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David Malament and the Conventionality of Simultaneity: A Reply

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1. In his influential article "Causal Theories of Time and the Conventionality of Simultaneity," David Malament began his paper as follows:[1]

> Adolf Grünbaum maintains that, within the framework of special relativity, the relation of *simultaneity relative to an inertial observer* is conventional rather than factual in character. His argument turns on two assertions:
>
> (1) The relation is not uniquely definable in terms of the relation of causal connectibility.
>
> (2) Temporal relations are non-conventional if and only if they are so definable.

The second assertion constitutes a version of the "causal theory of time." And in a 1989 letter to Max Jammer, Malament explained that when he wrote that article, he directed it exclusively against my own specific version of conventionalism.[2]

Malament then states his objection to the necessary condition in (2) qua version of the causal theory of time (Malament 1977, p. 293):

> So far as I know, criticism of Grünbaum's argument has always focused on (2). Michael Friedman [[3]], for example, sees no reason why we must adopt a causal theory of time or, for that matter, any other reductionist analysis of temporal relations. Even if (1) is true, he argues, it does not follow that there is no fact to the matter whether two events are simultaneous relative to a particular inertial observer.
>
> I am entirely sympathetic with Friedman's scepticism concerning (2).

But Malament's own argument against (1), as he construes it, proceeds without reference to the merits or demerits of the causal theory of time, since his concern is to refute (1) *within* the framework of a causal theory of temporal order "even while avoiding debate over

conventionalism and causal theories of time" (Ibid.). Therefore, to achieve expository clarity, I shall defer to Section 6 my retort to Friedman's objection to the causal ontology of temporal relations in the special theory of relativity.

Malament's argument is that he has demonstrated the unique definability denied by assertion (1), so that the "if" clause in assertion (2) then entails the non-conventionality (facticity) of the specified simultaneity relation, a conclusion he calls "rather ironic" (Malament 1977, p. 293). Alas, he does not give references to my writings to document his claim that I committed myself to (1) and (2) *in his particular sense of definability, which is predicated on specified constraints.* Indeed, I had not: As Allen Janis has importantly pointed out, one of these constraints--the first of four--is genuinely problematic, and I had certainly not taken it for granted, implicitly or otherwise, in my writings on the status of simultaneity in the inertial frames of the special theory of relativity ("STR").

In the causal context of the light cone structure of the STR, the facticity versus conventionality of the relation of simultaneity *relative to an inertial frame I* turns on whether the facts of causal connectibility and non-connectibility *mandate* (dictate) that relativized relation, on the one hand, or whether these facts provide scope for alternative non-trivial stipulations in constructing that relation, on the other. The issue raised by Malament's particular sense of definability is thus whether the first of the constraints he imposes on the causal definability of relative simultaneity is *mandated* by the pertinent causal facts or is non-trivially *stronger* than what is thus mandated; furthermore, if that constraint is stronger, we shall need to determine the bearing of dropping it on the unique definability of relative simultaneity in terms of the relation of causal connectibility.

2. Malament considers an inertial observer *O*, i.e., an observer at rest with respect to an inertial frame *I*. To facilitate the statement of the four constraints he imposes on any causally definable candidate for the relation of simultaneity with respect to *O*, he employs the following definitions (1977, p. 297): (a) A "causal automorphism" is a one-to-one mapping of the space-time onto itself which preserves the relation κ of causal connectibility among its event elements, and (b) an "*O* causal automorphism" is a causal automorphism that *maps the world line of O onto itself*. The four constraints he then imposes on any candidate $S(p, q)$ for the relation of simultaneity between two events *p* and *q* relative to *O* are the following:

(i) *S* is invariant under all *O* causal automorphisms,

(ii) *S* is an equivalence relation,

(iii) There exist world points *p* and *q*, one of which is on *O*'s world line while the other is not, such that *S*(*p*, *q*),

(iv) *S* is not the universal relation.

Having imposed all four of these constraints, notably the first, Malament is able to prove that the relative simultaneity relation of standard synchrony $\epsilon = 1/2$ is uniquely definable from κ and *O*. He denotes the latter relation by Sim_0.

