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Space and Time as Relations: The Theoretical Approach of Leibniz

Basil Evangelidis

Faculty of Humanities, Philosophy, Leiden University, Limesstraße 4d, 63450 Hanau, Germany;
v.evangelidis@umail.leidenuniv.nl; Tel.: +49-151-6818-4147

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Abstract: The epistemological rupture of Copernicus, the laws of planetary motions of Kepler, the comprehensive physical observations of Galileo and Huygens, the conception of relativity, and the physical theory of Newton were components of an extremely fertile and influential cognitive environment that prompted the restless Leibniz to shape an innovative theory of space and time. This theory expressed some of the concerns and intuitions of the scientific community of the seventeenth century, in particular the scientific group of the Academy of Sciences of Paris, but remained relatively unknown until the twentieth century. After Einstein, however, the relational theory of Leibniz gained wider respect and fame. The aim of this article is to explain how Leibniz foresaw relativity, through his critique of contemporary mechanistic philosophy.

Keywords: space; time; absolute; relative; motion; acceleration; relativity

1. Introduction

Leibniz was of the belief that space and time are not real entities but virtual relationships and mathematical concepts. He was led to this conclusion through the problem of the relationship of the mind with space, the study of the nature of the continuous in various mathematical fields, and the observation of linear and centrifugal movement, as well as the confrontation with atomism based on the assumption of the inexistence of vacuum. Space is an order of coexisting phenomena, as time is an order of successive phenomena. Today we call this view Relationalism: spatial and temporal relationships between objects and events are immediate and not reducible to space-time point relations, and all movement is the relational movement of bodies. The controversy about the ontological status of space and time began with the distinction between primary and secondary qualities developed by Democritus, Galileo, Descartes, and Locke.

According to Descartes, primary qualities (e.g., height, width, depth), unlike secondary qualities (e.g., roughness, color), are perceptible with an accuracy that depends on the position of the observer to the physical objects. Primary properties reveal the true nature of the body. Through this distinction, Descartes output meanings, which Leibniz also analyzed. These were: (1) observability; (2) the primary, true nature of the body, the object; and (3) spatial dimensions, as physical characteristics of the physical object. From the above premises, Newton concluded that there is a similar distinction between sensible space and time, where the sensible secondary properties appear, and the completely differently theorized, mathematically defined space and time, where unseen masses and atoms of physics exist. On account of this distinction, Newton introduced the terms “absolute and relative, true, and apparent, mathematical and common” (*Principia: The Mathematical Principles of Natural Philosophy*, Definition VIII, Scholium). Since we can imagine that extramundane space without bodies, as an extension, is independent of the bodies, then the space, according to Newton, is certainly not material, but has its own way of existence. Furthermore, absolute and relative motion can be identified by their

properties, their causes, and their effects. The absolute acceleration developed during rotation that is observable by the diverting forces from its axis is the high spot of the Newtonian argument [1].

In summary, Newtonian science distinguished absolute from relative space and time. Absolute, genuine, and mathematical time, in itself, flows regularly due to its nature, without dependence on anything from the exterior. Its other name is continuity. Relative, apparent, and common time is a certain perceptible, external, detailed, and unstable measure of the duration of movement. Absolute space, due to its own nature, without dependence on any factor from the outside, always remains the same and motionless. Relative space is a certain mobile dimension or measure of absolute space [2]. The famous controversy between Leibniz and Newton was not direct, but was mediated by Clarke, an English theologian. The fields of dispute were meant to be observability, measurement, and experiment. The relational theory of Leibniz was articulated in juxtaposition to the theory of Newton. Leibniz believed that space is something completely relative. That is to say, space is the order of coexistence, as the time is an order of sequences. Space implies, in terms of possibility, an order of things that exist at the same time, considered as if they existed together, without examining their form of existence. The frame of reference of space and time involves natural objects and their relations, events, and processes. Space is nothing other than the order of existence of objects which are observed as they exist together. For relational theory, the possibility of a material universe as an ensemble that moves either in space or in time is without meaning, as space and time do not exist independently from the order of bodies and incidents in the Universe. All relational theories for space-time attribute territorial, time, and space-time relations to material objects. Yet relations are not an absolute reality within the things, but a determination that thought, intellect, adds to things. All relations are ostensible, that is to say they are well consolidated phenomena. Space-time relations are not ontologically prior to the relations between natural bodies.

1.1. *Innate Mathematical Concepts*

According to Leibnizian relationalism, extension or space, surfaces, lines, and points are nothing beyond rational entities, innate ideas, and relations of orders, namely orders of coexistence. Relational truths are based on incidents of a representational nature that take the form subject—predicate. The utmost indivisible units include all their predicates in such a way that the relations are ostensible and reducible to categorical constitutive parts, that is to say attributes. The space, defined as a series of coexistence is not an empirical but a rational truth: it is a virtual entity. It belongs to a set of entities that are characterized by uniformity and contain no variety. The concepts of space and time, as well as other entities of pure mathematics, are not generalizations extracted from raw empirical material. They are already in our minds, and emerge with experience [3]. Space is a concept which does not correspond to an actual entity, it is innate idea and geometrical concept [4]. It belongs to the set of innate ideas that are objects of mathematical science.

The spatial extension is infinitely divisible and divided. Nevertheless, the true infinite, strictly speaking, is found only in the Absolute [5] (V, p. 144), while space is indefinitely extensive [6] (p. 278). According to Leibniz, the moments and the points are not parts of time and space, but only terms [5] (VI, p. 152). Simple terms referring to things come prior to the sums. The parts are real, defined, and prior in comparison to the whole; but in reference to the ideal entities, such as time and space, unity precedes, and the simple terms follow. The parts are only possible, indistinct, arbitrary divisions, following the whole.

