Leibniz on Motion and the Equivalence of Hypotheses[1]

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Abstract

Contrary to popular belief, I argue that Leibniz is not hopelessly confused about motion: Leibniz is indeed both a relativist and an absolutist about motion, as suggested by the textual evidence, but, appearances to the contrary, this is not a problem; Leibniz's infamous doctrine of the equivalence of hypotheses is well-supported and well-integrated within Leibniz's physical theory; Leibniz's assertion that the simplest hypothesis of several equivalent hypotheses can be held to be true can be explicated in such a way that it makes good sense; the mere Galilean invariance of Leibniz's conservation law does not compromise Leibniz's relativism about motion; and Leibniz has a straightforward response to Newton's challenge that the observable effects of the inertial forces of rotational motions empirically distinguish absolute from relative motions.

I. Puzzles concerning Leibniz's views about motion[2]

A relativist about motion holds that all motions are relative in the sense that the attribution of motion to any body makes sense only if it is supplemented by the explicit specification of another body, or, more generally, of a material frame of reference, in relation to which the body in question can be said to be moving. According to the relativist, there are no absolute motions, i.e., motions whose attribution to bodies makes sense without the specification of a material frame of reference. Using contemporary terminology, we can say that for the relativist spacetime does not have, or the spatiotemporal structure of the world does not include, any geometric structure that singles out a class of privileged frames of reference and defines a special class of absolute motions, as for instance an inertial or affine structure, which introduces a non-relative distinction between inertial and non-inertial motions, i.e., between motions that are uniform and rectilinear and motions that are accelerated.[3] Absolutism about motion is the denial of relativism about motion.

Leibniz's views on motion are notoriously difficult and complex. On the one hand, there is substantial evidence for the reading that Leibniz is a relativist about motion. First, Leibniz often characterizes motion as change of place. And since, on

Leibniz's view, places are defined in terms of spatial relations to bodies, it follows that motion, understood as change of place, is relative.

> To summarize my point, since space without matter is something imaginary, motion, in all mathematical rigor, is nothing but a change in the positions of bodies with respect to one another, and so, motion is not something absolute, but consists in a relation.[4]

Second, Leibniz endorses what he calls the "equivalence of hypotheses" (EH).

> As for absolute motion, nothing can determine it mathematically, since everything ends in relation. The result is always a perfect equivalence in hypotheses, as in astronomy, so that no matter how many bodies one takes, one may arbitrarily assign rest or some degree of velocity to any one of them we wish, without possibly being refuted by the phenomena of straight, circular, or composite motion.[5]

As this passage illustrates, in this context a hypothesis is to be understood as an assignment of specific states of motion or rest at a given time, with respect to an implicitly or explicitly specified reference frame, to the bodies of a closed system.[6] In the following, I will use the phrase 'the frame of hypothesis H' to refer to the frame of reference with respect to which H assigns states of motion. As a first pass, EH can be formulated as saying that the phenomena do not distinguish between hypotheses that correctly represent the relative motions of the involved bodies at a given time, regardless of the states of motion of the reference frames of these hypotheses. Or, more briefly: no experiment can distinguish between different frames of reference, regardless of their states of motion (General Relativity). We will return to the question of whether this formulation indeed captures the version of EH that Leibniz wants to defend. For now, it is sufficient to point out that if EH is understood as General Relativity, as it commonly is, Leibniz's endorsement of EH commits him to relativism about motion.

Third, it has seemed to many that Leibniz's relationalism about space(time) implies that he must be a relativist about motion.[7] According to Leibniz's relationalism, space(time) is not a quasi-substantial entity, which exists independently of bodies, as is claimed by substantivalists like Newton, but is defined in terms of the actual and possible spatial (and temporal) relations between actual bodies.[8] One could try to argue for the claim that relationalism about space implies relativism about motion by appeal to the famous Newtonian argument for the existence of absolute or substantival space that can be constructed on the basis of Newton's discussion in the Scholium to Definition VIII in the *Principia*. According to this argument, the existence of absolute motion is empirically confirmed by the observable inertial effects of the centrifugal forces of curvilinear or rotational motions—as is illustrated by Newton's thought experiment of the rotating bucket—which, on the assumption that absolute motion is motion relative to absolute space, implies that absolute space exists.[9] This argument suggests that anyone, like Leibniz, who denies the existence of absolute space, must also deny the existence of absolute motion and, thus, be a relativist about motion.

A less controversial way to support the reading that Leibniz's relationalism about space(time) commits him to relativism about motion would be to argue that on Leibniz's conception of space(time) the spatiotemporal structure of the world must be the sparse structure of what has come to be known as 'Leibnizian spacetime', in which only the simultaneity relation, temporal distance, and spatial (Euclidean) distance at a time are well defined.[10] Leibnizian spacetime does not have an inertial structure, and does not support privileged frames of reference or absolute motions. Upon closer scrutiny, both of these arguments turn out to be ultimately unconvincing, as we will see below, but, *prima facie*, they seem to support the case that Leibniz must be a relativist about motion.

On the other hand, to the dismay of Leibniz scholars, there is also robust evidence for the reading that Leibniz is an absolutist about motion. Leibniz frequently asserts that the real in motion is force, and that of two relatively moving objects the one that possesses the active force that is causing the observable change of place is truly or absolutely moving.

> As for motion, that which is real in it is force or power, namely, something in the preset state which carries with it a change for the future. The rest is only phenomena and relations.[11]
>
> I grant there is a difference between an absolute true motion of a body, and a mere relative change of its situation with respect to another body. For when the immediate cause of the motion is in the body that body is truly in motion….[12]

This is puzzling, because absolutism and relativism about motion are exclusive alternatives. In apparently endorsing both views at the same time Leibniz seems to be embracing an internally contradictory position.

The threat of an internal contradiction is arguably the gravest problem concerning Leibniz's views on motion, but the difficulties do not stop there. Leibniz's doctrine of the equivalence of hypotheses is surrounded by several more tricky puzzles. First, Leibniz's proofs for EH appear to be *ad hoc* and beset by many difficulties, and

Leibniz does not seem to have a response to Newton's challenge that the observable effects of the inertial forces of curvilinear motions empirically falsify EH.[13]

Second, Leibniz repeatedly asserts that the simplest, or most intelligible hypothesis among several equivalent hypotheses can be held to be true.

> I hold, of course, that all hypotheses are equivalent, and when I assign certain motions to bodies, I do not and cannot have any reason other than the simplicity of the hypothesis, since I believe that one can hold the simplest hypothesis (everything considered) as the true one.[14]

Setting aside the problems that it is notoriously difficult to make precise what 'simple' is supposed to mean in this context and that it is not clear that for any situation there will be only one simplest hypothesis, the identification of the truth of a hypothesis with its superior simplicity compared to other equivalent hypotheses is puzzling, because, on a natural understanding of 'equivalence', it seems that equivalent hypotheses should have the same truth-value.

A third puzzle concerns Leibniz's fundamental conservation law, according to which the living force of a closed system, measured by mass times velocity squared (mv^2), is a conserved quantity, i.e., a quantity that does not change over time. The problem is that this law does not hold in all frames of reference,[15] and, thus, violates EH, if the latter is understood as General Relativity.[16]

Not all of these problems have received equal attention in the literature. The most attention has been given to the apparent conflict between Leibniz's relationalism about space(time) and his apparent commitment to absolutism about motion. The prevalent reaction to this puzzle has been to attest hopeless confusion to Leibniz, a reaction first expressed by Samuel Clarke in his correspondence with Leibniz.[17] But, to my mind, the puzzle in question is not much more than a red herring, which has done much to detract commentators from engaging with Leibniz's theory of motion on its own terms. To clear the road for such an engagement in our later discussion, I will briefly rehearse how this puzzle can be dispensed with.

To the Newtonian argument for the claim that relationalism about space implies relativism about motion one can reply that, granting that the inertial effects of rotations demonstrate the existence of absolute motions, the stipulation that absolute motion is motion relative to absolute space is gratuitous. As has been argued in the contemporary context most prominently by Lawrence Sklar, a relationalist can happily admit that bodies possess absolute motions, while insisting that these should be understood as primitive intrinsic properties, which are independent of the existence of any other entities.[18] This is exactly how Leibniz conceives of absolute motions, as we will see below.

In response to this suggestion one might turn to the second argument mentioned above, according to which the structure of Leibniz's relationalist spacetime is not rich enough to support absolute motions, an argument that has been defended by John Earman. On Earman's view, a relationalist like Leibniz is entitled to appeal only to relative distances and relative quantities of motion in the construction of his spacetime structure, and this seems to yield only the structure of so-called Leibnizian spacetime, in which absolute motion is not well defined. Conversely, if the relationalist helps himself to a richer spatiotemporal structure that supports absolute motions, as is required for the proposal by Sklar, while insisting on the relational nature of spacetime, relationalism loses its bite and becomes virtually indistinguishable from instrumentalism, which "trivializes the absolute-relational debate."[19] In evaluating this objection, it is helpful to keep in mind, as has also been emphasized by John Roberts, that the dispute between the relationalist and the substantivalist is primarily a dispute about the ontology of space, or spacetime, and not about its structure.[20] That is, even if the substantivalist and the relationalist agree that a richer structure than the structure of so-called Leibnizian spacetime is required to write down a satisfactory physical theory, there still is a question about what the entity *is*, about whose structure they agree, a question that is non-trivial. The relationalist can admit that terms signifying geometrical structures that are defined on a four-dimensional manifold cannot be understood literally on his view, as referring to the structures of a quasi-substantial entity, spacetime. At the same time, he can insist that for him these terms are not mere fictions to be conceived of in an instrumentalist fashion, but are to be understood as referring to aspects of the spatiotemporal structure of the material world. The upshot of these brief considerations for our present purpose is that Leibniz's relationalism about space(time) does not necessarily commit him to relativism about motion, and, thus, that Leibniz's apparent admission of the existence of absolute motion is not inconsistent with his rejection of absolute space. For the remainder of this paper this particular puzzle about Leibniz's views on motion, thus, can and will be set aside.

This essay focuses on the other mentioned puzzles about Leibniz's views on motion, which have not received as much attention in the literature. Leibniz's apparent commitment to both relativism and absolutism about motion is the topic of section II. In section III, I offer a more detailed explication of the meaning of Leibniz's doctrine of the equivalence of hypotheses. I discuss Leibniz's main argument for EH in section IV, and examine Leibniz's account of solidity in section V, which plays an important supporting role in Leibniz's case for EH.