But before giving this proof, he declared: "To be sure, there are other two-place relations [of relative simultaneity] which are definable from κ and *O* [i.e., relative simultaneity relations corresponding to non-standard synchrony, for example, some fixed $\epsilon \neq 1/2$]. But all these are ruled out if minimal, seemingly innocuous conditions are imposed." One can agree at once that constraints (iii) and (iv) are minimal and innocuous. But, as we shall see, what matters in the context of the issue of the conventionality versus the facticity of relative simultaneity as formulated above, is that the first of Malament's constraints is demonstrably not "innocuous," because it is *not* mandated by the facts of causal connectibility or non-connectibility.

Since his constraint (i) may therefore be dropped and be replaced by a different one or another, I never took it for granted. And since Malament's sense of "definability" presupposes (i), I did not, and do not now assert either assertions (1) or (2) in *his* sense of "definability." Therefore, his demonstration that assertion (1) is false as he construes "definability" does not tell against my views. By the same token, in assertion (2), I do *not* subscribe to the "if" clause in his sense of "definability" as a sufficient condition for the non-conventionality of temporal relations. And yet Malament relies on just that "if" clause to deduce the *non*-conventionality of relative simultaneity from the negation of (1). Precisely because his constraint (i) is *not* mandated by the causal facts, and is thus replaceable, it will turn out that these facts allow a whole family of relative simultaneity relations that are definable from κ and *O*, so that assertion (1) becomes true rather than false as Malament would have it.

I shall use Allen Janis's scrutiny of Malament's constraint (i) to explain why I believe that Malament has failed to discredit my ontological version of the claim that the conventionality of relative simultaneity in the STR is a philosophically illuminating thesis. But it is expeditious

and simpler to deal first with (ii), which asserts that "*S* is an equivalence relation."

Let the clock of the inertial observer *O* assign a unique time coordinate *t* to every event on *O*'s world line. And let *O* also assign time coordinates to each event not on *O*'s world line. These assignments are to be governed by the following restriction: If a pair of distinct (i.e., non-coinciding) events is causally connectible (by means of light *in vacuo* or by other causal chains), they will be "time-separated" by being assigned *different* time coordinates; thus, the same time coordinate will be assigned to distinct events *only* if they are *not* causally connectible, i.e., only if they have a space-like separation, i.e., (in Hans Reichenbach's parlance) only if they are "topologically simultaneous."

As we know, the invariant relation of "topological simultaneity" (causal non-connectibility) is not transitive and hence is not an equivalence relation: If an event E_1 on *O*'s world line is topologically simultaneous with an event E' not on that world line, and if E', in turn, is topologically simultaneous with an event *E* on *O*'s world line but distinct from E_1, then E_1 and *E* will not be topically simultaneous, since they both belong to *O*'s world line, and are thus causally connectible.

By the same token, the topological simultaneity of two distinct events is *not sufficient* for their being assigned the same time coordinate *t*: If the topologically simultaneous pairs (E_1, E') and (E', *E*) were each assigned the same value of *t*, then *O*'s clock would be assigning the same time coordinate to both E_1 and *E* on its own world line in violation of our restriction that causally connectible events be time-separated.

But we shall say that two topologically simultaneous events are "*metrically* simultaneous" with respect to *O*, if and only if *O*'s clock does assign the same time coordinate to them. And since the relation of numerical equality among time coordinates is an equivalence relation, any relation of metrical simultaneity, as defined, will be an equivalence relation. Thus, for *any one* value of Reichenbach's ϵ ($O<\epsilon<1$) that *O* uses to assign time coordinates to events elsewhere from *his* clock--be it the value $\epsilon=½$ of standard synchrony *or* a value $\epsilon\neq½$ in that open interval corresponding to non-standard synchrony--the ensuing metrical simultaneity will be an equivalence relation.