Leibniz [7] compared the number with extension and with mathematical bodies. Whereas number has no existence without the things measured, the extension and the mathematical bodies are meaningless without entities that act or bear, or without movement. Space, time, and infinity are not real sets; and therefore, we have no positive idea about them [5] (VI, p. 159). Extension is a reduction from the extended, while the extended is a continuum whose parts exist at the same time [5] (V, p. 136). The mathematical entities are ideal, as for instance the “shape”, which is never exact and strictly specific in nature. It is not even a universally true and clear quality outside thought ([6] (p. 343); [5] (II, p. 199)).

The mathematical entities are modalities ([6] (p. 523); [5] (II, p. 195)), undefined quantities, with which we can access the discrete quantities of the real world [5] (VII, pp. 562–563).

1.2. *The Continuous*

In contrast to Newton, who believed that each point-material object coincides with a point of substantial space, Leibniz treated points as extremities or modalities or modes. The location, without doubt, is nothing more than a way of something, like the former or the latter [4] (pp. 101–102). A mathematical point itself is nothing but a way, namely an extremity [5] (II, pp. 347–348). The extension derives from the position but adheres also continuity to the position. Points are positioned in place, but they neither sustain continuity, nor can they stand by themselves [6] (p. 598).

The ideal, virtual continua are inherent mathematical ideas and they are not composed of parts or points, nor of moments, because the perception of the moment does not contain a sequence [5] (VI, p. 152). The continuum is everywhere dense, i.e., solid, homogeneous and ceaseless, a plenum, i.e., without breakage of continuity (uninterrupted) [8].

For Leibniz, space is infinitely divisible—in the Aristotelian sense of possibility. Space and time are an order of potentialities ([6] (p. 583); [5] (p. 568)). The spatial relationships, although they build up space, are antecedent and parasitic upon space. The Leibnizian space is not the simple sum of the ideal spatial relations but is prior to its parts and divisions. Entities of none, one, or two dimensions: flat, curved surfaces, straight lines, curves and points are the signs of mental division operations in the Euclidean framework [9,10].

“I observe, that the traces of moveable bodies, which they leave sometimes upon the immoveable ones on which they are moved; have given men occasion to form in their imagination such an idea, as if some trace did still remain, even when there is nothing unmoved. But this is a mere ideal thing, and imports only, that if there was any unmoved thing there, the trace might be marked out upon it. And 'tis this analogy, which makes men fancy places, traces and spaces; though those things consist only in the truth of relations, and not at all in any absolute reality”. (*The Leibniz-Clarke Correspondence*, V, p. 47)

Thus appears the unrelenting, the completeness of space, which is quondam, as it is not composed of extensional pieces of finite or infinite dimensional areas, separated from each other by two-dimensional boundaries, but is simply divisible, potentially divided. The apparent change and spatial extension are not authentically continuous, because their sequence is terminated. However, there are differences here: the spatial extension is a static representation, it lacks a privileged set of directions and forms a three-dimensional continuum. The apparent change is irreversible and therefore directional; it forms a linear or one-dimensional real continuum, as explained in [4] (pp. 103; 137).

1.3. *The Time and the Monad*

The Leibnizian theory of time is not articulated with completeness, though it is closely connected with the Monadology. In an early letter to Jacob Thomasius [5] Leibniz (1962, IV) wrote that time is nothing else beyond measure of motion. Since each magnitude is a number that consists of parts, why should the definition of time [11] by Aristotle (IV, p. 219) as a number of change surprise us?

Newton believed that a number of specific events concurrent with one another, they are simultaneous with a certain point in time. According to Leibniz, however, moments constitute only apparent change. A certain phenomenal duration is really dense or actually infinitely divisible, as the physical objects are. Nevertheless, time is uniform or homogeneous; we can divide it an infinite number of times, but it remains prior to its parts, due to the fact that it does not consist of them. It is an idealized entity that refers to the order of succession-relations in the changing phenomena, when we remove the peculiarities of their relata. The truths concerning the time structure are eternal and determine the changing of the phenomena [4] (pp. 134–136).

The fundamental law of being is temporality or succession [6] (p. 26). An empty space is something that we can imagine, but a gap in time incomprehensible [5] (VI, p. 155). Leibniz wrote to De Volder [6] that time, in contrast to space, is included both in spiritual and in material things, and therefore in perception, the activity of the Monad.

2. The Monads

The philosophical stimulation for the writing of *Monadology* was the problem of the Cartesian mind–body dualism. Leibniz was impressed by the belief that the pineal gland was associated with the communication between cognition and extension, the search for continuity between soul and body. He also sought to quash the naturalistic theory of Locke, who considered space as the common basis of the interaction between mind and matter. Leibniz did not think “that substance is constituted by extension alone, since the concept of extension is incomplete. Nor do I think that extension can be conceived in itself, but I consider it an analyzable and relative concept, for it can be resolved into plurality, continuity, and coexistence or the existence of parts at one and the same time” [6] (p. 516).

Leibniz formulated the *Monadology* gradually, by taking the appropriate distances from Cartesianism. Regarding the substance in two of his early works he noted: “1. *Substance* is being which subsists in itself; 2. *Being which subsists in itself* is that which has a principle of action within itself (...) no body is to be taken as substance, apart from a concurrent mind (...) Whatever is not substance is accident or appearance...” (Theological Writings Related to the Catholic Demonstrations, III, I). In addition he wrote, “I call substance whatever moves or is moved” (*Dissertatio de Arte Combinatoria*, I, Def. 2).