II. Being a relativist and an absolutist about motion at the same time

Before tackling the question of how to reconcile Leibniz's relativism with his absolutism about motion, one brief preliminary conceptual clarification is in order. One of Leibniz's basic metaphysical principles states that any genuine, real attribute must inhere in exactly one subject.[21] So, in Leibniz's mouth the question of whether there are any real or true motions, should, in the first place, be understood as the question of whether there are any motions that can univocally be attributed to specific subjects.[22] Now, it is the case that any motion that is absolute in the sense specified in the previous section is real in the sense just explained. That is, any motion whose attribution to a body B is meaningful without the specification of a material frame of reference is a motion that can be attributed univocally to B. But the converse is not true in general. For example, one could stipulate that of any two relatively moving bodies the motion should be attributed to the larger one of the two. In a world without any absolute motions, real motions in this sense exist, provided that not all bodies are equally large and at rest. But although the notions 'absolute motion' and 'real motion' are not extensionally equivalent in general, on Leibniz's view of motion they turn out to be so. As will be illustrated presently, according to Leibniz, the real motions in the world are the motions of corporal substances that possess active forces, which, given that active forces are intrinsic properties, means that these motions can be attributed to particular corporeal substances without reference to other entities. Accordingly, in the subsequent discussion I will follow Leibniz in using the terms 'real motion', 'true motion', and 'absolute motion' interchangeably.

We are faced with the situation that Leibniz seems to be committed to both relativism and absolutism about motion. An obvious strategy to solve this exegetical problem would be to argue that Leibniz is in fact committed to only one of these views, and merely appears to be committed to the other. This strategy is, for instance, adopted by John Roberts, who argues that Leibniz's considered view is, or should be, absolutism about motion, and by G.H.R Parkinson and Richard Arthur, who defend the reading that Leibniz's considered view is relativism about motion.

John Roberts suggests that the right translation of the upshot of Leibniz's views on motion into contemporary spacetime vocabulary is not that the spatiotemporal structure of the world is the structure of so-called Leibnizian spacetime, as (seemingly) required by relativism about motion, but rather a richer structure featuring absolute speeds but no absolute accelerations. Even though the true absolute rest frame cannot be empirically identified, this richer spatiotemporal structure of the world is a well-founded phenomenon because the absolute speeds of bodies are grounded in the active forces of substances. According to Roberts, Leibniz appears to have been confused about the correct relativity principle for his physics, though, and should have advocated only Galilean Relativity, the thesis that the phenomena do not permit a distinction between inertial frames of reference—that is, frames in uniform rectilinear motion—as opposed to General Relativity, which Leibniz seems to endorse. For if Leibniz's preferred relativity principle were to amount to General Relativity, then the premises of Leibniz's argument for his law of the conservation of living force, as illuminatingly reconstructed by Roberts, would turn out to be inconsistent.[23]

The main problem with Roberts' account is the quickness with which he dismisses Leibniz's apparent commitment to General Relativity as a "local inconsistency" that "we can correct…without doing much damage elsewhere".[24] As we will see below, it might indeed be advisable to read Leibniz's endorsement of EH as only amounting to a commitment to Galilean Relativity. But it is one thing to arrive at this reading through a careful analysis of Leibniz's texts and arguments, and something else entirely to stipulate this reading in order to "correct" a blunder on Leibniz's part. Another difficulty for Roberts' reading is that, given Roberts' characterization of the spatiotemporal structure of Leibniz's world, it is somewhat mysterious why Leibniz should have subscribed to Galilean Relativity. The transformations corresponding to Leibniz's relativity principle should leave all well defined features of the spatiotemporal structure of Leibniz's world invariant. But absolute speeds are not Galilean invariant, i.e., they are not invariant under transformations from one inertial frame to another.

While Roberts discounts Leibniz's apparent commitment to relativism about motion, G.H.R. Parkinson and Richard Arthur discount Leibniz's apparent commitment to absolutism about motion and argue that Leibniz is a full-blooded relativist. Parkinson's proposal is built on Leibniz's claim that no corporeal substance is ever absolutely at rest. Since it is in the nature of a substance to act, there is no corporeal substance without active force, and so every corporeal substance is absolutely moving at all times.[25] Parkinson takes this claim to be the basis of Leibniz's endorsement of EH, and tries to use it to solve the tension between Leibniz's apparent relativism and absolutism about motion. According to Parkinson,

> in advancing these views, Leibniz is not fundamentally inconsistent, but…he is putting forward views which he thinks not to be wholly accurate, but to be

> justifiable by virtue of their utility… Leibniz is saying…that to suppose that something does not exercise force is to make use of a convenient mathematical fiction. In other words: although it is sometimes useful to ignore this fact, what Leibniz calls the 'equivalence of hypotheses' always holds.[26]

Parkinson apparently thinks that EH obtains, because if no body is ever truly at rest it is impossible to attribute the motion of two relatively moving bodies to a particular one of them, which means that all motion is relative. And so when we do attribute motion to one body rather than another in a given case of relative motion we make use of a convenient fiction.

Unfortunately, although the latter claim is true, Parkinson's proposal does not work as a defense of EH, nor as a convincing reading of Leibniz. Parkinson's proposal is not a plausible reading of Leibniz, simply because the non-existence of true rest is not even mentioned in any one of Leibniz's own arguments for EH. And it is not clear how EH is supposed to follow from the non-existence of absolutely resting bodies, because even if there are no absolutely resting bodies it still could be determined for any relative motion what the specific states of absolute motion of the involved bodies are. And so it is not ruled out that the phenomena might distinguish between different hypotheses, even though we cannot directly identify which bodies are truly moving by comparing them with some absolutely resting body. Admittedly, as we will see below, a case can be made that the hypotheses that Leibniz primarily considers, and to which EH is primarily supposed to apply, are hypotheses whose reference frames correspond to the rest frame of one or more of the involved bodies. For example, the admissible hypotheses for the relative motion of A and B would be that A is at rest and B is moving, or that B is at rest and A is moving, as implicitly suggested by Parkinson. But on this understanding of what an admissible hypothesis is, all that can be inferred from the non-existence of absolutely resting bodies is that all admissible hypotheses are, strictly speaking, false. It does not mean, however, that all admissible hypotheses are necessarily indistinguishable by the phenomena. For example, suppose that A is moving in absolute uniform rectilinear motion, and suppose that B is accelerating in a straight line. In a world in which Newtonian mechanics is true, the two hypotheses mentioned above are distinguishable, even though both are false. For in A's rest frame, the Newtonian laws (in their standard formulation) hold, while in B's rest frame they do not.

Arthur's reading is based on a presumed parallelism between Leibniz's treatment of causation and of motion. Just as there is no real causation among substances, there are no absolute motions, and every change is absolutely mutual. And just as

Leibniz's criterion for when a substance can be said to act on another is merely intended to preserve our normal way of talking, so is Leibniz's criterion that the simplest hypothesis is to be regarded as the true one "only honorific: it 'saves' our ordinary intuitions about what does and what does not 'truly' move, whilst the equipollence of hypotheses remains in effect."[27] And when Leibniz says that what is real in motion is force "he is not referring to the phenomenally manifested *vis viva*…, but to an endeavor or conatus to change state that takes a substance through its own series of states."[28]

Some aspects of Arthur's reading are illuminating, especially, his remarks about the parallelism between Leibniz's treatment of causation and of motion. The main problem with Arthur's proposal concerns his understanding of what Leibniz means by "force" in this context. Arthur is, of course, right that at the most fundamental level of reality in Leibniz's world there is no causation, no space, and no motion, and, thus, no absolute motion either. All that is ultimately real are simple substances and their affections, i.e., their perceptions and their active (and passive) forces that move them through a series of states according to their own internal laws. But this does not imply that in the physical world, i.e., at a less fundamental level of reality, there are no motions, just as it does not imply that there are no cats. When Leibniz advertises his physics as being superior to Descartes' purely kinematic mechanics he is not proposing to replace Cartesian physics with his monadology. Rather, Leibniz is urging to give pride of place to the *physical* forces of bodies in our fundamental scientific theories. To be sure, these physical forces are grounded in the forces of simple substances (with the help of the pre-established harmony), but that does not mean that Leibniz must have the latter kind of forces in mind when he asserts that the real in motion is force. Leibniz states at least as often that the real in extension is force, where the context makes it clear that he is talking about physical forces, in particular, the passive forces of impenetrability and resistance.[29] Moreover, Leibniz says not only that the real in motion is force but also that there are true or real motions, and at several places he specifies that the force that is real in motion is "motive force," or the "force of acting and resisting."[30] These expressions clearly do not refer to the active forces of simple substances, but to the physical forces of corporeal substances.

In contrast to Roberts, Parkinson, and Arthur, who propose to solve the puzzle about Leibniz's seeming commitment to both relativism and absolutism about motion by declaring one of these commitments to be merely apparent, I want to suggest that Leibniz can be read as an absolutist and a relativist about motion at the same time without having to be read as endorsing an internally contradictory position. More precisely, I will propose two versions of such a reading of Leibniz, both of which have something to be said for them.

The key to the reconciliation of absolutism and relativism about motion on both of these readings is a careful appreciation of Leibniz's tiered ontology. Leibniz's distinction of reality into several ontological levels is widely acknowledged in the literature, but there is disagreement about the number of distinct levels, their distinguishing characteristics, the kinds of entities that are supposed to exist at each level, and possible changes in Leibniz's views concerning the ideal and phenomenal levels in the so-called middle years.[31] Most commentators favor some version of a three-level scheme featuring an ultimately real level of (simple) substances, a phenomenal level of physical bodies, and an ideal level of abstract objects.[32] As a first pass, this three-level interpretation is acceptable, but a closer examination reveals that several more ontological sub-levels ought to be distinguished. This is not the place to defend this more complex account of Leibniz's ontology in any detail, and a few explanatory remarks will have to suffice for now. The main recommendation for this more complex conception is that it allows us to solve several vexing exegetical puzzles concerning some of Leibniz's most discussed doctrines, including his conception of matter, his views about relations, his theory of space and time, and, as we will see below, his account of motion. The solution to the puzzle that Leibniz seems to be both an absolutist and a relativist about motion that I want to propose does not depend on how exactly the details of this further stratification of Leibnizian reality are spelled out. But in the interest of full disclosure and in order to prevent confusion, I will briefly sketch the outlines of my favorite interpretation of Leibniz's tiered ontology before indicating the general minimal features that have to be accepted for the proposed solution to get off the ground.

