

Leibniz's *Monadology* and its insights concerning quantum physics

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Abstract. This study examines Gottfried Leibniz's remarkable philosophical work *Monadology* in the context of his insights on some concepts in modern quantum physics. In particular, a connection has been detected between the properties of the monads and the corpuscular-wave dualism of the elementary particles, and ideological similarities have been identified with regard to the existence of a hidden, unmanifested reality as a reason for the "unfolding" of the material world. The phenomenon "non-locality" related to this idea has also found its analogies in Leibniz's concepts expressed in his work *Monadology*. Moreover, an analysis has been made of the relationship of *Monadology* to the modern concept of the holographic and fractal nature of the Universe. A conclusion has been made that in history of sciences, ideas quite frequently evolve and if not rejected, they would gradually get saturated with content and find their revitalization in some modern scientific theories.

Keywords: Leibniz, *Monadology*, philosophical insights, quantum physics, history of science

Introduction

Gottfried Wilhelm Leibniz has left a remarkable scientific and philosophical legacy. One of his most significant works is the so-called *Monadology*, that appeared more than three hundred years ago (in 1714). It is described as "An incredible synopsis of metaphysics that is so dense that you have to be careful about every phrase, every word" (Denkova 2015, 9). Some other authors characterize it as "the culmination of Leibniz's system, as it accurately and systematically presents his teachings" (Kondova 2012, 207).

It will be shown in this study that this famous philosophical work contains unexpected insights into some of the most intriguing ideas and findings of modern quantum physics, such as particle-wave dualism, non-locality, holographic and fractal nature of reality, multiplicity of worlds, etc. Such an incredible, discerning visionary makes the work *Monadology* a valuable source for the history

and philosophy of science, inspiring this study as well, where we have adopted as a research method the interpretation of a classical philosophical writing in terms of modern quantum physics.

Many authors have established a relationship between Leibniz's intellectual heritage and nowadays science: "[...] there still seems to be very little appreciation of how much Leibniz's work presages modern physics. Leibniz was in many ways first and foremost a theoretical physicist, with his metaphysics being designed to describe that deeper layer of physics that was empirically hard to address and required careful inference. That deeper layer looks extraordinarily like fundamental physics as it is now understood" (Edwards 2014). The famous American mathematician and philosopher Norbert Wiener has recognised Leibniz as the forerunner of field theory (Wiener 1934). Moreover, he finds it remarkable that "the Leibnizian principle of sufficient reason is a direct ancestor of the mathematical methods of quantum mechanics" (Wiener 1934, 481).

Nakagomi (1992) proposes a new model of quantum mechanics, relativity and mind, based on some ideas from Leibniz's *Monadology*. According to Cooperman, "In the ongoing quest for a quantum theory of gravity, Gottfried Wilhelm Leibniz's philosophy finds a modern revival" (Cooperman 2007, 3). Other authors also speak in their publications about some obvious conceptual similarities of Leibniz's *Monadology* and modern quantum physics (Porter 2009; Igamberdiev 2015; Dony 2017). Jane McDonnell explores the question of the relationship between actuality and potentiality in the spirit of *Monadology* authored by Gottfried Leibniz, in particular, considering his purely philosophical thesis about "possible worlds", drawing a parallel with the history of quantum mechanics, which emerged as a theory within modern physics and mathematics (McDonnell 2017). The author approaches the problem as a comparison of two different paradigms (philosophical and scientific), which largely converge in their final conclusions. According to Cooperman, in the current search for a quantum theory of gravitation, Gottfried Wilhelm Leibniz's philosophy, embodied in his *Monadology*, is revived in the works of Julian Barbour and Lee Smolin (Cooperman 2007).

Some authors see a connection between the fundamental nature of symmetries in quantum physics and Leibniz's Principle of Sufficient Reason: "First, they can all be understood as examples of the application of the Leibnizean Principle of Sufficient Reason (PSR): if there is no sufficient reason for one thing to happen instead of another, the principle says that nothing happens (the initial situation does not change). But there is something more that the above cases have in common: in each of them PSR is applied on the grounds that the initial situation has a given symmetry [...] The symmetry of the initial situation implies the complete equivalence between the existing alternatives (the left bundle of hay with respect to the right one, and so on). If the alternatives are completely equivalent, then there is no sufficient reason for choosing between them and the initial situation remains unchanged" (Brading, Castellani (eds.) 2003). Beall, for his part, interprets Leibniz's conceptions of space and time found in his *Monadology* as the metaphysical basis of the idea of non-locality in quantum mechanics (Beall 2015).

