness. Nor need we be concerned with Poincaré's argument that such an infinite intelligence would be a mere demigod, since it is a *non sequitur* that a being with perfect recollection of the past cannot be temporal. There is no conceptual difficulty in the idea of a being which knows all true past-tense propositions. That such a being would be temporal is evident from the fact that as events transpire, more and more past tense propositions become true, so that the content of his knowledge is constantly changing. Hence, it does not follow that if God is temporal, He cannot have perfect recollection of the past.

Poincaré's hypothesis suggests, therefore, that God's present is constitutive of relations of absolute simultaneity. Lorentz agreed. In a passage redolent of the *General Scholium* and *Opticks* of Newton, Lorentz in a letter to Einstein in January of 1915 broached considerations whereby "I cross the borderland of physics":

A 'World Spirit' who, not being bound to a specific place, permeated the entire system under consideration or 'in whom' this system existed and who could 'feel' immediately all events would naturally distinguish at once one of the systems U , U' , etc. above the others.

(Lorentz 1989: 274)

Such a being, says Lorentz, could "directly verify simultaneity". On this view, J. M. Findlay was wrong when he said, "... the influence which harmonizes and connects all the world-lines is not God, not any featureless, inert, medium, but that living, active interchange called ... Light, offspring of Heaven firstborn" (Findlay 1978–79: 6–7). On the contrary, the use of light signals to establish clock synchrony is a convention which finite and ignorant creatures have been obliged to adopt, but the living and active God, who knows all, would not be so dependent.

In God's temporal experience, there would be a moment which is present in metaphysical time, wholly independently of physical clock times. He would know, without any dependence on clock synchronization procedures or any physical operations at all, which events were simultaneously present in metaphysical time. He would know this simply in virtue of His knowing at every such moment the unique set of present-tense propositions true at that moment, without any need of a *sensorium* or physical observation of the universe.

How, then, would God's metaphysical time relate to our physical time? From what has been said thus far, it seems that God's existence in metaphysical time and His real relation to the world would imply that a Lorentzian interpretation of relativity is correct. Such a theory is required in view of divine temporality, for God in the "now" of metaphysical time would know which events in the universe are now being created by Him and are therefore absolutely simultaneous with each other and with His "now." This startling conclusion shows clearly that Newton's theistic hypothesis is not some idle speculation, but has important implications for our understanding of how the world is and for assessment of rival scientific theories.

Accordingly, we may argue

1. God exists.
2. An A-Theory of time is correct.
3. If an A-Theory of time is correct, there are tensed facts and temporal becoming.
4. If God exists and there are tensed facts and temporal becoming, then God knows tensed facts and is the cause of things' coming to be.
5. If God knows tensed facts and is the cause of things' coming to be, then God is temporal.
6. There are tensed facts and temporal becoming. (2, 3)
7. God exists and there are tensed facts and temporal becoming. (1, 6)
8. God knows tensed facts and is the cause of things' coming to be. (4, 7)

9. God is temporal. (5, 8)
10. If God is temporal, then a privileged reference frame exists.
11. If a privileged reference frame exists, then a Lorentzian interpretation of SR is correct.
12. A privileged reference frame exists. (9, 10)
13. A Lorentzian interpretation of SR is correct. (11, 12)

It seems to me that this argument is cogent. As a theist, therefore, I accept (13). However, I recognize that non-theistic thinkers will be little moved by the argument. Therefore, it would be interesting to ask whether for the sake of dialectical effectiveness the argument might not be freed of its theistic underpinnings. Reflection on the argument convinces me that this is, indeed, possible. For the yeoman's work in this argument is done, not the assumption of theism, but rather by the assumption of an A-theory of time. One may plausibly argue directly, I think, that if an A-Theory of time is correct, then a Lorentzian interpretation of SR is correct. In the sequel, therefore, I shall abandon the assumption that God exists and seek to assess the three competing, physical interpretations of SR given merely the fact that we have good grounds for affirming the reality of tense and temporal becoming.