On my preferred reading of Leibniz, the most fundamental ontological level of created reality comprises simple substances or monads, and (possibly) corporeal substances of a first kind, understood as (not necessarily spatial) aggregates of monads that are unified by the substantial forms of their respective master-monads.[33] If one wants to allow for a realist reading of Leibniz and to accommodate certain texts from the middle years and the Des Bosses correspondence, one might want to add a second substantial level to Leibniz's ontological scheme—which, to my mind, is ultimately dispensed with by Leibniz—that is inhabited by corporeal substances of a second and/or third kind, understood as quasi-Aristotelian substances composed of substantial forms and primary matter, and/or as (spatial) aggregates of monads unified by additional substantial principles of unity, so-called 'substantial chains'.

The second main level is the level of phenomenal reality. Briefly put, phenomena are characterized by their dependence on the perceptions or cognitions of souls, where minimally 'well-founded' phenomena can be conceived of as the common intentional objects of the (in part unconscious) coherent perceptions of all monads existing in a given possible world.[34] The phenomenal level itself is divided into (at least) three sub-levels, namely, 1) the level of common sense, whose phenomena correspond to the intentional objects of the shared pre-scientific world-view of all rational monads, which is based on their conscious, partly confused perceptions, 2) the level of physical science proper, whose phenomena correspond to the intentional objects of Leibniz's physics, and 3) the level of Leibniz's new (metaphysical) science of dynamics. It is at the latter level that corporeal substances of a fourth kind and their aggregates appear in Leibniz's scheme. A corporeal substance of the fourth kind—which, in my reading, is the only kind of corporeal substance that Leibniz really endorses—can be understood as a phenomenal body *insofar* as it has a soul, i.e., *insofar* as there is a monad that perceives the body most distinctly.[35] Corporeal substances of the fourth kind are the primary subject matter of Leibniz's new science of dynamics. At the same time, they can also be regarded as the phenomenal expressions or appearances of corporeal substances of the first, second, or third kind (if there are any), such that Leibniz's new science of dynamics can (could) be seen as indirectly dealing with these ontologically more robust corporeal substances as well. The three listed phenomenal levels differ with respect to the criteria of 'reality' or 'well-foundedness' that their phenomena conform to,[36] in the degree of 'distinctness' of the representations describing these phenomena, or, more precisely, in that the two less fundamental phenomenal levels incorporate 'ideal' features, i.e., features that are confused appearances of, or mental constructions from features existing at the more fundamental phenomenal level,[37] and in how closely the representations of these levels approximate God's privileged representation of the phenomenal world. The closer they are to God's representation, the closer they are to the phenomenal truth, because God's representation of the phenomenal world, which is free of confusions and perspectival distortions, defines what counts as ultimate phenomenal reality.[38]

The third main level of Leibniz's ontological scheme, finally, is the ideal level of abstract objects, which correspond to intentional objects of ideas in God's mind, including, for example, mathematical objects, abstract relations, and possible worlds.[39]

Not everybody will agree with the details of this account of Leibniz's tiered ontology, but, as announced, for the following proposal for how to solve the absolutism-relativism puzzle concerning Leibniz's views about motion we do not need the whole package, although it might be helpful to keep it in mind. Anybody who agrees with the following four general theses will be able to solve the puzzle in the way suggested below, regardless of how he wants to spell out the details, and, in particular, regardless of whether he wants to conceive of the corporeal substances that are the subject matter of Leibniz's new science of dynamics in an idealist or more realist fashion: 1) The most fundamental level in Leibniz's ontological scheme is the level of monads. 2) Leibniz's ontological scheme comprises a less fundamental level at which bodies exist that Leibniz classifies as phenomena, e.g., tables, chairs, or billiard balls. I will call this level 'merely phenomenal level'. This is the level that Leibniz's physics proper is concerned with. 3) Leibniz's ontological scheme comprises a level that is more fundamental than the merely phenomenal level but less fundamental than the level of monads. This level contains entities that are the subject matter of Leibniz's new science of dynamics. I will call these entities 'corporeal substances', and this level 'dynamical level'. 4) To each body at the merely phenomenal level there corresponds a corporeal substance, or an aggregate of corporeal substances at the dynamical level which the body in question can be said to 'express' or to appear as.

Given Leibniz's tiered ontology, the common core of my two proposals for how to reconcile Leibniz's apparent commitment to both relativism and absolutism about motion can be easily stated: Leibniz is indeed both a relativist and an absolutist, as the textual evidence suggests, but this is no problem, because he is a relativist about motion at the merely phenomenal level and an absolutist about motion at the dynamical level. There are no real or absolute motions at the merely phenomenal level, according to Leibniz, because there is no empirical criterion that would enable us to decide which one of two relatively moving bodies is truly in motion. Or, more precisely, there is no empirical criterion to uniquely determine which one of the many possible assignments of motion to the involved bodies that are compatible with the observed relative motion corresponds to the actual distribution of motion among the relevant corporeal substances at the more fundamental dynamical level of reality.

> As for the difference between absolute and relative motion, I believe that if motion, or rather the motive force of bodies, is something real, as it seems we must acknowledge, it would need to have a *subject*. For if *a* and *b* approach each other, I assert that all phenomena would be the same, no matter which of them is assumed to be in motion or at rest; and if there were 1000 bodies, I agree that the phenomena could not furnish us (not even the angels) with infallible grounds (raison) for determining the subject of motion or its degree, and that each separately could be conceived as being at rest…But you would not deny (I think) that it is true that each of them has a certain degree of motion, or, if you wish, a certain degree of force, notwithstanding the equivalence of hypotheses.[40]

The two possible readings of Leibniz that I want to submit for consideration agree that the spatiotemporal structure of the dynamical level of Leibniz's ontological scheme must be rich enough for absolute accelerations and absolute speeds to be well defined. (Absolute speeds must be well defined so that the measure mv^2 can be used as a measure of the living forces of corporeal substances with respect to a global true rest frame at the dynamical level; absolute accelerations must be well defined so that Leibniz can meaningfully talk about uniform rectilinear motions at the dynamical level, as will be discussed below.) But the two readings differ with respect to the question of what spatiotemporal structure should be ascribed to Leibniz's merely phenomenal level of reality. On the first reading, which I will call 'the strong relativist reading', Leibniz is a 'strong relativist', and the structure of the merely phenomenal level is the structure of so-called Leibnizian spacetime, in which no absolute motions of any kind are well defined. On the second reading, which I will call 'the weak relativist reading', Leibniz is a 'weak relativist', and the structure of the merely phenomenal level is the structure of so-called Galilean spacetime, in which absolute accelerations are well defined. The pros and cons of these two readings, including the question of how weak relativism could possibly count as a version of (general) relativism about motion, will be addressed in section IV.

In order to prevent misunderstandings it is important to be clear that my proposed solution to the absolutism-relativism puzzle about motion does not consist in turning Leibniz's relativism about motion into a merely epistemological position, which would be a version of Roberts' strategy for solving the puzzle by de-emphasizing Leibniz's commitment to relativism. In this regard, I also take myself to be disagreeing with Dan Garber who hints at a solution to the puzzle that turns on a level distinction as well. Garber distinguishes two levels in Leibniz's natural philosophy: the level of physics proper, which explains everything in terms of size, shape, and motion, and the level of dynamics, which treats force and corporeal substances to which force pertains.[41] Garber does not spell out in any detail how these two levels are related on his view, but his remarks suggest that he takes them not to be fully ontologically distinct.[42] More importantly, in contrast to my reading of Leibniz, on Garber's reading there seems to *be* a correct, albeit unidentifiable, frame for determining motion at the level of physics, namely, the one defined by the underlying forces at the level of dynamics:

> There is, in this sense, a correct frame for determining motion, the frame in which the motions observed are the effects of real underlying forces which are their causes. *But such a frame could never be identified*.[43]

So, on Garber's interpretation, the spatiotemporal structure at the level of physics, i.e., the merely phenomenal level in my terminology, is rich enough to support the existence of absolute motions. It is just that we could never identify such motions, because we could never identify the correct frame of reference. On my interpretation, it is not only the case that we cannot *know* what the correct frame of reference at the merely phenomenal level is, but, more strongly, that at this level there *is* no such correct frame and there *are* no absolute motions, precisely because such a frame could never be identified.[44]

Having resolved the apparent contradiction between Leibniz's absolutism and relativism about motion, our next task will be to further examine the grounds and nature of Leibniz's relativism at the merely phenomenal level by taking a closer look at his doctrine of the equivalence of hypotheses. Even though Leibniz is often reprimanded for his commitment to EH, it is only very rarely the case that EH's precise meaning or Leibniz's arguments for this doctrine are discussed in any detail. The remainder of this essay is intended to fill this *lacuna*.

III. The meaning of EH revisited

As already indicated, in the present context a hypothesis can be understood as an assignment of certain states of motion to the bodies of a closed system with respect to an implicitly or explicitly specified frame of reference. The equivalence relation in question applies to hypotheses that save the phenomena, i.e., that are compatible with the empirical evidence. Hypotheses that save the phenomena are not distinguished by the phenomena. EH not only concerns the phenomena at a given time, but at all times. In order to bring this out more clearly, it is be helpful to distinguish two notions of equivalence: 1) Two hypotheses H_1 and H_2 are t-equivalent if, and only if, they are not distinguished by the phenomena at time t, (or, in other words, if, and only if, H_1 and H_2 both save the phenomena at time t). 2) Two hypotheses H_1 and H_2 are equivalent (without qualification) if, and only if, they are not distinguished by the phenomena at some time t, and their evolved versions are not distinguished by the phenomena at any time later than t, (or, in other words, if, and only if, they save the phenomena at some time t, and their evolved versions save the phenomena at all times later than t.) The latter is the notion of equivalence in play in EH. An 'evolved version' of a given hypothesis H about a system of bodies is an assignment of certain states of motion to these bodies that is based on the same reference frame as H and that results from applying the laws of nature to the phenomena as described in H and letting the time parameter 'run forward'. One's assessment of whether a hypothesis saves the phenomena over a period of time, and of whether two hypotheses are equivalent, thus, depends on what one takes the laws of nature to be. And, conversely, one's views about what kind of reference frames yield equivalent hypotheses will have implications for what kind of invariance properties one expects the laws of nature to have.