The monad is simple, unified, indivisible, unborn, and imperishable. It is simple because it has no parts. The monads form compounds, composites, accumulations (*aggregata*) of simple things. They do not have an extension or form, and they are not visible. However, they are the real elements of natural things. Each unique substance expresses the whole universe in its own way and includes in its concept all events with all their circumstances and all the continuity of external things. The monads are endowed with perception and they are self-reactive. One monad can be distinguished from another by its perceptions, the representation of plurality in the simple, and appetitions, its tendencies, the striving from one perception to another. The nature of the monad is the representation. A monad represents the entire universe, but more distinctly it represents the body that constitutes its entelechy [12] (*Monadology*, p. 62).

The primary feature of the monads, their primary power is perception. Perception is a certain conjunction of the simple with the multiple; it is also the distinction, the identification and the selection, it is the creation and the harmony, as insisted in [13]. The monad as *ultimum subsistens* is the ultimate basis of all properties and determinations, as *ultimum perdurabile* is the foundation of any change and as *vis activa* is itself the source of activity [14]. Pure perceptions concern active states of the active primitive force, in other words the first entelechy which is the soul of living beings. All simple substances or created monads are entelechies of bodies [12] (*Monadology*, p. 18). The composition of the monadic entelechies gives the substantial form to the inorganic world, the principle of impetus. The unclear perceptions relate to potential situations of the passive primitive force (*materia prima*), derived from the spontaneity of the monad. Apart from the primary forces, there also exist derived ones: by the aggregation of *materia prima*, secondary matter is being produced, which is governed by active forces as the *vis viva*, namely the kinetic energy, and the *conatus*, expressing the potential speed. The secondary material however is governed by passive forces as well: *inertia* and *antitypia*, namely impenetrability, which will be analyzed by the physical theory of Leibniz.

2.1. The Immutable World of Monads Is Not in Space-Time

The spatial extension belongs to the domain of phenomena, while the monads are not placed in space; they only represent each other with spatiotemporal characteristics. A representation of a monad of the real world of representational monads is a real condition of the monad, which along with coexisting monads—which are found in suitable corresponding situations—formulate the real

world of the monads. A monad beholds the world of phenomena as if it were, in itself, in the center of this vision.

All substances are active. Space and time are produced by the monads and their primary characteristics, their properties. In concert with the principle of perfection and with its equivalent principle of the predetermined harmony, Leibniz concluded that space is a relation inherent in the cross-sectional situations, i.e., the perceptions of monads, whereas the mutual agreement of the monads is such that every perception of a given unit corresponds precisely to a perception of any other unit. The power or activity, and not the extension or passive receptivity, is the deterministic property of the reality [15,16].

A possible interpretation of the Leibnizian theory may be closer to the Kantian philosophy: space and time do not exist as completely independent instances or continua, but they make sense only in the subjectively generated contents of the observer's consciousness. The monad is this energetic observer, who after all lacks any windows; the monad is not located in space. However, it knows the space because it possesses the ability to perceive both the innate, necessary, tautological truths of reason, and the contingent truths of empirical facts [17,18].

2.2. The Monadic Change and the Mathematical Concept of Series

The Leibnizian philosophy of science is divided into three levels, the metaphysical, the conceptual (of the mathematical entities), and the apparent (of bodies). The metaphysical is the level of the mind. The monad or the mind does not accept influences but only affects the body and its representations. The idealizations of space and time are, as we have seen, orders of coexistence or succession. The concept of order originates from the ideal level, while the concepts of succession and coexistence reflect the phenomena. The monads are prerequisites and foundations of the phenomena ([6] (p. 536); [5] (II, p. 268)), they dispose neither a gradual onset, nor a gradual ending, but an abrupt onset and abrupt end [12] (*Monadology*, 6). Leibniz describes the monad as a focus of perception, of an anterograde situation that surrounds and represents the multiplicity within unity [12] (*Monadology*, 14). The monadic reality is changing entirely, moving from one state to another. This real change is a prerequisite for the good consolidation of apparent change. The monadic alteration is not just a virtual thing or an apparent time-like order, but a real time-like order [4].

“There is, moreover, a definite order in the transition of our perceptions when we pass from one to the other through intervening ones. This order, too, we can call a *path*. But since it can vary in infinite ways, we must necessarily conceive of one that is most simple, in which the order of proceeding through determinate intermediate states follows from the nature of the thing itself, that is, the intermediate stages are related in the simplest way to both extremes”. [6] (p. 671)

This change in the order of perceptions appears to have a distinct and discontinuous nature: each present state of a substance is a consequence of its previous situation. Clearly, the changes are not truly continuous, that is, there appear interruptions, ruptures of continuity. However, they are characterized by density, because the dense causal connections at the level of phenomena must be correct representations of dense causal connections, with dynamic form. Other times the change is characterized as continuous and flows in conformity with an internal principle. The action of the internal principle that brings about the passage from one perception to another is called *appetition* [12] (*Monadology*, pp. 10; 11; 15).

Two substances are never completely identical to each other: each monad is different from others. Leibniz would liken their difference with the difference between geometrical figures such as the circle, the ellipse, and the parabola. One may consider them as conic sections, obtained in accordance with the law of continuity throughout infinitely small subtle shifts (*Discourse on Metaphysics*, p. 53). The essence of the monad is beyond finite analysis and one can access it only through the law of individual series. The procured force is the situation at present, in its trend towards a next state, or the prior implication

of the next state. Meanwhile, the primary active force exists implying everything that will happen, that is, the nature of the primary active force consists in a law of duration of a progressive series that persists with no obstacle. The procured force is a term of the series, while the active force is the law of the series.