The Einsteinian interpretation

The characteristic feature of the Einsteinian interpretation of the SR formalism is its attempt to wed relativity with a classical 3+1 ontology of space and time. While this original interpretation is today largely disfavored in the foundations of physics community, it nevertheless continues to enjoy widespread acceptance among philosophers, particularly those embracing a tensed, as opposed to tenseless, theory of time and those advocating an endurantist, as opposed to a perdurantist, account of temporal persistence.⁸ It therefore merits our consideration. I shall argue that the Einsteinian interpretation is implausible and explanatorily deficient.

First, the pluralistic fragmentation of reality into distinct spaces and times associated with reference frames is an ontology which is, to put it bluntly, fantastic. This is a complaint voiced by many space-time realists.⁹ At the root of the complaint lies the conviction that there is a single world, an objective reality independent of observers, the conviction that if we both exist then what co-exists with me co-exists with you. It is fantastic to think that you and I, occupying the same location in space and time, but in relative motion, should in virtue of that motion literally dwell in two different worlds, which intersect only at a point. Yet SR requires that even if we are merely passing each other in automobiles, our hyperplanes of simultaneity do not coincide, and at sufficient distances empirically distinguishable events and things are occurring and exist for me which are future and therefore unreal for you. Other events which are in my future and therefore unreal are already actual for you. But if I decelerate and we come to relative

rest, then we share the same reality; events which were once present and real in relation to me are now non-existent and future. One can change frames and, hence, realities just by changing one's relative motion.

By contrast, on the Minkowskian interpretation, which makes no link between simultaneity and reality, events do not pop in and out of existence as I switch reference frames. All that changes is which class of events is orthogonal to my world-line in space-time at a designated point and, hence, which events I reckon to be simultaneous with my present. All the events subsist tenselessly, and different hyperplanes in space-time serve merely to mark out which events count as simultaneous relative to my inertial frame. There is a shared, objective reality which exists independently of observers or reference frames, and we all inhabit the same space-time world; we just reckon different events in that one world to stand in the relation of simultaneity with one another. On a space-time ontology, there is thus a unified, independent reality which is merely *measured* differently by observers using different coordinate systems. But on the Einsteinian interpretation, reality literally falls apart, and there is no one way the world is.

Second, the Einsteinian interpretation is explanatorily deficient. On the Einsteinian interpretation physical objects have properties of shape, mass, and duration only extrinsically, relative to inertial frames, yet why this is so is not explained (Christensen 1993: 260; Nerlich 1994: 5). Moreover, it is unclear why 3-dimensional objects enduring through time suffer relativistic effects such as length contraction and time dilation in virtue of their being in relative motion. It is important to realize that under the 3+1-dimensional ontology of the Einsteinian interpretation these relativistic effects are *just as much real, physical effects* as under aether compensatory theories such as Lorentz's. On the Einsteinian interpretation length contraction and clock retardation cannot be dismissed as merely apparent phenomena on the analogy of the mutual observation of diminishing size when two observers retreat from each other. Admittedly, since length contraction and time dilation are reciprocal and the result of merely relative motion, it does seem incredible that they could be anything more than mere appearances, just as the so-called "pure relativists" like Bergson and Dingle insisted (see Dingle 1940; Bergson 1965). But Einstein realized right from the start that these effects described in his theory were real, not apparent, and could be shown to be real by various *Gedankenexperimente*.¹⁰ Examples could be multiplied (see Shaw 1962: 72; and further, Jánossy 1971: 128–31; Lorenz 1982: 308–12) to prove that, perhaps contrary to expectation, the Einsteinian interpretation of relativity theory involves real, physical length contraction and clock retardation, just as much as does the Lorentzian theory. Podlaha concludes,

In the relativity theory, the length contraction and time dilatation in all frames is often viewed as a consequence of a 'perspective of observation,' similarly as a rod seems to change its length as observed under different