To illustrate the forgoing considerations and to get a better grip on how exactly EH should be understood, it is illuminating to take a look at Leibniz's formulation of proposition 19 in the *Dynamica*, which is generally taken to represent Leibniz's 'official' statement of EH, but which, curiously, has received only very scant attention in the literature.

> Proposition 19. The Law of Nature of the equipollence of hypotheses, or that a hypothesis once answering to the present phenomena will then always answer to the consequent phenomena, that we have established, is not only true in rectilinear motions (as we have already shown) but in general, in whatever ways the bodies should act among themselves, provided, of course, that the system of bodies is not communicating with others, or that no external agent supervenes.[45]

The first thing to note about this passage is that, strictly speaking, it is not a statement of EH but of a slightly different principle, which, following Leibniz, I will call 'equipollence of hypotheses' (EP). EH is a principle pertaining to multiple hypotheses and their evolved versions, while EP is a principle pertaining to one hypothesis and its evolved versions. Leibniz's formulation of proposition 19 suggests the following general template for EP, where the phrases in square brackets should be understood to function as placeholders for different possible further specifications:

> *General EP-template*: For all hypotheses whose frames of reference are moving [in a certain way], and for all closed systems of bodies that are moving [in a certain way] and undergoing interactions [of a certain kind], if a hypothesis saves the phenomena of a closed system of bodies at a given time t, then it, or, rather, its evolved versions, save the phenomena of the system at all times later than t.

From this general template of EP different specific versions can be generated by restricting the allowed reference frames, e.g., to frames in uniform rectilinear motions, or the allowed kinds of systems of bodies, e.g., to systems of bodies undergoing only collisions. EP thus formulated implies that if two hypotheses [of a certain kind] save the phenomena [of a certain kind] at a given time, then they, or, rather, their evolved versions, save the phenomena at all later times. As implicitly anticipated in my definition of 'equivalence' above, on my reading of Leibniz this is how EH should be understood.

> *General EH-template*: For all hypotheses whose frames of reference are moving [in a certain way], and for all closed systems of bodies that are moving [in a certain way] and undergoing interactions [of a certain kind], if two hypotheses are not distinguished by the phenomena of a closed system of bodies at a given time t, then they, or, rather, their evolved versions are not distinguished by the phenomena of the system at any time later than t.

Conversely, if we assume EH it follows that if a hypothesis [of a certain kind] saves the phenomena [of a certain kind] at any time t, then its evolved versions save the phenomena at all times later than t. That is, although conceptually distinct, EH and EP turn out to be extensionally equivalent, which explains why Leibniz sometimes seems to use the terms 'equivalence' and 'equipollence' interchangeably. This also means that any proof of proposition 19 will be a proof of EH as well, and *vice versa*.

A second noteworthy feature of Leibniz's formulation of proposition 19, helpfully commented on by Howard Stein, is that Leibniz's formulation in the original Latin leaves it undetermined how precisely the generalization "is not only true in rectilinear motions (as we have already shown) but in general, in whatever ways the bodies should act among themselves" should be understood. Proposition 14, which is the proposition that 19 generalizes, asserts EP for bodies in uniform rectilinear motions that interact through collisions without any explicit specification of the allowed frames of reference.[46] This allows us to conclude that the generalization in proposition 19 certainly pertains to the interactions of the involved bodies, but it still leaves undecided whether the generalization from merely rectilinear motions to the general case is supposed to apply to the motions of the involved bodies or to the motions of the implicit reference frames. Stein suggests, on the basis of the Galilean invariance of Leibniz's collision laws, that in the former case proposition 19 would merely amount to Galilean Relativity, whereas in the latter case it would correspond to General Relativity.[47] In Stein's assessment, Leibniz's texts weigh almost equally for each alternative.[48]

It is, indeed, a non-trivial question which one of the suggested readings of proposition 19 should be preferred, but there is a way to reconcile them. As anticipated in the discussion of Parkinson above, some of the passages in which Leibniz talks about EP or EH and many of his examples suggest that in his understanding of these principles the reference frames of the hypotheses under consideration are understood to be restricted to the *rest frames* of one or more of the *involved bodies* (and, possibly, the center of mass frame of the system). For example, for the case of the relative motion of a ship and the sea, the only hypotheses that Leibniz explicitly considers are that the ship is moving with respect to the sea, or that the sea is moving with respect to the ship.[49] So, when Leibniz asserts that the phenomena of a given closed system of bodies do not distinguish between different hypotheses, he could be read as primarily saying only that the phenomena do not distinguish between hypotheses that use different rest frames of the involved bodies as frames of reference. On this reading, EP and EH can be formulated more specifically as follows:

> *More specific EP-template*: For all closed systems of bodies that are moving [in a certain way] and undergoing interactions [of a certain kind], and for all hypotheses whose frames of references are rest frames of one or more of these bodies, if a hypothesis saves the phenomena of a closed system of bodies at a given time t, then it, or, rather, its evolved versions, save the phenomena of the system at all times later than t.
>
> *More specific EH-template*: For all closed systems of bodies that are moving [in a certain way] and undergoing interactions [of a certain kind], and for all hypotheses whose frames of references are rest frames of one or more of these bodies, if two hypotheses are not distinguished by the phenomena of a closed system of bodies at a given time t, then they, or, rather, their evolved versions, are not distinguished by the phenomena of the system at any time

later than t.

If this is the correct understanding of EP and EH, as I take it to be, reading the generalization in proposition 19 as referring to the motions of the involved bodies turns out to amount to the same thing as reading it as referring to the motions of the reference frames. This leads to the following principle:

> *Proposition 19 made explicit*: For all closed systems of bodies that are moving in any of the ways in which it is physically possible for bodies to move, and that interact in any of the ways in which it is physically possible for bodies to interact, and for all hypotheses whose frames of reference are rest frames of one or more of these bodies, if a hypothesis saves the phenomena of a closed system of bodies at a given time t, then it, or, rather, its evolved versions, save the phenomena of the system at all times later than t.

On this interpretation, what kind of relativity principle proposition 19 amounts to depends on Leibniz's views about how bodies can move. This question will be taken up in the next section. Unless otherwise indicated, I will assume in the following that Leibniz does restrict the allowed reference frames for the formulation of hypotheses to the rest frames of one or more of the involved bodies, i.e., I will assume that Leibniz understands EH and EP as illustrated by the more specific templates, and proposition 19 in the way just stated.

Before turning to Leibniz's proof of proposition 19, I will use the results of our discussion in the previous section to further explicate the meaning of EH, and to answer a few more of the puzzles about Leibniz's views about motion raised in section I. The separation of Leibniz's relativism and absolutism about motion to different levels of reality, discussed in the previous section, suggests a further elucidation of what it means for two hypotheses to be equivalent. If two hypotheses are equivalent in the sense that the phenomena do not distinguish between them, this also means that, based on the phenomena, each one of them has to be judged an equally good candidate for being the assignment of motion that corresponds to the actual distribution of motion among the relevant corporeal substances at the more fundamental dynamical level. Or, in other words, based on the empirical evidence, the frames of reference of equivalent hypotheses at the merely phenomenal level all have an equally good chance of corresponding to a true rest frame, or, at least, a true inertial frame, at the more fundamental dynamical level.

To my mind, acknowledging this further connotation of 'equivalence' not only helps to make Leibniz's own notion of equivalence more lucid, but it could also be explored profitably in contemporary discussions about what ontological lessons should be learned from the existence of incompatible representations of nature that are empirically equivalent. One lesson that is often drawn is that those features with respect to which the incompatibility arises should not be treated as real or objective. The conception of equivalence that I am attributing to Leibniz would provide a way to resist this inference. Although these features are indeed not real or objective as far as the merely phenomenal world is concerned, at a more fundamental level there are, or at least can be, objective and real features that correspond to them.

Moving on to Leibniz's claim that the simplest of a set of equivalent hypotheses can be held to be true, note that even for a relativist about motion it is desirable to have a criterion, e.g., Leibniz's simplicity criterion, by means of which one hypothesis of a set of equivalent hypotheses can be selected for use in our descriptions of the merely phenomenal level. Such a criterion allows the relativist to account for the fact that we usually ascribe real motions to particular bodies (at the merely phenomenal level) in our common thought and talk, even though, strictly speaking, there are none. In this respect, the ascriptions of real motions can be regarded as a matter of convenience, and of saving our commonsense intuitions, as stressed by Parkinson and Arthur—but only insofar as we are talking about motion at the merely phenomenal level of reality, *pace* Parkinson and Arthur. Given that at the merely phenomenal level there are no real or absolute motions, we could even understand Leibniz's simplicity criterion as the proposal that at this level the simplest hypothesis can be regarded as true by convention.

On the other hand, given that at the more fundamental dynamical level there are real or absolute motions, the convention in question should not be understood as nothing but a matter of pragmatics or human psychology. For if we broaden our evidence basis beyond actual or possible experience, it turns out that the simplest or most intelligible hypothesis of a set of equivalent hypotheses does have better epistemological credentials after all. According to Leibniz, the actual world is the best possible world, which means, roughly, that it jointly maximizes the amount of reality or being, variety, and simplicity of laws.[50] This means that there is some reason to suppose that the simplest hypothesis has a 'morally' better chance of corresponding to the actual distribution of motion at the dynamical level of reality, even though from a purely phenomenal, or physical point of view no hypothesis can be singled out as preferable.

So, by suggesting that the simplest hypothesis can be held to be true, Leibniz could have in mind both that the simplest hypothesis is commonly taken to be true as a matter of convenience or convention, and that it has the best chance of corresponding to the actual distribution of motion among the relevant corporeal substances at the more fundamental dynamical level.