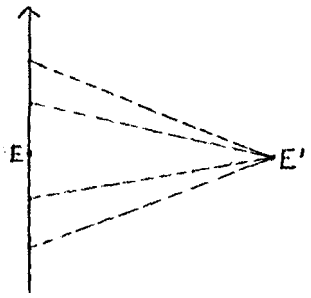
It is very important *not* to confuse the preceding assignment of time coordinates from one and the same clock *O* to events not on *O*'s world line, with the time coordinatization in the

following different situation: Two separate observers *A* and *B* at rest in the same inertial frame *each* assign time coordinates to events on the other's world line using the *same non*-standard synchrony $\epsilon_m \neq ½$. In that case, once the *B*-clock is in such non-standard ϵ_m synchrony with the *A*-clock, the *A*-clock will *not* be in ϵ_m synchrony with the *B*-clock, i.e., the same non-standard synchrony is not symmetric as between separated clocks and hence is not an equivalence relation.[4] In other words, the *B*-clock's time coordinatization of events at the *A*-clock will disagree with the *A*-clock's own time coordinatization of these events. Thus, in the case of non-standard clock synchrony, if two spatially separated events are assigned the same time coordinates by the *A*-clock--i.e., are metrically simultaneous from *A*'s point of view--they will not be metrically simultaneous from *B*'s point of view.

Indeed, I have shown that if the *same* non-standard synchrony ϵ_m is used to synchronize a clock *B* from a clock *A*, and a clock *C* from *B*, then the *C*-clock will not be in ϵ_m synchrony with *A*.[5] Thus, non-standard synchrony is intransitive rather than merely non-transitive. Hence such synchrony fails in a further respect to be an equivalence relation. So much for Malament's constraint (ii), demanding that *S* be an equivalence relation.

Before turning to Janis's scrutiny of constraint (i), several considerations are in order to set the stage for it.

3. To articulate the sense in which I shall claim that, in the STR, the relevant physical facts do *not* mandate a unique relation of relative simultaneity, let me explain carefully in just what sense the pertinent physical facts postulated in Newtonian physics *do* mandate a unique and indeed absolute relation of simultaneity between pairs of events. And I shall do so without appeal to Newton's substantivalist ontology of time (or space).[6]



Let the solid line on the left in the diagram above be a portion of the world-line of a clock U_1

which is at rest at a point A of an inertial system I. And let E' be an event belonging to the career of another clock U_2 at rest at a point B of I. Furthermore, suppose that any clock U which moves in I and intersects the world-line of U_1 has the same reading as the latter for the event of their first encounter. It is then a fact that (after allowance for the effects of what Reichenbach has called "differential forces") U will have the *same reading* as U_1 for any *subsequent* encounter with it. This *agreement* between U and U_1 is not, however, the sole respect in which Newtonian and relativistic clock transport *differ* from one another.

In the Newtonian world of arbitrarily fast particles (or causal chains), the career S of U_1 contains a *unique* event E which cannot *also* belong to the career of any moving clock U (or other particle) containing with E'. Once the Newtonian time system is elaborated, this fact can be expressed by the statement that "the same body (U) cannot be at two different places (A and B) at the same time." And the specified unique event E divides S into disjoint open subintervals of events X and Y having the following properties: *every* event x in X and *every* event y in Y can also belong to the world-line of a moving clock U whose intersection with the world-line of U_2 is E'. Furthermore, if each clock U was *locally* synchronized with U_1, the time t' of E' on *every* U is the same and is numerically *between* the time of x on U (or U_1) and the time of y on U (or U_1). The world-lines of such clocks U are shown by dotted lines. And the betweenness of E' on these world-lines is a matter of purely ordinal temporal fact. For it does *not* depend on invoking any durational measure of an event interval xE' or $E'y$. Thus, for *any* x in X and *any* y in Y, E' is temporally between them on the basis of the identical reading t' of suitably fast moving clocks U whose respective careers likewise comprise x and y. And E' is the only event on the world-line of U_2 sustaining these betweenness relations to *all* of the members of X and Y.

But it is also true (by our definition of X and Y) that E is the only event in S which is temporally between every x in X and every y in Y. It follows that (i) E' and E are temporally between identically the same events in S, and (ii) in any system of quasi-serial temporal order comprising the events on U_2 and in S, E' and E occupy the same place with respect to the order of earlier and later *as a matter of ordinal temporal fact*. Hence on the basis of temporal betweenness relations alone, E' is uniquely simultaneous with E within S, and E is uniquely simultaneous with E' within the career of U_2.

