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Prospects for a new account of time reversal

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ABSTRACT

In this paper I draw the distinction between intuitive and theory-relative accounts of the time reversal symmetry and identify problems with each. I then propose an alternative to these two types of accounts that steers a middle course between them and minimizes each account's problems. This new account of time reversal requires that, when dealing with sets of physical theories that satisfy certain constraints, we determine all of the discrete symmetries of the physical laws we are interested in and look for involutions that leave spatial coordinates unaffected and that act consistently across our physical laws. This new account of time reversal has the interesting feature that it makes the nature of the time reversal symmetry an empirical feature of the world without requiring us to assume that any particular physical theory is time reversal invariant from the start. Finally, I provide an analysis of several toy cases that reveals differences between my new account of time reversal and its competitors.

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1. Introduction

The following two questions about time reversal are intimately related to one another:

1. What does the time reversal operator look like (or, equivalently, how does a physical state or a series of physical states change under time reversal)?
2. Which physical theories are time reversal invariant?

In the philosophical literature on time reversal, authors frequently attempt to justify an answer to one of these questions by assuming an answer to the other question. Why they do so is obvious: if one knows how the time reversal operator acts on physical states, it is relatively easy to conjure up a time reversal operator in the context of a particular physical theory and then check to see whether this time reversal operator maps solutions of these physical theory's equations to solutions. Conversely, if one assumes from the beginning that a particular theory is time reversal invariant, one can utilize the mathematical structures of the theory (e.g. the symmetries under which the theory's differential equations are invariant) to determine what properties a time reversal operator should satisfy. I will call accounts of time reversal that assume an answer to 1 and use this response to generate an answer to 2 "intuitive" and accounts of time reversal that assume an answer to 2 and use this response to generate an answer to 1 "theory-relative". This distinction amounts to a difference in how one attempts to *justify* their particular approach to time reversal. These two approaches serve as archetypes that are typically imperfectly instantiated; not every approach to time reversal falls neatly into one of these two categories, and indeed, what I call "intuitive" accounts of time reversal may, in fact, import some facts about the time reversal invariance of particular physical laws into their account. However, the new distinction I draw here between intuitive and theory-relative accounts does provide a rough, helpful guide for dividing up the accounts of time reversal that appear in the literature and understanding common concerns about several popular accounts of time reversal. These concerns will motivate the novel account of time reversal I present in the final sections of this paper.

In this paper I examine several intuitive and theory-relative accounts of time reversal. In the first section I consider the work of Horwich (1987), Albert (2000), Malament (2004), and Arntzenius and Greaves (2009), all of whom provide intuitive accounts of time reversal. In the second section I quickly consider the work of Wigner (1959) and the "textbook account" considered by Arntzenius and Greaves, both of which are theory-relative accounts of time reversal. I discuss the general shortcomings of both intuitive and theory-relative accounts as a way of motivating a new approach

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to time reversal which I sketch in section five of this paper. Finally, at the end of the paper, I consider how this new account of time reversal would treat time reversal in toy models governed by select sets of physical laws so that the reader may better understand the implications of my new account of time reversal.

1.1. Mathematical background

Before proceeding with my analysis, I should quickly provide the reader with the necessary mathematical background to make sense of the analysis to follow. The theories I am concerned with for the purposes of this paper are, roughly, physical theories that at the very least provide us with (1) a set of dependent variables $u=(u_1, u_2, \ldots)$, (2) a set of independent variables $x=(x_1, x_2, \ldots)$, (3) a set of algebraic and/or differential equations e which represent the laws of the physical theory and involve all and only the variables found in $x \cup u$ and derivatives of the dependent variables in u with respect to the independent variables in x, and (4) some sort of translation guide that tells us what each of the variables in $x \cup u$ represents in the real world.[1] Call U the space representing the dependent variables in u and X the space representing the independent variables in x.