IV. Proving EH

Leibniz provides several arguments for EH. For reasons of space, I will only discuss what is arguably Leibniz's main argument. Leibniz repeats this argument at several places, and it is the argument that is best integrated with many other of his fundamental physical principles. I will focus on the presentation of the argument in the *Dynamica* in form of the proof of our old friend, proposition 19. Unpacking all of the premises of Leibniz's proof turns out to be a fairly complex undertaking, but Leibniz's initial presentation of the proof is very short:

> "This is demonstrated from prop. 16 [should be 17], namely, that all motions are nothing other than composite rectilinear uniform ones, for which the thing follows by prop. 14."[51]

As already mentioned, proposition 14 asserts EP for systems of bodies in uniform rectilinear motions that interact through collisions without explicitly specifying the allowed frames of reference.[52] Adopting the suggestion from the previous section to restrict the allowed frames of reference to the rest frames of the involved bodies, this proposition amounts to the thesis that Galilean Relativity obtains with respect to collision phenomena. This thesis is uncontroversial and accepted by almost all parties to the debate about the nature of motion at Leibniz's time.[53] Proposition 17 asserts that all motions are composed of uniform rectilinear motions. Strictly speaking, propositions 14 and 17 do not suffice to establish proposition 19, but they do so when supplemented with two further premises that are implicit in Leibniz's discussion: the premise that all interactions can be reduced to (elastic) collisions, and the premise that any motion that is composed of uniform rectilinear motions is itself uniform and rectilinear, about which more below. Thus, more formally we can state the proof of proposition 19 as follows:

1. EP for systems of bodies in uniform rectilinear motions that interact through collisions. (Proposition 14)
2. All motions are composed of uniform rectilinear motions. (Proposition 17)
3. All interactions can be reduced to (elastic) collisions. (Additional premise)
4. Any motion that is composed of uniform rectilinear motions is itself uniform and rectilinear. (Additional premise)
5. Proposition 19, i.e., EP for systems of bodies in any kind of physically possible

motions that interact in any physically possible way. (from 1, 2, 3, and 4)

The nerve of this proof is proposition 17, which, unlike proposition 14, is controversial. In order to evaluate the merits of Leibniz's proof, we, therefore, need to take a closer look at Leibniz's support for proposition 17:

> For all motion is in itself uniform and rectilinear; but all action in bodies consists in motion. Therefore rectilinear motion cannot be inflected except through the impression of another motion that happens upon it, a motion that is also rectilinear in itself (granted prior un-harm), and hence no origin of curvilinear or deformed motion is intelligible, except through the compositions of rectilinear uniform ones.[54]

The basis of this proof is the claim that all bodies naturally move uniformly and rectilinearly, which implies that all seemingly non-uniform, or seemingly curvilinear motions of bodies must be the result of initial uniform rectilinear motions and subsequent interactions with other bodies. In order to establish proposition 17 from this intermediate conclusion, we need two more implicit premises: the assumption, yet again, that all interactions can be reduced to (elastic) collisions, and the thesis that being composed of uniform rectilinear motions is nothing but being the result of an initial uniform rectilinear motion and subsequent collisions, which, as the cited passage makes clear, is evidently how Leibniz conceives of composition in this context. The stated intermediate conclusion and the first implicit premise imply that all seemingly non-uniform, or seemingly curvilinear motions of bodies must be the result of nothing but initial uniform rectilinear motions and subsequent collisions. Together with the second implicit premise this establishes that all seemingly non-uniform, or seemingly curvilinear motions are composed of uniform rectilinear motions. More formally, the proof of proposition 17 can be reconstructed as follows:

1. All bodies naturally move uniformly and rectilinearly. (Premise)
2. All (seemingly) non-uniform, or (seemingly) curvilinear motions of bodies must be the result of initial uniform rectilinear motions and subsequent interactions with other bodies. (from 1)
3. All interactions can be reduced to (elastic) collisions. (Additional Premise)
4. Being composed of uniform rectilinear motions is nothing but being the result of an initial uniform rectilinear motion and subsequent collisions. (Definition)
5. All (seemingly) non-uniform, or (seemingly) curvilinear motions of bodies must be the result of nothing but initial uniform rectilinear motions and subsequent collisions. (from 2 and 3)
6. All (seemingly) non-uniform, or (seemingly) curvilinear motions are composed

of uniform rectilinear motions. (from 4 and 5)

7. All uniform rectilinear motions are composed of uniform rectilinear motions. (Additional self-evident premise)

8. All motions are composed of uniform rectilinear motions. (from 6 and 7)

Leibniz's peculiar conception of what it means to be composed of uniform rectilinear motions also puts us in the position to justify premise 4 of the proof of proposition 19, according to which any motion that is composed of uniform rectilinear motions is itself uniform and rectilinear. On first glance, this premise might have looked like a classic fallacy of composition. But if being the result of nothing but an initial uniform rectilinear motion and subsequent collisions is what it means to be composed of uniform rectilinear motions, then the premise follows. For—as Leibniz indicates in the proof of proposition 14 and more explicitly discusses in connection with proposition 20, on which more below—collisions do not change uniform rectilinear motions into non-uniform rectilinear or circular motions: if the initial motions of the involved bodies before a collision are uniform and rectilinear, their motions after the collision are uniform and rectilinear as well.[55] That is, any motion that is the result of nothing but an initial uniform rectilinear motion and subsequent collisions is itself uniform and rectilinear.

The cogency of the proofs of propositions 17 and 19 depends on the theses that all interactions can be reduced to (elastic) collisions, and that all bodies naturally move uniformly and rectilinearly, both of which are problematic. It is reasonable to assume that Leibniz takes the first of these theses to be a basic principle of the mechanistic philosophy, to which he is firmly committed (in form of a slightly idiosyncratic version of mechanism).[56] But even though this thesis might be a self-evident, basic background assumption for Leibniz, he is aware that not everybody agrees with it. And so he goes on to provide an indirect defense of it, which will be considered in the next section.

The main problem with the second thesis, that all bodies naturally move in uniform rectilinear motions, is not that it might be questioned. Leibniz's main rivals, Descartes and Newton, both subscribe to versions of this thesis, either explicitly, or implicitly by endorsing the principle of inertia, according to which every body remains in its state of uniform rectilinear motion or rest, unless acted upon by an external force.[57] Hence, as far as the support of the thesis goes Leibniz would be within his rights to assume it as given. The main problem with the thesis that all bodies naturally move uniformly and rectilinearly is that in the mouth of a relativist about motion, like Leibniz, it does not seem to make any sense. This thesis, or, indeed, any talk about uniform rectilinear motion, is meaningful only if the spatiotemporal structure of the world supports a meaningful distinction between accelerated and uniform motion. But such a structure also makes the notion of absolute motion meaningful, and seems, thus, not to be available to a relativist about motion.[58]

This problem is the main exegetical ground for the reading that Leibniz is a weak relativist, mentioned above, which is one of the readings I want to suggest in this paper. According to the weak relativist reading, the spatiotemporal structure of the merely phenomenal level of reality is not the structure of so-called Leibnizian spacetime, as on the strong relativist reading, but the structure of so-called Galilean spacetime, in which the notion of uniform rectilinear motion is well defined. This answers the objection under consideration.

As anticipated in section II, the main question that needs to be addressed in order to make the weak relativist reading plausible is the question of how weak relativism could possibly count as a version of (general) relativism about motion, given that absolute motions, namely, in form of absolute accelerations, are also well defined in Galilean spacetime. Our previous discussion puts us in the position to answer this question. The result just discussed, that all motions are composed of uniform rectilinear motions, because all 'natural' motions are uniform and rectilinear, and, thus, that all motions are themselves uniform and rectilinear, can be taken to mean that the only physically possible motions of physical bodies are uniform and rectilinear for Leibniz. Absolute motion is possible only in the abstract, in the sense that the concept of absolute motion is meaningful, but it is not physically possible, let alone actual. This would mean that proposition 19 corresponds merely to Galilean Relativity, which is indeed the appropriate relativity principle for a world (or, rather, a level of reality) with the structure of Galilean spacetime. All frames of reference that are rest frames of one or more of the bodies of a closed system—which we are assuming to be the only reference frames admissible in the formulation of hypotheses—are in uniform rectilinear motion, simply because *all* bodies are in uniform rectilinear motion. Now, since on this reading, as a matter of physical possibility, there cannot be any bodies that are in non-uniform or curvilinear motion, proposition 19 would still be strong enough to ground the relativity of *all* actual and physically possible motions, and, thus, serve the function of a general relativity principle.[59] All actual and physically possible motions are relative, because all actual and physically possible motions are uniform and rectilinear, and because all uniform rectilinear motions are relative. Or, in other words, no experiment can distinguish between different actual or physically possible (material) frames of reference, regardless of their states of motion.

The weak relativist reading also has the additional attractive feature that the mere Galilean invariance of Leibniz's conservation principle no longer presents a problem. If Leibniz's strongest relativity principle is Galilean Relativity, Galilean invariant laws of nature is exactly what one should expect.

On the strong relativist reading, according to which the structure of Leibniz's merely phenomenal level of reality is the structure of so-called Leibnizian spacetime, the objection that Leibniz is not entitled to talk about uniform rectilinear motions cannot be answered quite as gracefully, but it can be answered. To see how, recall that, on both of my readings, the spatiotemporal structure of the dynamical level is rich enough to support a distinction between accelerated and uniform motion. Leibniz's argument for the composition of all motions from uniform rectilinear motions in proposition 17 could, then, be understood to apply in the first place to the motions of corporeal substances at the dynamical level of reality, as opposed to the motions of bodies at the merely phenomenal level. That is, proposition 17 could be taken to state that at the dynamical level of reality there are no motions except uniform rectilinear ones, which means that all motions at the merely phenomenal level are appearances, or expressions of uniform rectilinear motions at the dynamical level. This reading of proposition 17 is supported by Leibniz's defense of the claim that all bodies naturally move uniformly and rectilinearly, which turns out to be a defense of the claim that all *corporeal substances* naturally move uniformly and rectilinearly: the nisus or conatus of corporeal substances, i.e., the smallest increments of their motions, always tend in straight lines, which (supposedly) implies that the natural motions of corporeal substances are uniform and rectilinear.[60] When Leibniz speaks of uniform rectilinear motions of bodies in the proofs of propositions 14, 19, and 20, strictly speaking, he could be understood to be talking about the merely phenomenal appearances or expressions of uniform rectilinear motions at the dynamical level. For example, the proof of proposition 19 could be rephrased as follows: by proposition 14, EP holds for systems of bodies that interact by collisions, and whose motions are appearances/expressions of uniform rectilinear motions. But, by proposition 17, all motions at the merely phenomenal level are appearances/expressions of uniform rectilinear motions. With the assumption that all interactions can be reduced to collisions, this implies that EP holds in general at the merely phenomenal level. On this understanding, proposition 19 would be an expression of General Relativity.