In order to characterize further the ontological status of the simultaneity furnished by

Newtonian clock transport, it behooves us to comment on the bearing of causal relations in Newton's theory on its time relations. Newton's third law of motion (law of action and equal, opposite reaction), coupled with his law of universal gravitation, tells us that our E and E' are linkable by reciprocal instantaneous gravitational influences. These can be represented as causal chains $EE'E$ or $E'EE'$ whose "emission" at either E or E' coincides with its "return" to either E or E'. And since no Newtonian body can be at two different places simultaneously, no Newtonian body or clock can link E to E' so that these events coincide spatio-temporally with event-members belonging to its career. Indeed, in Newton's world, gravitational influence chains are the only causal chains whose careers can include simultaneous events such as E and E'. And gravitational chains comprise none but simultaneous events. Moreover, any set of pairwise *non*-simultaneous events can be linked by a *non*-gravitational causal chain which is genidentical, i.e., which is constituted by the career of one and the same body. The career of a single standard clock is, of course, an instance of merely one particular species of genidentical causal chain.

It would clearly be inconsistent with Newton's temporal order to demand, as is done in the STR, the *non*-simultaneity of two events connectible only by the fastest causal chain rather than by a single clock. For on Newton's theory, our events E and E' are simultaneous according to its clock readings, and yet they are connectible by Newton's fastest causal chain (gravitation) and only by such a chain. By contrast, the STR requires its clocks to be set so as to issue in the non-simultaneity of any two events which can belong only to the career of its fastest causal chains (light), even though these events cannot both be on the world-line of a single clock.

It is clear from our analysis that in Newton's world events are simultaneous as a matter of physical fact because of nonmetrical temporal relations furnished by that world's clocks and/or causal relations. Spatially separated Newtonian clocks at A and B can be consistently synchronized by transporting a third clock U from A to B and making each of them locally synchronous with U when it coincides with them. We see that the sameness of the time numbers furnished for simultaneous events by such synchronized clocks A and B renders an equivalence relation that exists between these events as a matter of physical fact. Thus the existence of the relation to which the Newtonian theory applies the name "simultaneous" does not involve any conventional ingredient. What is conventional here is the particular identity of the time number assigned alike to all members of a class of simultaneous events. The identity of that number

results from one arbitrary setting of one clock. But the equivalence relation of simultaneity rendered by the same clock numbers is not predicated on a convention in Newton's theory.

Newtonian simultaneity is absolute in the standard physical sense that the simultaneity of two events E and E' is *invariant* with respect to all reference frames. But Newton's simultaneity is also factual, as opposed to conventional, because it is vouchsafed by purely ordinal temporal facts furnished by the clocks and/or causal relations in his world.

This then is the sense in which, I claim, the pertinent physical facts in Newton's world mandate a unique and indeed absolute relation of simultaneity. It will behoove us to bear this state of affairs in mind, by way of contrast to the STR, when we inquire to what extent the relevant physical facts mandate a relation of relative simultaneity in the STR.

4. Howard Stein made a helpful distinction that I shall bring to bear on my appraisal below of Friedman's critique of me, which Malament endorsed:[7]

> There are really two distinct aspects to the issue of the "conventionality" of Einstein's concept of relative simultaneity. One may assume the position of Einstein himself at the outset of his investigation--that is, of one confronted by a problem, trying to find a theory that will deal with it satisfactorily; or one may assume the position of (for instance) Minkowski--that is, of one confronted with a theory already developed, trying to find its most adequate and instructive formulation. The issue in its latter aspect has been dealt with--in my opinion, conclusively--by David Malament (1977), . . .
>
> As to the procedure of Einstein, he of course had no "space-time geometry" *within* which to propose a concept of simultaneity; on the contrary, the task he had conceived was precisely that of *constructing* a suitable space-time geometry--or equivalently, in Einstein's own terms, of devising a suitable new kinematics.