In order to justify, expand, deepen, and systematize these or other similar ideas, we have performed our study and here we present our findings.

The idea of existence of elementary particles and of the particle-wave dualism

Particle-wave dualism is a universal property of matter, which is expressed in the fact that all micro-objects have both corpuscular and wave properties. This dualism was first established for the photon. In some cases, electromagnetic waves (in particular light) appear as waves, and in others as a stream of particles (quanta). In certain cases, it can show a corpuscular character (heat radiation, photo effect, etc.) and present itself as a stream of photons, and in others - to demonstrate its wave properties (interference, diffraction, polarization, etc.). The higher the frequency of the radiation (i.e., the shorter the wavelength), the more clearly its corpuscular properties are expressed, and vice versa - at a low frequency (large wavelength) its wave properties come to the fore.

In 1923, the French scientist Louis de Broglie, having in mind the obtained connections between the corpuscular and wave characteristics of light, hypothesized that such a behaviour is inherent for the other kinds of elementary particles, too. In this way, a wave can be attributed to each moving particle, which is later called de Broglie wave. De Broglie waves have no analogue in classical physics. They are neither elastic nor electromagnetic and are not emitted by a single source. Their nature is specific and can rather be considered as waves inherent in matter (Energiya i impuls na fotona). Particle-wave dualism was the reason for introducing by Niels Bohr the so-called “complementarity principle” in physics, and Werner Heisenberg formulated his “uncertainty principle” also in order to explain the dual nature of the quantum objects.

According to Leibniz’s *Monadology*, the world consists entirely of monads, fundamental entities par excellence - “true atoms of nature” (Cooperman 2007, 30). “The Monad, of which we shall here speak, is nothing but a simple substance, which enters into compounds. By ‘simple’ is meant ‘without parts’” (*Monadology*¹, para. 1). Leibniz describes the monads as possessing characteristics of separate particles, insofar they “must have some qualities...” (*Monadology*, para. 8), and “each Monad must be different from every other” (*Monadology*, para. 9). In terms of modern quantum physics, different kinds of elementary particles vary in their properties like mass, charge, spin, etc. As individual detached essences, “The Monads have no windows, through which anything could come in or go out” (*Monadology*, para. 7).

At the same time, Leibniz attributes some wave nature to the monads as well: “The created Monad, is subject to change, and further that this change is continuous in each” (*Monadology*, para. 10), and “the natural changes of the

¹ All quotes from *Monadology* are from the electronic issue of Robert Latta’s translation made in 1898 (Leibniz 1898).

Monads come from an internal principle, since an external cause can have no influence upon their inner being” (*Monadology*, para. 11). He speaks also about “particular series of changes, which constitutes, so to speak, the specific nature and variety of the simple substances” (*Monadology*, para. 12). Further, “a simple substance must be affected and related in many ways, although it has no parts” (*Monadology*, para. 13). These continuously changing elementary substances could be interpreted in this case namely as a spreading wave, because a single indivisible particle cannot undergo any inner transformations.

Leibniz and the idea of a hidden “metareality” and of the non-locality

The idea of a “sub-reality”, where everything exists in the form of pure potential and is interconnected, building a large whole unity, is not a new one. In quantum physics, it has been proven that a vacuum is not really an empty space, but a quantum field filled with vibrating energy – something like a dark, raging “ocean” of virtual particles that constantly appear and disappear in pairs consisting of a particle with a negative charge and a particle with a positive charge. They exist for a very small fraction of a second before colliding and annihilating each other in a small surge of energy. The birth of the Universe from the Big Bang is also interpreted by some modern physicists as a “quantum fluctuation” in the primary vacuum. This is how Leibniz himself presents a similar idea:

“We may also hold that this supreme substance, which is unique, universal and necessary, nothing outside of it being independent of it, - this substance, which is a pure sequence of possible being, must be illimitable and must contain as much reality as is possible“ (*Monadology*, para. 40).

Another intriguing problem in modern physics, related to the hidden nature of the universe, is that of the so-called dark matter (a hypothetical substance that is invisible but has a powerful gravitational effect, which explains the way the Universe gets structured). What is known is that a mere 5% of Universe’s mass is owed to the matter we know. While about 25% makes the share of dark matter, the resting 70% makes dark energy (Greene 2004).