The problems of perception are translatable into terms of geometry, differential analysis, perspective, minimum perceptions etc. The complicated and infinitesimal movements of substances are represented by extreme curves of curves, namely by geometric models which mount the vibration of the monad with its maximum and minimum curve. The curve of the maxima is always increasing, and the curve of the minima always decreases. Progression emerges when the increase is greater than the decrease. The order is more fundamental than the disorder, as the real against the phenomenon. It is impossible to find in space the ultimate privileged spot from where one can approach the universal harmony. The sun is privileged and non-privileged from the viewpoint of the fixed stars. In an equivalent way, there is no privileged point of time [13].

Leibniz proposed a new mathematical model inspired by the theory of infinite series. However, although aware of the distinction between divergent and convergent series, he did not propose a criterion for their distinction. Anyway, he tended to choose the most perfect series. In terms of combinatorics the “richest” series is one that involves differences and reversals. There is a class of negative or reciprocating type, for the one, the unity: without parts, without form, without division. It does not involve death, initiation, change. There is a progressive class with clearly aggregative characteristics for the multiple: parts, shape, division, dissolution, destruction, beginning, creation, increase, decrease, every form of influence. These reverse features of the one and the multiple are not expressed in accordance with an arbitrary order, but follow the development of two laws, of composition and analysis: they are synthesized by external parts, which directly unfold into the elemental world of geometry and mechanics, attributing the onset of motion in a naturalistic way. The latter two classes are sequences of positive or negative geometrical and mechanical propositions, which order the sum of the terms. They are also sequences of negative or positive propositions of a new set of terms, established by the primary relationship of the analysis of the parts, i.e., of the access to dividing up the indivisible, the atom or the element; of dissolution of heaps of cohesion, resistance, impermeability; of destruction and passing to complexity; and of change, reduction and attenuation, i.e., intersection of some part of a compound [13].

3. Space, Time, and Motion in the Physical Theory of Leibniz

Descartes believed that the essence of things is the extension which they occupy in space. He reduced all the characteristics of the bodies in modes of extension, supposing that physical changes are movements in space. Leibniz, after 1676, when he turned more clearly against Cartesianism, was confident that the data we observe are limited to material things, their properties, and relations [19]. The Leibnizian Relationalism is based on two key aspects: (1) space-time is not a substance, namely there is no substratum of spatial, temporal, and spatiotemporal points, endowed with spatiotemporal relations ontologically prior to the spatiotemporal relationship between physical objects and events; and (2) the motion is relative, and all spatiotemporal relations are arranged between physical objects and events.

On the contrary, Newton, while accepting that many relationships have no observational consequences, showed that the absolute acceleration of a physical object that rotates is itself observable. To depict the forces generated by the circular motion, he used two mental experiments, the centrifugal forces on the surface of the water in a rotating bucket, and the tension of a string joining two spheres rotating about their center of mass. According to these representations, linear accelerations create observable forces. Newton attributed these absolute accelerations and generated forces to absolute space, which is an unchanging reference system. Therefore, the Newtonian science considered as absolute the differences between state of rest, uniform motion, and accelerated motion. Samuel Clarke, in his renowned correspondence with Leibniz, pinpointed the importance of absolute acceleration.

If the movement of the water in the thought experiment was only relative, yaw forces from the rotation axis would be zero. Leibniz however refused to accept absolute acceleration, although he claimed that we must distinguish between “mere relative change” and “absolute true motion of a body”. Leibniz made this distinction only with respect to the cause of movement: In each movement of two material objects, the body that really moves is the cause of the change in itself:

“I find nothing in the *Eighth Definition of the Mathematical Principles of Nature*, nor in the *Scholium* belonging to it, that proves, or can prove, the reality of Space in itself. However, 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 change is in the body, that body is truly in motion; and then the situation of other bodies, with respect to it, will be changed consequently, though the cause of that change be not in them”. (*The Leibniz-Clarke Correspondence*, V, p. 53)

This is not the absolute motion of Newton, but true motion relative to another body. Leibniz characterized the true motion as a subcase of relative motion: the actual motion is relative movement whose cause is the body that really moves. He believed that the centrifugal and centripetal movements are examples of dead forces [potentia mortuus] that are infinitely weaker than the living force. What was, according to Leibniz, real and absolute in motion was the driving force, a tendency to move that consists in *vis viva*, a real and substantial entity, a fundamental absolute quantity which is inherent in substances [20–22].

3.1. The Matter, the Body, and the Coincident Movement

Newtonian physics was unthinkable without corpuscles. On the contrary, Leibniz rejected the existence of ultimate, indivisible, firm material particles [23]. Matter is real multiplicity, a cumulative entity consisting of an infinite number of units [5] (p. 379). It is discontinuous and actually infinitely divided. However, there is no part of space without matter [5] (pp. 278–279). The matter itself is homogeneous, equally divisible anywhere, and varies with the motion [6] (p. 407).

To the above premises corresponds the logical consequence that there are no atoms with infinite rigidity. Matter is itself in flux [6] (p. 415). The body is extended, mobile, and resistant [6] (p. 277). Each body is simultaneously fluid and solid [6] (p. 407). Leibniz believed that the solidness or the unity of the bodies originates from the mind, and there are as many minds as vortices, and as many vortices as solid bodies [24] (pp. 114–132).