It is an advantage of the strong relativist reading that it avoids having to ascribe the rather implausible thesis to Leibniz that there are no curvilinear or non-uniform motions whatsoever. There are at least relative curvilinear and relative non-uniform motions at the merely phenomenal level, even though at the dynamical level all motions are uniform and rectilinear.

The main difficulty for this reading is the old problem stemming from the mere Galilean invariance of Leibniz's conservation law.[61] Merely Galilean invariant laws of nature do not hold in all frames of reference, and, thus, allow the phenomena to distinguish between some of these frames, which constitutes a violation of General Relativity.[62] This problem is quite serious, and no explicit solution is forthcoming from Leibniz himself, but the following considerations can help to alleviate the difficulty, to a certain extent. First, given that the dynamical level of reality is ontologically more fundamental than the merely phenomenal level, it is not implausible to assume that Leibniz understands his most fundamental law of nature to apply primarily to the dynamical level, and only derivatively to the merely phenomenal level.[63] That the phenomena (at the merely phenomenal level) seem to violate the conservation law when described with respect to certain frames of reference could be attributed to the fact that they incorporate features that are 'ideal', due to their dependence on finite minds. For example, according to Leibniz, at the merely phenomenal level we ascribe specific shapes and continuous motions with durations, determinate velocities, and determinate directions to bodies, while the entities at the dynamical level to which these bodies correspond are aggregates of infinitely many corporeal substances, which are moving in infinitely many different ways, and whose motions change at every instant due to impacts from other substances.[64] These multiple minute substances and their complex instantaneous motions 'blend together' in our perception of determinate phenomenal bodies, which, it could be argued, somehow gives rise to the seeming violations of the conservation law. If, *per impossibile*, we could consciously and distinctly perceive the minute substances and their motions and use them as reference bodies, no violations would appear.[65]

A second strategy to alleviate the difficulty would be to introduce additional forces in those reference frames in which the conservation law is seemingly violated, such that the law is restored again.[66] As long as these forces can be understood as *relative* forces, their observable effects need not be seen as providing an empirical criterion to distinguish absolute from relative motions of the kind Newton took himself to have identified in the observable effects of the inertial forces of circular motions, a suggestion that Leibniz rejects.[67] That is, these Leibnizian additional forces could be understood as merely indicating *a special kind* of relative motions.

Admittedly, both of these suggestions for how to meet the difficulty raised by the mere Galilean invariance of Leibniz's conservation law on the strong relativist reading would have to be further fleshed out in order to be fully satisfactory, which is a project involving several challenges. This is the reason why, if forced to express my preference for one of my readings, I would choose the weak relativist one.

The only questions that remain to be answered in order to clear Leibniz from the charge of hopeless confusion are how he responds to Newton's proposal of an empirical criterion to distinguish absolute from relative motions, and how he defends the thesis that all interactions can be reduced to collisions, which, as indicated above, is crucial for Leibniz's claim that all motions are composed of uniform rectilinear ones. These questions will be addressed in the following section.

V. Leibniz on solidity

Leibniz explicitly agrees that if there were genuine solidity or cohesion in the world, as if "through thrown ropes," i.e., due to a force of attraction between the different parts of the body in question, then curvilinear motions could not be regarded as complex uniform rectilinear ones, and the observable effects of the inertial forces of curvilinear motions would indeed provide a legitimate empirical criterion to distinguish absolute from relative motions, as claimed by Newton.

> Indeed, I recall of some famous man that the seat or subject of motion could certainly not be discerned from rectilinear motions, but from curvilinear ones, because what is truly moved, tends to recede from the center of its motion. And I admit that this would be so, if there were something of the nature of a rope, or of solidity, and, hence, circular motion, as it is usually conceived. However, if things are considered exactly, it is found that circular motions are nothing but compositions of rectilinear ones, and that in nature there are no other ropes than these laws of motion themselves.[68]

To start with the latter point, why would it not be true that all curvilinear motions are composed of uniform rectilinear motions if there were genuine solidity or attractive forces? Even if we grant that all bodies naturally move uniformly and rectilinearly, in this case it would not be true that all curvilinear motions are composed of uniform rectilinear motions, because not all curvilinear motions would be the result of nothing but initial uniform rectilinear motions and subsequent collisions—which, you will recall, is what it means to be composed of uniform rectilinear motions on

Leibniz's view. Some curvilinear motions would be the result of initial uniform rectilinear motions, collisions, *and* the attractive forces of the parts of the involved bodies that account for their solidity. Or, in other words, not all curvilinear motions would be composed of uniform rectilinear motions, because the first of the two problematic theses of the previous section, i.e., the claim that all interactions can be reduced to collisions, would be false. Leibniz illustrates this point with the following example: imagine a solid rod LM, whose parts are assumed to be held together by attractive forces, which is struck simultaneously in its extremities, L and M, with equal force in contrary directions by two impeding bodies A and B, which move uniformly and rectilinearly with the same velocities in opposite directions. LM will begin to rotate around its midpoint N, which means that the uniform rectilinear motions of A and B will have been converted into a curvilinear motion of LM.[69] Thus, Leibniz concludes,

> …the matter close to L or M, that tends to recede from the center N, will be retained solely by the solidity of the body and not contrary impressed motion; and, hence, this circular motion does not consist in a composition of rectilinear ones….[70]

The existence of genuine solidity would not only invalidate Leibniz's argument for propositions 17 and 19, it would also furnish us with an empirical criterion to distinguish absolute from relative motions, thus refuting proposition 19.

> By positing solidity and, hence, rotations that are not born from the composition of rectilinear motions, a reason to distinguish absolute motion from rest is given.[71]

For, as Leibniz goes on to explain, in this case we could design experiments that would distinguish between different hypotheses. For example, suppose that the relative motion under consideration is the rotational motion of a solid rod relative to a room. There are two admissible hypotheses: the rod is rotating and the room is at rest, or the rod is at rest and the room is rotating. Now, imagine that we "dissolve the solidity" of the rod by severing the connection of one of its end-parts from the remaining part of the rod. If the first hypothesis is true, the severed part will shoot off along a tangent. If the second hypothesis is true, all will remain as before.[72]

So, in order to defend the thesis that all interactions can be reduced to collisions, and, with it, the thesis that all motions are composed of uniform rectilinear motions, and in order to rebut Newton's proposal that the observable effects of inertial forces allow us to distinguish absolute from relative motions, Leibniz needs to come up with a suitable alternative account of the solidity of bodies, i.e., alternative to the account in terms of "thrown ropes" or attractive forces between the parts composing a body. On Leibniz's alternative account, the solidity of bodies is to be explained "by a certain motion of pressing down."[73] That is, the cohesion of the parts of a body is a result of the "crowding together" of them by the surrounding medium. Or, as Leibniz formulates it in proposition 20 of the *Dynamica*:

> The solidity of bodies or the cohesion of their parts arises from the motion, or tendency of one body colliding with another.[74]

Space constraints prohibit a detailed discussion of Leibniz's account of solidity, which raises some tricky, but, to my mind, not unanswerable questions.[75] For now, I will confine myself to examining what is most important for our present discussion, namely, the question of how this account helps Leibniz to answer the challenge to his proof of proposition 19, and the question of how it puts him in a position to reply to Newton. Although Leibniz's account of solidity has received some attention in the literature, these two questions have been strangely neglected so far.

Leibniz's explanation of solidity permits him to hold on to the claims that all interactions can be reduced to collisions, and that all motions, including rotations, are composed of uniform rectilinear motions, i.e., are the results of nothing but initial uniform rectilinear motions and subsequent collisions. For what keeps the different parts of an apparently solid rotating body in place are the collisions with the surrounding medium, which means that the rotational motion of the body is a result of nothing but initial uniform rectilinear motions and subsequent collisions.

> For if we assume something we call solid is rotating around is center, its parts will try to fly off on the tangent; indeed, they will actually begin to fly off. But since this mutual separation disturbs the motion of the surrounding bodies, they are repelled back…. Thus, the rotation arises from the composition of the rectilinear nisus for receding along the tangent and the centripetal conatus among the parts. Thus, all curvilinear motion arises from rectilinear nisuses composed with one another, and at the same time, it is understood that all solidity is caused by surrounding bodies pushing a body together; if matters were otherwise, then it could not happen that all curvilinear motion is composed of pure rectilinear motions.[76]

Leibniz's account of solidity also puts him in the position to reject Newton's proposed empirical criterion for the distinction between absolute and relative motions. As the foregoing quotation illustrates, Leibniz admits that there are centrifugal forces associated with rotations. Leibniz can also admit that the presence of these forces marks out a *special class* of relative motions at the merely phenomenal level. Furthermore, Leibniz can acknowledge that the observable effects of centrifugal forces can be useful as indicators of (relative) motion, namely, in situations where there are no other perceptible bodies in relation to which the motion could be detected. But, at the same time, Leibniz can go on to insist that centrifugal forces are relative forces, and that the observable inertial effects do not permit us to introduce a distinction between absolute and relative motions at the merely phenomenal level, because they do not permit us to decide whether it is the body or the (usually imperceptible) surrounding medium (or both) that is (are) moving.