As to Einstein's account of the ontological status of simultaneity relative to an inertial frame, we need to turn first to Section 1, entitled "Definition of Simultaneity," in his 1905 paper.[8]

There he uses the German word "*Festsetzung*," which I translate by "stipulation," when he tells us of the need for a "*Festsetzung*" to make temporal comparisons at spatially separated

points. This "*Festsetzung*" comes into play, he says, when we endeavor to define a "time" that is "common" to space points *A* and *B*. The latter time, he explains, can now be "defined," "indem man *durch Definition* festsetzt," i.e., "by stipulating *by means of a definition*," that the one-way transit times of a reflected light ray in opposite directions of the path *AB* are equal.[9] This is his optical specification of the familiar standard synchrony of clocks. Thus, events at *A* and *B* that are assigned equal time coordinates by this *stipulation* are metrically simultaneous on the strength of it.

In 1954 (originally 1916), Einstein made it even more explicit that he contrasts a "stipulation" with a "supposition" or a "hypothesis" such that *there is no fact to the matter whether two events are simultaneous relative to a particular inertial observer.*[10] There he considers two points *A* and *B* at a railway embankment, and the line segment between them whose mid-point is *M*. An observer at *M* can observe the joint arrival at *M* of light flashes originating at *A* and *B*, respectively. As to whether the two flashes originated simultaneously on the embankment, Einstein writes:[11] ". . .That light requires the same time to traverse the path $A \rightarrow M$ as for the path $B \rightarrow M$ is in reality neither a *supposition nor a hypothesis* about the physical nature of light, but a *stipulation* which I can make of my own freewill in order to arrive at a definition of simultaneity."

5. We shall now see that the facts of causal connectibility and non-connectibility in the STR--hereafter "light cone causality"–do not mandate Malament's constraint (i): These facts provide scope for the causal definability of a family of infinitely many non-standard equivalence relations of simultaneity with respect to one and the same inertial observer *O*. As we recall, Malament was able to rule out these non-standard simultaneity relations in favor of the standard relation Sim_0 by imposing his constraint (i) in addition to his other three. As we recall, his constraint (i) is that the relation *S* of simultaneity relative to *O* be invariant under all causal automorphisms that map *O*'s world line onto itself ("*O* causal automorphisms").

But a reformulation of a construction that Allen Janis gave in 1983[12] enables us to see that this constraint is not mandated either by light cone causality or by *S*'s being an equivalence relation of simultaneity relation relative to *O*. Let me quote from Janis's reformulation (private communication, December 15, 2000, italics added):

As Malament shows (p. 296), standard simultaneity specifies that the events

> simultaneous with a given event on *O*'s world line are those events lying in the hyperplane orthogonal to *O*'s world line and containing the given event. Suppose *O* were to make a different [non-standard] choice of simultaneity, as follows: By specifying a set of three parameters, *O* can uniquely designate a time-like line that is inclined to *O*'s world line, intersecting it at a given event *E*. This line could be interpreted as the world line of an observer, say *A*, moving with respect to *O* (and the components of *A*'s velocity relative to *O* could serve as the aforementioned three parameters), *but it should be emphasized that this construction is to be thought of as something carried out entirely by O*: *A*'s world line is to be described from the point of view of *O*'s inertial frame. *O* then specifies that the events *simultaneous* with the event *E* on *O*'s world line are those events lying in the hyperplane orthogonal to *A*'s world line and containing *E*. (Since a hyperplane orthogonal to a time-line is necessarily space-like, *O*'s specification is necessarily consistent with [light cone] causality.) If we then define "*A* causal automorphisms" as those causal automorphisms that take *A*'s world line into itself, and replace "*O* causal automorphisms" by "*A* causal automorphisms" everywhere in the statement and proof of Malament's uniqueness theorem, the proof would go through just as before [i.e., *for any one choice* of a particular time-like world line *A*, a *particular* non-standard simultaneity relation would be uniquely defined].

In short, events that are standardly simultaneous in *A*'s rest frame are now non-standardly simultaneous in *O*'s rest frame. But there are an infinitude of time-like world lines *A*, each one specified by a set of three parameters, and each one generating a particular non-standard simultaneity relative to *O*. And since the use of the three parameters is entirely compatible with light cone causality, no one simultaneity relation relative to *O* is the *only* one definable from κ and *O*, although standard simultaneity is the only one definable from κ and *O alone*, as shown by Malament.