The sense is the natural resistance of the body against what is trying to divide it; it is a kind of reaction. The human body is a hydraulic–pneumatic machine containing liquids, which act not only through their weight and other mechanisms that are overt to our senses, but also in certain hidden ways as solution, precipitation, congealment, filtration, evaporation, etc. [6] (pp. 162; 282–283). In a letter to Remond [25] (pp. 74–75), Leibniz distinguished between matter and the body. Matter is nothing but impenetrability and extension. It is an inert material without spirit, without a principle of activity, and for this reason, without motion. The body on the other hand is a combination of matter and an activity principle that may cause motion. Leibniz insisted, in contrast to Descartes, that space and extension are different from the body, because otherwise the motion of the body would not be a real thing. The essence of the body is not to be extended but to move [26] (p. 10).

Writing to Arnauld, [5] Leibniz (1962, I, p. 75) insisted that the essence of the body is motion, or a principle of motion, and that extension is unrelated to a principle like this. Therefore, the existence of a body is not subject to spatial or extensional conditions, as there exists “in omni corpore principium intimum incorporeum substantiale a mole distinctum, et hoc illud esse, quod veteres, quod Scholastici substantiam dixerint, etsi nequiverint se distincte explicar, multo minus sententiam suam demonstrare” [5] (I, p. 62). Unlike Descartes, Leibniz did not consider immobility as opposed to the motion. Immobility is a special limiting case of motion, as well as equality is a limiting case of inequality. In a digression of his criticism to the epistemology of Locke, Leibniz noted that no substance in the nature is devoid of activity

and that “there is never a body without movement, because—more generally—there is never a substance that lacks activity. (...) But I believe that reason also supports this, and that is one of my proofs that there are no atoms—because if there were atoms, there *could* be atoms that underwent no change and were perfectly at rest” [27] (*New Essays on Human Understanding*, Preface).

In his *Critical Thoughts on the General Part of the principles of Descartes*, Leibniz presents interesting thought experiments with two cubes, which are perfectly adjacent and then separated, when other bodies collide vertically with one or with both of them (in opposite directions), to show that atomists do not give a sufficient reason neither of the consistency of atomic compounds nor of their dissolution, namely why atoms do not coalesce huge and more than adamantine, completely indestructible compounds. The primary cause of the indestructible continuum is the movement, specifically coincident movement and the impenetrability. The bodies are solid when their movements coincide. The internal movements are subtle, rapidly unfolding even in solids, as occurs in the winter when “the permanent internal motion of the parts of matter acting in harmony alone predominates in most liquids; hence they harden and sometimes freeze solid” [6] (p. 408).

3.2. *The Vacuum*

Leibniz claimed that there are no bodies at rest, because otherwise they would not differ from vacuum. If a body were at rest, it could do not have any cohesion or consistency, because it could be impelled and divided by motion, no matter how small it may be (Letter to Antoine Arnauld, G, I, 71).

“From this there follows a demonstration of the Copernican hypothesis and many other novelties in natural science. The other proposition is that all motion in a plenum is homocentric circular motion and that no rectilinear, spiral, elliptical, oval, or even circular motion around different centers can be understood to exist in the world, unless we admit a vacuum. It is unnecessary to speak of the rest here. I mention these because something follows from them which is useful for my present purpose. From the latter principle it follows that the essence of body does not consist in extension, that is, in magnitude and figure, because empty space, even though extended, must necessarily be different from body”. [6] (p. 148)

The vacuum remains only a possibility, as in the above inscrutable passage. “Empty space can in no way be distinguished from the perfectly fluid. There is no perfectly fluid body. There is no vacuum” [6] (p. 278), because the actual division of the bodies sprawls out until their ultimate minimum points. Leibniz believed that the same reason that shows that extramundane space is illusory, proves that every empty space is an imaginary thing. To deny the existence of the vacuum, Leibniz juxtaposed with the Newtonian argument (that the fall of bodies in a fluid depends on the specific density of the fluid), the inadequacy of empirical induction. Clarke insisted that the different resistances of mercury and water are produced by their different densities and therefore there is a need for more of a vacuum where there is less resistance. Leibniz would find the chance to correct that different densities depend not so much to the quantity of matter, but on the difficulty of finding space [viscosity], which creates resistance. Furthermore, with regard to the experimental data of Guericke and Torricelli, Leibniz proposed the following counterargument: “glass has small pores which the beams of light, the effluvia of the loadstone, and other very thin fluids may go through” (*The Leibniz-Clarke Correspondence*, V, p. 34).

Leibniz once wrote that he agreed with Huygens that the concept of empty place and extension alone is the same. He added that “mobility or antitypy themselves cannot be understood from extension alone but from the subject of extension, by which place is not merely constituted but filled” [6] (p. 390).

3.3. *Movement, Vortices, and Energy*

From the natural system of the Cartesian philosophy Leibniz rejected, as we have seen, the matter-extension concept, but maintained the principle of plenitude, according to which every

extended space should be complete with matter. Descartes had conceived as a fundamental physical principle the law of conservation of the quantity of motion, the absolute constancy of momentum ($m \cdot v$; mass times the velocity equals momentum). However, experiments of Galileo and Huygens had shown that the $m \cdot v$ is not constant: the dynamic proportional measure of the size of an object is not its geometrical dimensions but its mass, while the speed of a body is proportional to the root of the distance it travels [28]. The quantity of the fundamental physical concept of *vis viva* $m \cdot v^2$ vaguely describes the conservation of energy. Leibniz generalized the principle of conservation of energy as a fundamental metaphysical principle.