This year, researchers from Dark Energy Survey (Dark-Matter-Map) published the best map ever created of the dark matter in the Universe. This is quite an interesting achievement taking into consideration that at this stage we know too little about this mysterious substance. The project was created using a method studying how gravity from the neighbouring galaxies influences the way how we can see the farther galaxies. Thanks to this, a map was prepared, including broad regions with presumed dark matter in relatively close parts of the Universe. The data could also help study dark energy, a still unexplained force most likely responsible for the accelerated expansion of the Universe.

The already established “occupancy” of the Universe with different types of matter and energy (although not all of them are directly detected at this stage) fully corresponds to one of the ideas expressed in *Monadology*: “Thus there is nothing fallow, nothing sterile, nothing dead in the universe...” (*Monadology*, para. 69).

Another formulation in quantum physics related to the concept of metareality is that of the collapse of the wave function (expressed in Erwin Schrödinger's famous equation) and the idea that, without an observer, elementary particles exist in a fuzzy quantum state of pure potentiality. The so-called Werner Heisenberg uncertainty principle, on the other hand, postulates that it is impossible to determine simultaneously with sufficient accuracy the spatial position and momentum (i.e., velocity) of an elementary particle. This again refers to the idea of the existence of a deeper reality associated with this uncertainty and the process of formation and functioning of the "real" world. Lawton interprets these formulations in quantum physics in the spirit of Leibniz's *Monadology*: "Leibniz would argue that the collapse of the wave function is equivalent to a predicate rising to the level of a representation. That is, before we make a measurement we have no representation although the predicate is lying in wait within our monad. When we make the measurement, the wavefunction collapses, and the representation arises from the predicate" (Lawton 2003, 15). Here we cite one of the paragraphs of *Monadology* that largely complies with this statement:

"It is farther true that in God there is not only the source of existences but also that of essences, in so far as they are real, that is to say, the source of what is real in the possible. For the understanding of God is the region of eternal truths or of the ideas on which they depend, and without Him there would be nothing real in the possibilities of things, and not only would there be nothing in existence, but nothing would even be possible" (*Monadology*, para. 43).

In a 1935 publication, Albert Einstein, Boris Podolsky, and Nathan Rosen presented their study of the extent to which correlated quantum states of elementary particles would interact with each other. They found that when two particles are strongly connected, they lose their separate quantum states and instead share a single, unified state. This uniform state will become known as quantum entanglement. This means that if two particles are entangled, their quantum states are strongly connected and unite, then the measurements of one of the particles automatically affect the properties of the other, no matter how far apart they are (Sutter 2021). An ideological correlate of this findings of quantum mechanics can be identified in the following paragraph of *Monadology*: "Wherefore it follows that this inter-communication of things extends to any distance, however great. And consequently every body feels the effect of all that takes place in the universe, so that he who sees all might read in each what is happening everywhere, and even what has happened or shall happen, observing in the present that which is far off as well in time as in place: σύμπνοια πάντα [sympnoia panta], as Hippocrates said" (*Monadology*, para. 61).

Interpreting this problem (for the intertwined states of particles from the point of view of Leibniz's philosophy), Dony manages to generalize it, giving it a universal ontological status: "As is known, entanglement phenomena can generally be described as phenomena where the states of distinct entities cannot be fully specified without reference to each other and to the whole complex in which they enter. In such cases, it is not possible to assign an absolute value to one parameter, independently of the assignation we make to another related one - hence their non-separability. Yet, as I will have shown, likewise it is precisely a key idea of Leibniz's ontology that a single state of a substance can be

exhaustively described only if one takes into account the whole substantial series and the whole world, according to a corresponding law” (Dony 2017).

Doronin, for his part, clearly links the phenomenon of “non-locality” to the existence of a hidden, fundamental reality: “Quantum theory justifies the existence of a deeper and more fundamental reality - unmanifested and non-local. Quantum theory comes close to the quantitative description of intangible objects and non-local correlations” (Doronin 2011, 23). According to his interpretation of quantum theory, any closed system is in a non-local (unmanifested) state due to the lack of an external environment and no one to perform the reduction. It is an intangible state that he defines as pure information, existing as emptiness, a non-local state.