In this important sense, assertion (i) in Malament's opening paragraph is true after all, rather than false, as he would have it.

Yet as Janis (1983) and van Fraassen have noted, the descriptive simplicity of standard

simultaneity is manifested anew by the fact that Malament's constraint (i) dispenses with Janis's three parameters. Thus, as van Fraassen put it, this constraint enables Malament to define standard relative simultaneity from κ and *O alone*. Yet constraint (i), not being mandated by light cone causality, issues no less in a conventional choice of simultaneity Sim_0 than do the constructions via the world lines *A*, which issue in non-standard relations of simultaneity. I therefore conclude that Malament's remarkable proof has not undermined my thesis that, in the STR, relative simultaneity is conventional, as contrasted with its non-conventionality in the Newtonian world, which I have articulated. Thus, I do not need to retract the actual claim I made in 1963 as follows:[13] "Unlike the Newtonian situation, . . .the physical facts postulated by [special] relativity require the introduction, *within a single inertial frame S*, of a convention stipulating which *particular* pair of topologically simultaneous [i.e., space-like separated] events. . .will be chosen to be metrically simultaneous."

6. Now let me respond to Malament's endorsement of Michael Friedman's views, which I had occasion to cite preliminarily at the end of Section 1.

First, I am quite surprised that both of them see "no reason why [in the STR] we must adopt a causal theory of time or, for that matter, any reductionist analysis of temporal relations." In my view, there are indeed good reasons, and they seem to be persuasive:

(i) In the STR, *the entire system of invariant temporal relations* among events is based ontologically on causal relations by being coextensive with them: (a) As we saw in Section 2, events in the theory sustain invariant relations of "time-separation" if and only if they are causally connectible respectively by the career of a particle of non-zero rest-mass or by the motion of a photon; (b) other events sustain invariant relations of space-like separation, if and only if they are *not* thus causally connectible. Thus, Malament wrote (1977, p. 294): "Two point events are said to be *causally connectible* if and only if it is possible for a photon or particle with non-zero rest-mass to travel between them (in either direction)." Furthermore, relations of metrical simultaneity relative to inertial frames--whose ontological status I just characterized in Section 5 and shall consider further below--are confined in the STR to events having a causally grounded space-like separation.

(ii) The recognition that, in the STR, the whole system of invariant temporal relations is *ontologically coextensive* with the specified causal relations provides a clear framework for

Einstein's construction of the new kinematics by which he replaced the Newtonian one. And hence I consider it justified to determine the ontological status of metrical simultaneity relative to an inertial frame within the context of a causal theory of time.

By contrast, Friedman's point of view provides *no ontological why and wherefore* for the space-time structure of Minkowski space-time, nor of the ontological rationale for its superiority to its Newtonian predecessor. Instead of giving a justifiable ontological underpinning to the superseding theory as against its predecessor, Friedman is content with a statement that they *differ geometrically* (Friedman 1977, pp. 404–405):

> . . .I shall treat both Newtonian mechanics and special relativity as *space-time* theories. I view both theories as theories about a four-dimensional manifold, space-time, and the geometrical structures that characterize it. Where the two theories differ is with respect to the geometrical structures that space-time actually possesses. In particular, differences between the two theories as to time and simultaneity are to be understood as differences in the geometrical properties predicated of space-time. I adopt this view of the two theories because it seems to me to make their similarities and differences--their comparison--especially clear.

To this, he adds (Friedman 1977, p. 410), again without any why and wherefore:

> Our world is a Minkowski space-time, not a Newtonian space-time; and neither a frame-independent global time nor a frame-independent simultaneity relation exists.