A theory's algebraic equations can be represented as $n-1$-dimensional manifolds of the n-dimensional manifold $X \times U$. If the theory is more sophisticated and, like most theories of physical interest, refers to ordinary or partial differential equations additionally or exclusively, then these equations are represented not as submanifolds of $X \times U$ but as submanifolds of the space $X \times U \times U^{(1)} \times \cdots U^{(n)}$, where $U^{(i)}$ is the ith prolongation or jet space whose coordinates represent the derivatives of the dependent variables in u with respect to the independent variables in x up to order n. So, for instance, if we are dealing with a theory whose variables are the dependent variable p, which represents position, and the independent variable t, which represents time, and whose equations involve velocity (dp/dt) and acceleration (d^2p/dt^2) only, then the theory's equations would be represented by submanifolds of the space $T \times P \times P^{(1)} \times P^{(2)}$. Call $X \times U \times U^{(1)} \times \cdots U^{(n)}$, the space on which theory's equations are represented as submanifolds, the theory's variable space.[2]

This framework allows us to define symmetries of our physical theories as maps from points in a theory's variable space to points in a theory's variable space that map all and only points that fall within the submanifold representing the theory's equations to points that fall within the submanifold representing the theory's equations. Put more simply, symmetries will always and only take solutions to the equations in e to solutions. This definition of a symmetry has the virtue of serving as a natural extension of the notion of point symmetries found in the mathematical literature on symmetries of differential equations (see, for instance, Olver, 1993 and Hydon, 2000a) and providing us with a neutral framework from which we can assess the pronouncements of different accounts of time reversal. We might otherwise worry, for instance, that Horwich's and Albert's accounts of time reversal, which seem to take time reversal to be a map from a phase space to itself, may be, in some sense, incommensurable with Malament's notion of time reversal, which is defined as a transformation of a geometric object defined on spacetime. Both Albert's notion of time reversal and Malament's, however, induce transformations of the same theory's variable space, and so we can use my framework to compare them straightforwardly.

For the purposes of this paper, I will use the notation $T(x)$ to represent the transformation induced by the symmetry T on the 1-dimensional subspace characterized by the variable x alone. Less technically, the claim that $T(x)=x'$ effectively isolates the effect of the time reversal operator to the variable x and tells us, in effect, how time reversal "acts on" on this variable. In cases where I write $T(\Psi)$, where Ψ is the fully-specified state of a physical system, T should once again be simply understood as a function from variable space to itself.

2. Intuitive accounts of time reversal

I will limit my survey of the literature to accounts of time reversal that deal with one particular physical theory, classical electrodynamics, because this particular theory has generated such fruitful discussion in the literature on time reversal and because it is helpful to see directly how different approaches to time reversal deal with the same physical theory. Intuitive accounts of time reversal may differ from one another, but they all employ the same general strategy for determining whether particular theories are time reversal invariant, which runs basically as follows:

1. Begin with familiar physical properties (such as position and perhaps velocity) of whose behavior under the time reversal operator we have an intuitive grasp.
2. Utilize some formal relations provided for us by the theory in question to determine how the values of other fundamental physical properties of the theory transform under time reversal.
3. Check to see if any solution of the theory is mapped to a solution by the putative time reversal procedure. If so, then the theory is time reversal invariant. If not, then the theory is not time reversal invariant.

A general procedure for laying out a taxonomy of intuitive accounts of time reversal, then, can be given by providing the following information about each account: (1) the intuitions which drive the particular characterization of time reversal needed for the author's account, (2) the consequences of this characterization of time reversal for the transformation of the fundamental properties of a physical theory under time reversal, and (3) the verdict the account delivers concerning the time reversal invariance of particular theories.

Note that this strategy, as it stands, makes room for degrees of purity within the intuitive accounts of time reversal thanks to step 2. Because step 2 explicitly relies on the formal relations provided by the theory in question to relate one physical property to another, and since some of these relations may need to be established by substantive physical laws that are taken to be definitional (or at least constitutive of the property in question) and assumed to be time reversal invariant, these intuitive accounts will be closer to theory-relative accounts than "purer" intuitive accounts, which would take advantage of fewer or no such law-like formal relations. We will see this hybrid approach in the first intuitive account I will consider, Horwich's, and follow it up with a consideration of the "purest" intuitive account I will consider, Albert's. Note, however, that no matter how pure an intuitive account of time reversal may be, the general strategy taken by all such accounts will leave them open to the concerns I raise below in Section 4.

[1] I am playing fast and loose with the formalities regarding this "translation guide" and how it syncs up the mathematics of our theory with measurements in the real world, but this is because I wish to remain as neutral as possible as to the question of how physical theories represent what they represent as very little of the analysis to come in this paper hinges on the specific features of this "translation guide".

[2] Further details on this part of the framework can be found in Olver (1993).