The concept of entanglement is inextricably linked to the concept of decoherence. This is a process in which, as a result of the interaction of the system with the environment, the coherence of its state in superposition is disturbed. At the same time, the degree of quantum entanglement decreases, i.e., the overall unity disintegrates and the harmony that exists in the maximally intertwined state disappears. As a result, the subsystems begin to separate from each other until their complete independence, while at the same time their localization takes place, i.e., each subsystem receives its specific visible form, its “dense body”. Simply put, decoherence is a process in which bodies emerge from emptiness, from non-existence, from the non-local quantum source. As a result of this process, dense local objects in the world around us appear, including various classical fields, such as the electromagnetic or gravitational. According to Doronin, decoherence and recoherence are the most fundamental physical processes in the reality around us. When the system is a single and indivisible whole, the degree of entanglement is equal to one. This is a non-local state and then there are no classic “visible” objects in this system (even at the subtle levels of reality). In this way, a closed system can be in a maximum intertwined state and not contain local (classical) components (subsystems). However, if it begins to interact with its environment, the degree of entanglement between its subsystems gradually decreases and they manifest themselves as local objects (Doronin 2011).

Leibniz presents a similar picture of the world, of course, in accordance with his inherent deism: “Thus the final reason of things must be in a necessary substance, in which the variety of particular changes exists only eminently, as in its source; and this substance we call God. [...] Thus God alone is the primary unity or original simple substance, of which all created or derivative Monads are products and have their birth, so to speak, through continual fulgurations of the Divinity from moment to moment, limited by the receptivity of the created being, of whose essence it is to have limits. In God there is Power, which is the source of all, also Knowledge, whose content is the variety of the ideas, and finally Will, which makes changes or products according to the principle of the best” (*Monadology*, para. 38, 47, 48).

And in paragraph 87 of his *Monadology*, Leibniz summarizes his conception of the existence of two realities (overt and covert, i.e., unmanifested) as follows: “As we have shown above that there is a perfect harmony between the two realms in nature, one of efficient, and the other of final causes” (*Monadology*, para. 87).

Insights about the holographic and fractal nature of the Universe

A number of ancient philosophers have expressed ideas that essentially refer to the modern scientific assumption of the holographic nature of the Universe. A typical example in this regard is the famous “Plato’s Cave”, an allegory presented by the ancient Greek philosopher in his treatise “Republic”.

Plato suggests imagining people chained to a rock at the bottom of a cave and looking in the direction of one of the arched walls. They cannot see who and what is behind them. Light comes only from the fire lit in the middle of this cave. It creates shadows, and Plato suggests that they are perceived by prisoners as real, living beings, and the echo as a real sound, not a reflection of reality, because that is all they see or hear (The Myth (or Allegory) of Plato’s Cave). However, the real world is much richer, more complex, full of various objects and dynamic phenomena.

The holographic image was discovered in 1947 by Dennis Gabor (Dennis Gabor 2020). It is a three-dimensional object created by means of a laser beam, and it looks completely real. In order to obtain a holographic image of an object, the light emitted by a single laser is divided into two separate beams. The first beam is reflected by the object to be photographed. The second beam is then allowed to collide with the reflected light from the first. Thus, they create an interference pattern, which is recorded on a photographic plate. To the naked eye, the image on the film has nothing to do with the object being photographed and looks like concentric circles. But as soon as another laser beam (or in some cases just a bright light source) passes through the film, the three-dimensional image of the original reappears. The three-dimensionality of such images is extremely convincing. They can be viewed from different sides, but when you try to touch it, you find that there is really nothing there. However, some scholars invented a hologram that even creates in the hand a sensation of touch (TechNews.bg 2021).

But three-dimensionality is not the only remarkable aspect of holograms. Another specific quality of it is that information about the whole is contained in each part of it. In general, the hologram contains some hidden order, indicating unity on a deeper level. This interesting issue is enriched and further developed by a number of scientists, such as the American quantum physicist David Bohm (Quantum Physics: David Bohm). In his work, Bohm came across an impressive example of quantum interconnectedness in the study of plasma. To his surprise, he found that when electrons were in a plasma state, they ceased to behave as separate particles and began to behave as if they were part of a larger and interconnected whole. After numerous research efforts, Bohm came to the idea that perhaps the things we perceive as messy are not at all.