Hence next let me inquire into the *fundamentum in re*, if any, of the simultaneity of two events relative to an inertial frame. Malament notes approvingly (1977, p. 293) that, according to Friedman, I had failed to establish "that there is no fact to the matter whether two events are simultaneous relative to a particular inertial observer." Yet I have now done so in Section 5. And in my citations from Einstein's writings of 1905 and 1954 in Section 2 above, he had explicitly asserted just such *non-facticity* for *frame-dependent* simultaneity. As will be recalled, he wrote (see Note 10): ". . .That light requires the same time to traverse the path $A \rightarrow M$ as for the path $B \rightarrow M$ is in reality neither a *supposition nor a hypothesis* about the physical nature of light, but a *stipulation* which I can make of my own freewill in order to arrive at a definition of simultaneity." To reach that conclusion, Einstein was clearly looking at how he *constructed* the

new kinematics of his STR; he was not taking its finished geometrical formulation at face value as a basis for articulating its underlying space-time ontology. And the standard simultaneity he stipulated by his light signal method is, of course, Malament's Sim_0.

One lesson I derived from Einstein's historic case was to reject as *uncritical* the attempt to read off the ontology of a space-time theory from its geometrical formulation, when taken at face value; this attempt, I claim, begs the question with respect to such noteworthy stipulative (conventional) ingredients as the theory may contain. Referring to my view, John Winnie[14] wrote concurringly:

> One moral of this view is clear, and well worth heeding. The standard formulations and practices surrounding a physical theory do not provide clear and explicit guides to its ontological claims. At best, they furnish preliminary clues to be used by the critical scientific realist in his efforts to create a reconstructed version of the theory that will exhibit its physical commitments with greater perspicuity.

Alas, Friedman's procedure is just the opposite. How, I ask, does he determine whether assertions of relative simultaneity in the STR have a *fundamentum in re* (ontological referent)? He peremptorily assumes a substantivalist interpretation of the entire geometrical structure of Minkowski space-time. But, as I explained above, I have *positive reasons* for espousing a causal theory of time in the STR. And, as I have argued, that causal theory provides a *clear rationale* for Einstein's explicit assertion that there is no fact to the matter in ascriptions of frame-dependent metrical simultaneity in the STR, Malament's formal result notwithstanding. How can Friedman explain that Einstein used light propagation in keeping with the causal theory of time to provide an avowedly *stipulative* enunciation of frame-dependent simultaneity relations? Einstein made this stipulation *before* deriving the Lorentz transformations which contain it and to which Friedman nonetheless gives a uniformly substantivalist interpretation. Thus, Friedman did not join the issue with me when he wrote (1977, p. 430):

> Grünbaum's argument, unlike Reichenbach's, has the advantage that *if* it were correct, we *could* draw semantic conclusions about the truth-value of sentences containing "simultaneous" on the basis of the referential properties of their key terms. For, if Grünbaum's argument is correct, it follows that

> "simultaneous" has no referent--there is no objective physical relation for it to refer to. And this would make the conventionalist contention that sentences like "Events e_1 and e_2 are simultaneous with respect to state of inertial motion M" lack determinate truth-value highly plausible. However, it seems to me that Grünbaum's actual argument is much less persuasive than Reichenbach's. Reichenbach has given some plausibility to the claim that statements about distant simultaneity may be unverifiable within the context of special relativity. As far as I can see, Grünbaum has given us no reason to accept the view that the only objective temporal relations are constituted by causal relations. Indeed, how could one possibly support such a view? Our only grip on which properties and relations are objective constituents of the physical world is via our best theories of the physical world. The properties and relations that we hold to exist objectively are those that our best physical theories postulate. And since our best theories do not merely postulate the kind of *ordinal* (causal) temporal relations favored by Grünbaum--they postulate *metrical* relations as well--we have no reason to grant such ordinal (causal) relations the privileged ontological status that Grünbaum wants to ascribe to them.

But, as we saw, Einstein stated emphatically that assertions of metrical simultaneity in the STR are *not* "hypotheses" which are "postulated" in Friedman's sense, ontologically on a par with, say, the postulate that light is the fastest causal chain. Why then does Friedman feel entitled to gloss over that important ontological difference by using the same term "postulate" for both? By the same token, he does not tell us what he makes of the following 1949 ontological declaration of Einstein's:[15]

> We now shall inquire into the insights of definite nature which physics owes to the special theory of relativity.
>
> (1) There is no such thing as simultaneity of distant events;

Indeed, if Friedman's claims, and Malament's endorsement of them, *were* sound, they would impugn not only my views but also Einstein's conventionalist conception of the ontological status of frame-dependent simultaneity. After all, if Malament had succeeded in showing that his standard simultaneity relation Sim_0 is non-conventional, he would have

succeeded in proving Einstein and Reichenbach wrong, no less than me. I am therefore greatly puzzled that neither Malament nor Friedman said a word about the derogatory bearing of their critique of me on Einstein's pioneering conception.