The laws of motion depend on the metaphysical principle of equality of cause and effect: if the effect were greater we should have mechanical perpetual motion, while if it were less, we should not have continuous motion. Leibniz also denied the possibility of generating a state of entropy, considered by Newton in his *Optics*. There can be no reduction or increase of the amount of energy. He could not accept that in a system, action is generated only with the increase of energy from a lower to a higher level. Moreover, Leibniz accepted Descartes' view that the motion in an infinite universe, where there is no vacuum, firstly implies an infinite number of vortices, an idea firstly conceived by Leucippus. The space was filled with an ether of ultrafine particles and the rotation of the Sun caused circular motions, vortices, in the ether, which pushed the planets around the Sun like boats in a whirlpool [28].

The question of the gravity was associated with the theory of vortices, supported by Descartes, Huygens, and Leibniz, and the refusal of the latter to accept the action at a distance, because it is not observable. Leibniz considered as the cause of both gravity and planetary attraction the cycloidal motion of ether (*De Causa Gravitatis, et Defensio Sententiae Autoris de veris Naturae Legibus contra Cartesianos*), a very thin fluid, from traction spokes, which disturbs the material in infinite ways, on all sides, with the result however that the movement of planetary bodies converges to a certain direction in a particular region, whereas the more massive bodies tend towards the center of the vortex. Correspondence between Huygens and Leibniz [6], which discusses the theory of Newton, throws light on their differences with Newton. The planets do not just move in ellipses, but they also move all at the same level in the same direction around the sun.

Therefore, Leibniz rejected Newtonian attraction, because it could produce movements only in a wider rather than a limited area of three-dimensional space. In another letter, Leibniz wrote prescriptively to Abbe Conti that the most different causes engage with one another in our explanation of gravity and we simultaneously have spherical radiation, magnetic attraction, the dislodgement of spinning material, the inner motion of the fluid, and the circulation of the atmosphere, which all together cooperate to the production of centrifugal and centripetal force. Furthermore, in *Tentamen de Motuum Celestium Causis*, Leibniz, based on Kepler's laws, described the fluid orbs that move the planets.

4. Arguments

The key features of the Newtonian conception of absolute space and time were, according to [29], as follows. Absolute motion, absolute space, and time are inherent in a substratum of spatial or space-time points. These structures are endogenous (intrinsic) in space and time, unchanged and stable. The mathematical realism of Newton, in terms of space and time, was proven fertile in the field of observation [30].

By contrast, the arguments of Leibniz are relational. They are based on an armory of principles. At the level of logical necessity there are two self-evident principles: the principle of perfection and the principle of identity. The principles of plenitude and harmony are involved in the principle of perfection; the principle of contradiction is included in the principle of identity. As for the law of sufficient reason, it is based on the perfection of the universe and the possibility of analysis that is presupposed by the principle of identity. At the level of existence, the principles of continuity and individual differentiation (principle of indiscernibles) are derived by the law of perfection. The law of the best possible includes in particular: the principle of maximum and minimum in mathematics,

least action or extremum in physics, and the law of the parsimony in the methodology. Furthermore, under certain temporal and spatial conditions, the sufficient reason implies mechanical causality, while identity becomes equivalent in its various forms—equality in algebra, congruence and similarity in geometry, equivalence in symbolic logic, and conservation of power, with all its derivative forms, in dynamics [6] (p. 45), [31].

4.1. *The Argument about Observability*

To make sense with an assertion of the existence of an entity or an attribute of the world, should the presence or absence of that entity or attribute, or a change in such a characteristic, have observational consequences. Let us suppose that space itself exists as a substance. In that case, it makes sense to ask: What is the position of the whole material world in space? How fast does the world, as a whole, move with respect to substantial space? However, only with observation can we determine the spatial relationships between the physical objects, the movements of material objects, positioning with respect to one another, etc. There are no available observations for an understandable identification of the position of the world as a whole in the substantial space, nor of its speed in reference to the substantial space, etc. Therefore, it becomes clear that such claims do not make sense according to the principle of verification, and there can be no substantial space [3] (pp. 173–174). Here is a Leibnizian version of the argument:

“Motion does not indeed depend upon being observed; but it does depend upon being possible to be observed. There is no motion, when there is no change that can be observed. And when there is no change that can be observed, there is no change at all”. (*The Leibniz-Clarke Correspondence*, V, p. 52)

4.2. *The Principle of Indiscernibles*

“To suppose two things indiscernible, is to suppose the same thing under two names”. (*The Leibniz-Clarke Correspondence*, IV, p. 6)

“Space is something absolutely uniform; and without the things that are placed in it, a point in space does not differ in any respect whatsoever from another point in space”. (*Ibid*, III, 5)

The arguments based on the principle of indiscernibles usually take the following form: Suppose we have the possible worlds A and B, such that they are identical to each qualitative attribute. Then A is the same possible world as B.

In his correspondence with Clarke, Leibniz used two similar arguments. Firstly, imagine a second universe like ours, except that all matter is shifted and placed in another location in the absolute space, without any change in the relationship between objects. If the space is Euclidean both places are exactly the same, so there would be no observable differences. Secondly, imagine a universe just like ours, except that the absolute speed of each piece of material varies and differs in an unchanging, fixed amount, without any change in the relationship of one object to another. Since the two speeds differ only by an amount that remains constant, no observable differences will be reported. The two universes are not distinguishable. If there were absolute space, the particles would have completely different motions, therefore the supposition of an absolute space is contradictory to the principle of indiscernibles. The absolute space and absolute space-time are not observable, and they give birth to indistinguishable situations. The principle of indiscernibles is based on the principle of sufficient reason.