But, one might wonder, what about Newton's second thought experiment of the two rotating globes?[77] Newton explicitly stipulates in this experiment that the possible world under consideration contains nothing but two rotating globes connected by a rope. In this case, it seems, we have no choice but to attribute the motion that manifests itself in the tension of the rope to the two-globe system, simply because there is nothing else to which the motion could be attributed. And so it appears only reasonable to adopt as a general rule that the motion should always be attributed to the body that exhibits the observable inertial effects, even in those cases where there is an ambient medium. Given our previous discussion of Leibniz's account of solidity, Leibniz's response to this argument is not hard to guess. For Leibniz, a world containing nothing but two rotating globes connected by a rope is nomologically impossible. Without an ambient medium, cohesive ropes or solid globes gravitating towards each other simply do not exist.[78] There might be situations where it seems to us that EH is violated, but only because we cannot see the nomologically necessary ambient medium.[79]

VI. Conclusion

The purpose of this paper was to clarify Leibniz's views on motion and his doctrine of the equivalence of hypotheses, and to establish that, contrary to popular belief, Leibniz is not hopelessly confused about these matters. Our investigation has shown that Leibniz's position on motion is not internally contradictory: Leibniz is an absolutist about motion at the dynamical level of reality, and a relativist about motion at the merely phenomenal level. The spacetime structure at the dynamic level is rich enough to support absolute accelerations and absolute speeds. I have suggested two possible readings of Leibniz's views on motion regarding the merely phenomenal level. On the weak relativist reading, EH is understood as Galilean Relativity, and the spatiotemporal structure of the merely phenomenal level is the structure of so-called Galilean spacetime. On the strong relativist reading, EH is understood as General Relativity, and the spatiotemporal structure of the merely phenomenal level is the structure of so-called Leibnizian spacetime. Leibniz is a (general) relativist about motion at the merely phenomenal level, even on the weak relativist reading, because on this reading the only physically possible motions are uniform and rectilinear, which means that all actual and physically possible motions are relative. Both of these readings can be squared with the mere Galilean invariance of Leibniz's conservation law, and both of them can handle the problem that *prima facie* the notion of uniform rectilinear motion, which Leibniz needs for his proof of EH, does not seem to be available to a relativist, although on the weak relativist reading these tasks can be accomplished more gracefully. By saying that two hypotheses are equivalent, Leibniz does not only mean to assert that the phenomena cannot distinguish between them, but also that, based on the empirical evidence alone, they have an equally good chance of corresponding to the actual distribution of motion among the relevant corporeal substances at the dynamical level of reality. Leibniz's criterion that among several equivalent hypotheses the simplest one can be held to be true can be understood as saying both that, at the merely phenomenal level of reality, this hypothesis is commonly regarded as true as a matter of convenience or convention, and that, taking into account that the actual world is the best of all possible worlds, it has the best chance of corresponding to the actual distribution of motion among the relevant corporeal substances at the dynamical level of reality. Finally, Leibniz does not reject Newton's absolutism about motion or his proposed empirical criterion for the distinction between relative and absolute motion in terms of the observable effects of the centrifugal forces in rotational motions out of hand, but provides both an elaborate proof of EH, which is well-integrated with other aspects of Leibniz's physical theory, and a detailed story, based on his account of solidity, about why Newton's criterion does not have to be accepted. Of course, there are many reasons why one might prefer Newton's theory of motion to Leibniz's, e.g., that Newton's theory is the one that carried the day in the actual development of science, or that Leibniz's theory is much less worked out. But I hope to have shown in this paper that one popular reason for preferring Newton over Leibniz is actually a very bad reason, namely, that Leibniz's views on motion are hopelessly confused or even inconsistent, which is simply not true.

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Notes

[1] I presented an earlier version of parts of this paper at the New England Colloquium for Early Modern Philosophy at Harvard University in 2005. I am grateful to the audience for stimulating questions. I also would like to thank my colleague Karl Ameriks and an anonymous referee for this journal for helpful comments, and Glenn Hartz for being an infinitely patient and cheerful editor.

[2] This paper is concerned with Leibniz's mature views on motion, i.e., his views from around the late 1680s onwards. In addition to the abbreviations listed in the back of this volume, the following ones will be used: LC-n=Leibniz's nth letter to Clarke, English translation from Alexander 1956; SD=*Specimen Dynamicum*. The translations of all quotations for which no published English translation is explicitly referenced are my own.

[3] The formulation "spacetime does not have, or the spatiotemporal structure of the world does not include…" is used in order to indicate that relativism about motion is compatible with both substantivalism and relationalism about space(time). I will say more about the relation between relativism/absolutism about motion and relationalism/substantivalism about space(time) below.

With respect to my use of contemporary spacetime terminology to characterize certain features of Leibniz's views about space(time) and motion at several places in this paper, I want to stress that I do not wish to imply that Leibniz himself was thinking about the questions at hand in these terms. I mainly use this terminology for ease of communication and in the service of greater precision in the characterization of those aspects of Leibniz's views for which it is reasonable to assume that the contemporary formulation adequately captures what Leibniz himself had in mind, despite the fact that he expressed his views in different terms.

[4] *Phoranomus*, C 590, AG 91; cf. NE, A VI.6, 297; SD, GM VI, 247.

[5] *New System*, G IV, 486-87, L 459; cf. *Phoranomus*, C 590.

[6] Cf. SD, G VI, 251, AG 134-35: "…whichever hypothesis we finally adopt, that is, to whatever things we ascribe absolute rest or motion in the end."

[7] Cf. CL-4, §13-14, G VII, 384; CL-5, §53, G VII, 428; Russell 1900, 85-87; Alexander 1956, xxvi-xxvii; Stein 1977, 31; Earman 1989, 131.

[8] Cf. LC-3, §4, G VII, 363, Alexander 26: "Space denotes, in terms of possibility, an order of things which exist at the same time, considered as existing together…."

[9] For a more modest version of this argument we can replace the assumption that absolute motion is motion relative to absolute space with the weaker assumption that the best explanation of absolute motion, namely, Newton's, represents it as motion relative to absolute space. This version of the argument establishes the existence of absolute space through an inference to the best explanation and might, for that reason, be deemed unacceptable.

[10] For a fuller explication of the structure of Leibnizian spacetime, see Earman 1989, chapter ii.

[11] *Clarification of Bayle's Difficulties*, G IV, 523, L 496; cf. *A Specimen of Discoveries*, A VI.4B, 1622-1623.

[12] LC-5, §53, G VII, 404, Alexander 74; cf. *Metaphysical Foundations of Mathematics*, GM VII, 20; DM, §18, A VI.4B, 1559.

[13] Cf. Newton, *Principia*, 68: "The effects distinguishing absolute motion from relative motion are the forces of receding from the axis of circular motion."

[14] Letter to Huygens, Sept., 1694, A III.6, 183, AG 309; cf. *Phoranomus*, C 590-91; *New System*, G IV, 487.

[15] If the total living force is conserved in a given reference frame R, the conservation law is violated in any frame that is accelerated with respect to R.

[16] Yet another puzzle is that Leibniz's measure of living force, mv^2, is a frame-dependent quantity, even though living force is supposed to be the "real" in motion. For recent discussions of this and related puzzles concerning Leibniz's proposed measure of living force and his conservation law, cf. Roberts 2003, and Slowik 2006.

[17] Cf. CL-5, §53, G VII, 428; cf. note 7.

[18] Cf. Sklar 1974, 230.
[19] Cf. Earman 1989, 126-128, 163-166.
[20] Cf. Roberts 2003, 555.
[21] Cf. LC-5, §47, G VII, 401, Alexander 70: "[T]wo different subjects, as A and B, cannot have precisely the same individual affection; it being impossible that the same individual accident should be in two subjects, or pass from one subject to the another."
[22] Cf. *Critical Thoughts on Descartes*, G IV, 369, L 393 "If there is nothing more in motion than this reciprocal change, it follows that there is no reason in nature to ascribe motion to one thing rather than to others. The consequence of this will be that there is no real motion." Cf. *A Specimen of Discoveries*, in the margin, A VI.4B, 1621: "There is no absolute place, nor absolute motion, because there are no principles for determining the subject of motion." Cf. LA, April 30, 1687, G II, 98; LA, January 4/14, 1688, G II, 133.
[23] Cf. Roberts 2003, 566-567.
[24] Roberts 2003, 567.
[25] Cf. LC-5, §53, G VII, 404, Alexander 74: "'Tis true that, exactly speaking, there is not any one body that is perfectly and entirely at rest; but we frame an abstract notion of rest, by considering the thing mathematically." Cf. LA, October 9, 1687, G II, 115-116; Letter to de Volder, June 23, 1699, G II, 184; *On the present world*, A VI.4B, 1511.
[26] Parkinson 1969, 107.
[27] Arthur 1994, 232.
[28] Arthur 1994, 234.
[29] Cf. *Second Explanation of the New System*, G IV, 499.
[30] Cf. *A Specimen of Discoveries*, A VI.4B, 1622; see note 12.
[31] The middle years are usually identified with, roughly, the period from the mid-1680s to the second half of the first decade in the 18th century. In my view, Leibniz's mature philosophy was basically in place by the mid-1680s, some later changes in emphasis and presentation notwithstanding. For the purposes of this paper, I need not rely on this contention and will present Leibniz's complex ontology in a way that should be acceptable also to those commentators who see Leibniz's views as having undergone substantial transformations after the mid-1680s before finally solidifying in their late mature form in the final decade of Leibniz's life.
[32] Cf. McGuire 1976; Hartz and Cover 1988; Garber 1985, 203-208; Adams 1994, 254f.; Garber 1995.

[33] I say "created reality" because, on Leibniz's view, the most real entity of all, existing at a level of its own outside of the world, is, of course, God.

[34] Robert Adams defends a view of Leibnizian phenomena as intentional objects in more detail in Adams 1994, chapter 9. I disagree with Adams' identification of aggregates of monads with phenomena in the indicated intentional object sense, but there is not enough room to explicate this disagreement here.

By calling the relevant perceptions 'coherent' I mean to say both that the relevant perceptions of different monads cohere with each other, i.e., represent the same phenomenal world at the same time, and that the relevant perceptions of each individual monad are internally coherent, which distinguishes them from (actual) dreams and hallucinations, cf. note 36.

[35] Thus, my conception of corporeal substances of the fourth kind is, as it were, the converse of the qualified monad conception of corporeal substances proposed by Cassirer and discussed by Adams (cf. Adams 1994, 269). According to the qualified monad conception, a corporeal substance is a monad *insofar* as it has a body.

[36] Leibniz proposes several criteria for phenomena for being real or well-founded, which permits a distinction between different degrees of well-foundedness, e.g., internal coherence, inter-subjective coherence, conformity to general necessary truths, conformity to the laws of nature, coherence with God's representation of phenomena, predictive power, and whether the phenomenon in question can be shown to "result from" more fundamental entities. Cf. *Of Universal Synthesis and Analysis*, A VI.4A, 543-544; *On the Method of Distinguishing Real from Imaginary Phenomena*, A VI.4B, 1500ff.; NE, 374-75, 392; DM, §14, §32, A VI.4B, 1550f., 1580-81; *Reply to Bayle*, G IV, 569; Letter to De Volder, June 30, 1704, G II, 268f.