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[1] D. Malament, "Causal Theories of Time and the Conventionality of Simultaneity," *Noûs* 11 (1977): 293–300.

[2] M. Jammer, "Hans Reichenbach und der Begriff der Gleichzeitigkeit," in *Hans Reichenbach: Philosophie Im Umkreis der Physik*, ed. H. Poser and U. Dirk (Berlin: Akademie Verlag, 1998), 23.

[3] This reference is to Michael Friedman's "Simultaneity in Newtonian Mechanics and Special Relativity," in *Foundations of Space-Time Theories*, ed. J. Earman, C. Glymour, and J. Stachel, Minnesota Studies in the Philosophy of Science, vol. 8 (Minnesota: University of Minnesota Press, 1977), 403–432.

[4] H. Reichenbach, *Axiomatization of the Theory of Relativity* (Berkeley: University of California Press, 1969), 45.

[5] A. Grünbaum, "Simultaneity by Slow Clock Transport in the Special Theory of Relativity," *Philosophy of Science* 36, no. 1 (March 1969): 9–11.

[6] Here I draw almost verbatim on separate passages that I strung together from my earlier discussion of Newtonian simultaneity in my *Philosophical Problems of Space and Time*, 2d ed. Boston Studies in the Philosophy of Science, vol. 12 (Dordrecht, The Netherlands: D. Reidel Publishing Co., 1973), 684–685; 686; and 688. The chapter from which these passages are drawn (Chapter 20) was reprinted from my (1969) article in Note 5.

[7] H. Stein, "On Relativity Theory and the Openness of the Future," *Philosophy of Science* 58 (1991): 153.

[8] See A. Einstein, "Zur Elektrodynamik Bewegter Körper," in *The Collected Papers of Albert Einstein*, ed. J. Stachel, vol. 2 (Princeton: Princeton University Press, 1989), 277–279.

[9] Ibid., 279, italics in the original.

[10] A. Einstein, *Relativity, The Special and The General Theory*, translated by R. W. Lawson, 15th ed., enlarged (London: Methuen, 1954), ch. 8. I am greatly indebted to Robert Rynasiewicz

for steering me to this reference, which I had forgotten.

[11] Ibid., 23.

[12] A. I. Janis, "Simultaneity and Conventionality," in *Physics, Philosophy and Psychoanalysis, Essays in Honor of Adolf Grünbaum*, ed. R. S. Cohen and L. Laudan (Dordrecht, The Netherlands: D. Reidel Publishing Co., 1983), 101–110, esp. 107–108. A like construction is also outlined by John Norton in his "Philosophy of Space and Time," in M. Salmon et al. (eds.), *Introduction to the Philosophy of Science*. (Englewood Cliffs, NJ: Prentice Hall, 1992), ch. 5, 223–226. Both Janis (p. 106) and Norton (pp. 225–226) mention that in Peter Spirtes's 1981 Pittsburgh Ph.D. Dissertation, Spirtes provides a different recipe for defining an infinitude of non-standard equivalence relations of simultaneity. But, in my view, Janis rightly objects to the philosophical gloss that Spirtes puts upon these other definitions.

[13] A. Grünbaum, *Philosophical Problems of Space and Time* (New York: Alfred A. Knopf, Inc., 1963), 351; italics in original.

[14] J. Winnie, "The Causal Theory of Space-Time," in *Foundations of Space-Time Theories*, ed. J. Earman, C. Glymour, and J. Stachel, Minnesota Studies in the Philosophy of Science, vol. 8 (Minnesota: University of Minnesota Press, 1977), 192–193.

[15] A. Einstein, "Autobiographical Notes," in *Albert Einstein: Philosopher-Scientist*, ed. P. A. Schilpp (Evanston, IL: Library of Living Philosophers, 1949), 61.

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