4.3. *The Principle of Sufficient Reason*

Suppose that a theory allows us to distinguish between two different states of the world, A and B. Nevertheless, it is impossible in principle to discover the causal reason: why A should be real, instead of B, or vice versa. Then the theory must be rejected.

“... if space was an absolute being, there would something happen for which it would be impossible there should be a sufficient reason”. (*The Leibniz-Clarke Correspondence*, III, p. 5)

The principle of sufficient reason declares that everything that exists in a state of affairs *s*, exists for an integrated reason, which (1) constitutes the necessary and sufficient condition for *s*; (2) shows clearly and precisely why it takes place *s* instead of another; (3) provides, when possible, a full description, a complete explanation of *s*; and (4) does not require another reason of the same type.

4.4. The Principle of Plenitude

The universe is plenteous, everything is a plenum, and all matter is interlinked [12] (*Monadology*, 61), so that each movement can have effects even on the most remote bodies and each body is influenced by the bodies with which it comes into contact, and also by those who come into contact with the latter, and so on. Clarke had the impression that, with the principle of plenitude, Leibniz identifies space with matter. The latter, convinced that absolute space and absolute space are only a representation of relations, replied in compliance with the principle of plenitude:

“I don’t say that matter and space are the same thing. I only say, there is no space, where there is no matter; and that space in itself is not an absolute reality. Space and matter differ, as time and motion. However, these things, though different, are inseparable.”

“But yet it does not at all follow that matter is eternal and necessary; unless we suppose space to be eternal and necessary; a supposition ill grounded in all respects”. (*The Leibniz-Clarke Correspondence*, V, pp. 62–63), [32]

4.5. The Principle of Continuity

How a continuum can be constructed of discrete points? The source of the difficulties with the composition of the continuous lies in the fact that we grasp matter and time as substances. The Leibnizian gateway from the labyrinth of the composition of the continuous is to view the world of the continuously extended matter as secondary and derivative [28] (p. 83).

In 1687, Leibniz produced the principle of continuity by considering the concept of infinity in geometry. Later, he solved the problem by considering real but strictly individual dynamic centers, whose qualitative, causal, gradual interaction generates mechanical interactions at the level of phenomena and consequently apparent changes articulated in the virtual continua of space and time [33] (p. 142).

The mechanistic philosophers of the seventeenth century denounced active principles. With the principle of inertia alone, they explained every motion of matter. Leibniz criticized Descartes focusing on his failure to see that motion must be established with energy. At the same time, the Enlightenment movement supported a European and global international cooperation and Gottfried Wilhelm Leibniz had correspondents ranging from London to Beijing [34].

5. Conclusions

The spatial and temporal structures of the Newtonian theory are intrinsic, inherent in a substratum of spatiotemporal points, while in the ideal space-time of Leibniz the relations are external (extrinsic) to space and time. Relations are interface determinations completely independent of the possible phenomenal relata, while the structures of absolute space and time are unchanged and stable.

The Leibnizian arguments do not always appear convincing. In fact, with his argument of a world where the West would take the place of the East, Leibniz tries to combine the principle of sufficient reason with the principle of indiscernibles, in an obscuring manner, when asking for the sufficient reason of the displacement, while probably begging the question. The argument would seem invalid according to logic, because Leibniz asks “why every thing was not placed the quite contrary way, for instance, by changing East into West,” eliminating a required premise that should describe the

coordinates of East and West. In another argument again, when assuming that we change the position of the world within space, Leibniz maintains as immutable the internal spatial relationships of physical objects, one in relation to the other, which seems contradictory to the very own Leibnizian belief that there is no body that does not move. However, one should consider the strongest argument of Leibniz, based on the infiniteness of the world. In comparison with the infinite, any displacement may be insignificant.

A powerful argument against the Leibnizian relationalism is developed in [35] (pp. 189–206): Important complications emerge if we introduce coordinate systems in space and time. Places and dates acquire now internal relations which should stay untouched by any permutation. The introduction of inertial temporal and spatial coordinates is embedded within an empirical rationalism that encounters space, time, and space-time dimensions in a non-relational manner. Furthermore, the various possible worlds are not different names for the same subject: they are distinguishable. Another Leibnizian argument referred to time: if the world were created a few million years earlier, it would be indistinguishable from this one here, since “the beginning, whenever it was, is always the same thing” (*The Leibniz-Clarke Correspondence*, IV, p. 15). There is a confusion around the dubious principle of indiscernibles: if two objects x and y are exactly alike, they are also numerically identical, regardless of the permanent or contiguous character of their similarity. Genuinely logical, however, is only the principle of the indiscernibility of the identicals: if k and l are numerically identical, that is, they are simply different names for the same object, then k and l are exactly alike [36].

Clarke emphasized the issue of inertial phenomena, referring to the example of Galileo with the ship. The movement of the ship is really a different situation with truly different effects even though they may be beyond our perception. A sudden stop of the ship would bring about other more tangible effects. Clarke noted that the argument about Newton’s absolute motion is mathematical and that it demonstrates according to real effects the absolute motion, therefore cannot be answered by simply asserting the opposite. The space and the time are not only an order of things; they are real quantities. Mathematization established the actual inertial motion, as described by Newton, as an indispensable concept for a consistent physics.