[37] For instance, (continuous) extension is the appearance of an abstract aspect of corporeal substances of the fourth kind, namely, their continuously 'diffused' passive forces. In allowing the two less fundamental phenomenal levels to include ideal features I am disagreeing with Hartz and Cover's claim that Leibniz advocates a "metaphysical apartheid between ideal things and well-founded phenomena" (Hartz and Cover 1988, 512). For reasons of space this disagreement cannot be discussed here, but I want to register my contention that the textual evidence and general exegetical considerations speak against Hartz and Cover's reading. In calling something ideal or imaginary Leibniz does not always mean to contrast it with the phenomenal, but he sometimes merely wants to indicate that the phenomenon in question is of a special kind, namely, one that contains ideal features, i.e.,

features due to abstraction or confusion. For example, on my reading, ideal space, understood as an abstract system of order of possible spatial relations between actual phenomenal bodies, or matter characterized by the attribute of extension, which, *qua* extended, is continuous, are nevertheless (well-founded) phenomena for Leibniz and exist at the less fundamental phenomenal levels. At the more fundamental phenomenal level, space is nothing but the totality of instantiated spatial relational properties of actual corporeal substances, and matter is an aggregate of corporeal substances, which, *qua* aggregate, is discrete.

[38] Cf. Notes for a letter to Des Bosses, February 5, 1712, G II, 438; DM, §14, G IV, 439; T, §403, G VI, 356.

[39] The difference between ideal entities at the phenomenal level(s) and ideal entities at the ideal level is that the former conform to more of Leibniz's criteria for being well-founded, cf. notes 36 and 37.

[40] Letter to Huygens, 12/22 June 1694, A III.6, 131, AG 308; cf. LA, April 30, 1687, G II, 98; *Phoranomus*, C 590.

[41] Cf. Garber 1995, 283-284.

[42] Cf. Garber 1995, 284: "The two levels are difficult to separate completely and treat entirely independently."

[43] Garber 1995, 308. For a similar view, cf. Levey 2005, 72-73.

[44] If the latter statement sounds odd, note that if phenomena are understood as intentional objects of perceptions/cognitions, which I take Leibniz's understanding of phenomena to be, what the phenomena are is determined by how they are conceived or represented.

[45] *Dynamica*, GM VI, 507.

[46] Cf. *Dynamica*, GM VI, 500.

[47] Cf. Stein 1977, 32.

[48] Cf. Stein 1977, 4.

[49] Cf. LA, July 4/14, 1686, G II, 57.

[50] Cf. *PNG*, §10, G VI, 603; *Monadology*, §58, G VI, 616.

[51] *Dynamica*, GM VI, 507; cf. SD, G VI, 253. In Leibniz's text of the *Dynamica*, the numbering is off; there is no 'proposition 16'. Proposition 15 is directly followed by proposition 17, which says that "all motions are composed from rectilinear uniform motions." So, in the proof of proposition 19 by 'proposition 16' Leibniz clearly means the proposition that is entitled 'proposition 17'.

[52] That EH holds for uniform rectilinear motions is ultimately grounded in the actual world's being the best of all possible worlds, cf. T, §347, G VI, 320: "This

[that EH holds for uniform rectilinear motions] is nice, but one does not see that this should be absolutely necessary…. There is nothing more appropriate than this occurrence, and God chose the laws that produce it; but one does not see any geometrical necessity in it."

[53] Although Descartes endorses the principle of Galilean Relativity in the abstract, his laws of collision violate it, for which he is reprimanded by Leibniz, cf. SD, G VI, 247.

[54] *Dynamica*, GM VI, 502; cf. Letter to de Volder, June 20, 1703, G II, 252.

[55] Cf. *Dynamica*, GM VI, 500-501, 509. A potential counterexample to this principle will be discussed in section V

[56] Cf. *Against Barbaric Physics*, G VII, 337, AG 312: "That physics which explains everything in the nature of body through number, measure, weight, or size, shape and motion, which teaches that nothing is moved naturally except through contact and motion, and so teaches that, in physics, everything happens mechanically, that is intelligibly, this physics seems excessively clear and easy." Leibniz's version of mechanism is idiosyncratic in that he also takes the (phenomenal) forces of bodies into account in his mechanistic explanations of the phenomena.

[57] Cf. Descartes, *Principles of Philosophy*, II, §37, §39, AT VIIIa, 62-63; Newton, *Principia*, 70.

[58] This criticism is also voiced in slightly different forms by Stein 1977 and Earman 1989, 72.

[59] Leibniz contemplates the possibility of rejecting the existence of curvilinear motions as early as 1676, cf. *On Motion and Matter*, A VI.3, 492.

[60] Cf. SD, G VI, 252. Leibniz does not explicitly tell us why he thinks that the conatus of corporeal substances always tend in straight lines, but it is plausible to speculate that this assumption, like many others in his science of dynamics, is grounded in the principle of perfection, i.e., the thesis that the actual world is the best possible one, or, more precisely, in a principle implied by the principle of perfection, namely, the so-called principle of determination: the conatus of substances tend in straight lines because, among all possible ways in which they could tend, the straight line is singled out, and, in that sense, most 'determinate'.

[61] For the purpose of our discussion, we can ignore that Leibniz's conservation law actually only holds for a restricted class of closed systems of bodies, namely, systems in which there is no transformation of kinetic energy into any other form of energy. We are interested in how Leibniz conceives of EH, so all we need to care about is how he conceives of his conservation law, and not how he should

have conceived of it. And it is fairly clear that he takes it to hold for all closed systems of bodies.

[62] Cf. note 15.

[63] How exactly this assumption might be squared with Leibniz's derivations of his conservation law is a question that goes beyond the scope of this paper.

[64] Cf. *Wonders concerning the Nature of Corporeal Substance*, A VI.4B, 1465: "(…) Even though extension and motion are more distinctly understood than other qualities, for the others are to be explained by using them, it must nevertheless be admitted that neither extension nor motion can be understood distinctly by us at all, because we are always involved in difficulties concerning the composition of the continuum and the infinite, and because there are in truth no certain shapes in the nature of things and, hence, no certain motions." Cf. NE, A, VI.6, 210; SD, G VI, 235. For an illuminating discussion of the quasi-fractal character of motion in Leibniz's earlier writings, cf. Levy 2003. It should be emphasized that this more complex characterization of motion at the dynamical level does *not* imply that there are no uniform rectilinear motions at this level after all, or that these motions are mere abstractions. It remains true that corporeal substances naturally move uniformly and rectilinearly; it just has to be acknowledged that none of these motions lasts longer than an instant.

[65] In talking about 'minute substances' I do not wish to suggest that at the dynamical level of Leibniz's ontology there are ultimate, most minute substances out of which all other substances are composed. Leibniz explicitly rejects such a view of the composition of matter and asserts that matter is infinitely divisible. At the same time, however, he also insists that matter is composed of true unities, i.e., he insists that matter is an aggregate of corporeal substances, because, on Leibniz's view, without any true unity there would not be any true being either. My remarks in the main text are fully consistent with this Leibnizian conception of matter—whose defensibility (and coherence) is a topic for another occasion.

[66] For purposes of illustration, consider the implementation of this idea in the more familiar context of Newtonian mechanics. The seeming violation of Newton's second law (**F**=m**a**) by the phenomena when described with respect to a rotating reference frame can be fixed by introducing centrifugal and Coriolis forces, and by modifying the acceleration term **a** in the second law to include a negative centrifugal acceleration and a negative Coriolis acceleration.

[67] Cf. Letter to Huygens, 12/22 June 1694, A III.6, 131, AG 308: "Newton recognized the equivalence of hypotheses in the case of rectilinear motions; but he

believes, with respect to circular motions, that the effort circulating bodies exert to move away from the center or from the axis of circulation allows us to recognize their absolute motion. But I have reasons that lead me to believe that there are no exceptions to the general law of equivalence."

[68] *Dynamica*, GM VI, 508.

[69] *Dynamica*, G VI, 508-509.

[70] *Dynamica*, GM VI, 509.

[71] *Dynamica*, GM VI, 509.

[72] *Dynamica*, GM VI, 509. *Prima facie*, it seems that with this concession Leibniz is granting more to his opponent than he has to. For, one might argue, if centrifugal forces are conceived of as relative forces, the same centrifugal forces would be acting in both of the described scenarios. That is, the severed part would fly off in both cases and the two hypotheses could not be distinguished after all. Leibniz's concession can be rendered more intelligible against the background of his own account of solidity. As will become clearer below, Leibniz's reasoning behind his concession might be that centrifugal forces can plausibly be classified as relative only if there is no genuine solidity. For otherwise one could easily imagine a possible world in which nothing exists except a solid rotating rod that is experiencing centrifugal forces, which, thus, would have to be classified as absolute.

[73] *Dynamica*, GM VI, 509.

[74] *Dynamica*, GM VI, 508; cf. *A Specimen of Discoveries*, A, VI.4B, 1630.

[75] The most pressing objection to Leibniz's account of solidity, raised by John Earman, is that it seems mysterious how the inner parts of a solid body whose outer extremities are set in motion by the impact of other bodies can 'know' that and how they are supposed to move. Cf. Earman 1992, 72. Another potential problem with Leibniz's account of solidity is that the 'crowding in' by the ambient medium cries out for an explanation, an explanation, one might argue, that is impossible without ascribing attractive forces to some bodies or the ether. Both of these challenges can be answered by appealing to Leibniz's conception of the universe as a plenum, i.e., as maximally full, and his doctrine of the interconnection of all things, in particular, the communication of every motion to all bodies. For reasons of space, the detailed presentation of these answers will have to wait for a different occasion.

[76] SD, G VI, 252, AG 136; cf. *Dynamica*, GM VI, 510-511.

[77] Cf. *Principia*, 70.

[78] Cf. *Addition to the Explanation of the New System*, G IV, 587-88; NE, A, VI.6, 61; LC-3, §17, G VII, 366-67; Letter to Burguet, August 5, 1715, G III, 580; T,

§355, G VI, 326. Leibniz accounts for the seeming gravitational attraction between bodies in the same 'mechanistic' fashion in which he accounts for the seeming attraction between the parts of a solid body, i.e., in terms of the "pressure" of the ambient medium, which, in the case of gravity, is explained by appeal to rotating vortices in the medium.

[79]Cf. *Dynamica*, GM VI, 508: "And, hence, the equipollence of hypotheses might sometimes not be apparent to us, because sometimes not all events are apparent, due to the imperceptibility of the ambient bodies (…)." Cf. SD, G VI, 254.