Of special significance was Leibniz’s counterargument against the mathematical argument of Newton regarding absolute acceleration: Leibniz supported that the Absolute is the inherent in the body force or motive power, the *vis viva*. This interpretation was an overt subterfuge, in conflict with the first law of Newtonian mechanics, the law of inertia, which explains that a point mass either moves linearly and smoothly or remains at rest, unless acted upon the influence of external forces or when the forces affecting are cancelled out. Leibniz’s objection was based on the following distinction: that the *vis viva* refers only to impacts, while the observed pendulum movement, the rotation, and the orbits are manifestations of the dead force ($m \cdot dv$), infinitely smaller than the vital force [37].

Nevertheless, Newton clarified the absolute motion with his first law. Absolute motion is created or modified only by the impact of force to the (moving) body, and it changes with any impact of force upon it, while the relative movement can be changed or created, without the influence of force on the relatively moving body, and it is not necessary to change with every impact of force upon it. The principle of inertia is an empirical principle, manifested as: (1) inertia of a body that remains in rest, insofar it is not influenced, but also by the impact of forces, as an escape from rest either with distractions or with resistance or gradually; and (2) as the inertia of a body that moves linearly and smoothly, insofar it is not influenced, but also as a change of direction, or an acceleration or deceleration under the impact of forces.

We conclude that the two thought experiments and the arguments of Newton intended to establish the absolute circular motion and the absolute acceleration during rotation, and they are connected to the second law of conservation of momentum, and, indeed, of the angular momentum. According to this law, the angular momentum of a particle or the main torque of an inertial system is modified only by the influence of external forces, whereas internal forces can only change the torque of parts of the system and the angular velocity. Newton concentrated his attention on the issue of absolute

acceleration during rotation, because a simple variation of the angular speed, can be, according to the second law, the effect of internal forces. The absolute acceleration, however, may increase the moment of inertia, the angular momentum of the system overall. In modern parlance, the dimensionality of angular velocity is T^{-1} , and the one of angular acceleration T^{-2} .

Leibniz tended to pinpoint an explanation originated with Huygens, who referred to the cycloidal motion of ether that disturbs the matter in countless ways, from all sides, in order to address, in a somewhat limited way, the inertia as resistance, absolute due to the viscosity of the fluid and relative due to its density. With such claims, he derived the conclusion that every motion is either rectilinear or is reduced to a synthesis of rectilinear movements. The accelerated motion, either curved or rectilinear, was represented by Leibniz with polygonal infinitesimals as a series of smooth rectilinear motions interrupted by impulses of dead force. Newton, however, represented the accelerated motion with a continuous curve and the forces and accelerations involved are finite and not infinitesimal [37].

From Relationalism to Relativity

The concept of Leibnizian space came prior to that of spatial relations, but it was not an absolute framework of measurement. A position in space was determined only in relation to another position, as far as the latter could be regarded as fixed. That is exactly what led Anapolitanos [4] (p. 103–104) to evaluate the theory of Leibniz not only as relationalist, but also as relativistic theory, since one of the basic postulates of the special theory of relativity is that there is no preferential spatial system of reference. Leibniz however remained attached to metaphysical notions such as that of the mind, as the cause of motion. The dominant scientific theory, until the appearance of the theory of relativity, was that space and time were absolute reference systems of things, objects, and events. The argumentation of Leibniz questioned the verifiability of absolute space, because in any systems of coordinates with relatively uniform motion we have not a means to distinguish the absolute uniform motion. “How would the world be, if there was a reportable unobservable change?” “The same”, would Leibniz reply [38,39]. The Newtonian, however, might support the following: it is not true that in any possible world, observability, i.e., observational conditions, disprove the existence of real space

Nevertheless, in the special theory of relativity, we still have an absolute motion, in terms of a class of highly abstract and unobservable entities. The speed of light is always the same in all systems of coordinates, whether or not the light source is moving, and with any way it may move. How does the speed of light remain constant in two coordinate systems that are in relative uniform motion? This has to do with the relativity of time introduced by the Lorentz transformations.

The contribution of Leibniz in theoretical physics of space and time was operative, though not prescriptive. The emphasis on the concept of relation has contributed indirectly to the discovery of the main results of the theory of relativity, according to the Lorentz transformations: the relativity of simultaneity, the time dilation, and the length contraction of the bodies. The special theory of relativity accepts the fixedness of relations only for systems of coordinates that move with relative uniform motion: the time is determined by clocks, the spatial coordinates by sets of rods, and the movement may affect clocks and rods, as shown by the effects of the electromagnetic field; events that in a reference system coincide or occur at the same point in space, in other inertial systems can occur at different times or in different places in space, while the deletion of points of the space-time manifold is used by relativists to construct cosmological models.

The motivation of Einstein, when he formulated the general theory of relativity, was, besides the problem of gravity, a thought experiment to eliminate the absolute motion. However, he only revised the concept of absolute space, which was replaced by the concept of the displacement field, which is a component of the total field. There is no space without field, the space is now a quality of the field. The structures yet are endogenous, the metric of space is a function of the distribution of matter and energy, and the laws of physics are accepted in every system of reference [30].

The relativity of motion presupposes variable structures, frames of reference of the Riemannian geometry. The acceleration here is a result of the curvature of space-time, which produces dramatic

changes in the observable gravitational effects. The equivalence of all spatial points, i.e., the homogeneity of space, the isotropy, i.e., the equivalence of all space directions, and the homogeneity of the time, in the light of Leibniz's saying that a point in space does not differ in any respect whatsoever than any other, seem to conform to relationalism, but in fact, the principles of the general theory are realistic propositions. They apply exactly to the absolute space-time and approximately to real systems, while the validity of the general theory is not limited to inertial systems.

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