Beneath the hologram is clearly hidden a deeper order of existence (called “implicit”), a vast and more primordial level of reality that gives rise to all the objects and phenomena of our physical world in much the same way that a holographic plaque gives rise to hologram. This does not mean, according to Bohm, that the Universe is a giant undifferentiated mass. Things can be part of an indivisible whole and still have their own unique qualities. The analogy with Leibnitz’s ideas here is obvious: “[...] each Monad, whose nature being to rep-

resent, [...] the Monads are limited. In a confused way they all strive after [*vont a*] the infinite, the whole; but they are limited and differentiated through the degrees of their distinct perceptions” (*Monadology*, para. 60).

The Argentinian string theorist Juan Maldacena links string theory to the holographic model (Maldacena 2005). According to his remarkable theory, a universe that exists in two dimensions and does not contain gravity can be completely equivalent to a three-dimensional universe with gravity. The three-dimensional world could arise from the physics of the two-dimensional universe as a three-dimensional holographic image from the flat hologram. The two-dimensional universe exists on the border of the three-dimensional one, where there are strongly interacting quarks and gluons. The physics of internal volume includes the quantum theory of gravity. Maldacena finds a clear link between the physics that take place in an area and the physics that unfolds along the boundaries of that area. This is exactly what he interprets as a clear realization of the holographic principle.

A similar picture of the world is presented by the American physicist Michio Kaku, explaining how string theory or its extended version, the so-called M-theory, suggesting the existence of 10 or 11 dimensions of reality, lead to the idea of a holographic universe: “Perhaps the three-dimensional world we live in is only a shadow of the real world, which has ten or eleven dimensions. [...] When we walk down the street, our shadow follows us and moves like us, but it exists in two dimensions. In the same way we are shadows that move in three dimensions, but the real ones we move in ten or eleven dimensions” (Kaku 2021, 132).

In the meantime, Professor Afshordi and his team, studying the irregularities in the Cosmic Microwave Background (CMB) or the “glow” of the Big Bang, found evidence to support the holographic explanation of the Universe (Afshordi et al. 2017). The authors of the study managed to make complex comparisons between the features of the CMB data and quantum field theory, finding a way to explain almost all cosmological observations of the early Universe, while confirming the holographic principle as completely relevant.

Leibniz presented some similar insights in his work *Monadology*, where in paragraph 62 he claims that “[...] each created Monad represents the whole universe [...] this body expresses the whole universe through the connexion of all matter in the plenum [...]” (*Monadology*, para. 62).

Similar to (and even derivable from) the concept of a holographic universe is the idea of a universe featuring a fractal structure. Fractals are geometric shapes with fractional dimensions, which are most characterized by the self-similarity to the smallest structural details, i.e., at any scale, each individual element reproduces the structure of the whole set. And here is how Gottfried Leibniz imagined reality more than 300 years ago: “Now this connexion or adaptation of all created things to each and of each to all, means that each simple substance has relations which express all the others, and, consequently, that it is a perpetual living mirror of the universe” (*Monadology*, para. 56). In paragraph 65, he indicates again that “each portion of matter” “expresses” the whole Universe (*Monadology*, para. 65).

This is surprisingly consistent with recent advances in physics. For example, Coleman and Pietronero assert in a publication of theirs that “the distribution

of visible matter in the universe appears to be fractal and multifractal up to the present observational limits (200 Mpc; about one twentieth of the Hubble radius of the entire universe) without any evidence for homogenisation” (Coleman, Pietronero 1992). There is another author, who also got to a similar conclusion: “If you take a look at the structures that form in the Universe, many of the things we see on large scales appears at smaller scales, too” (Siegel 2021). According to him, the Universe is not a real fractal, but even with structures that are approximately fractal, it poses extreme cognitive challenges and many space lessons have yet to be learned.

The connection between this intriguing picture of the world and Leibniz’s *Monadology* has been noticed by many researchers, although they do not use the term “fractal”. Here is for example the opinion expressed by Beal: “Monads have no “windows.” Yet each monad is a representation to a greater or lesser extent of everything else in the Universe because it is linked to all other monads by means of its relation to God. That is, each monad is a reflection of the entire Universe precisely because it is in some way a projection of a part of God” (Beal 2015). Gefter also noted that monads, as a fundamental ingredient of reality, are a unique reflection of the entire Universe (Gefter 2019). According to Wiener, this reflection is best perceived as a parallelism (albeit incomplete) between the internal organization of the monads and the organization of the world as a whole. This is to say that “the structure of the microcosm runs parallel to that of the macrocosm” (Wiener 1934, 480). There are some other authors who also discuss in their publications similar aspects of the relationship between individual monads and the Universe (Walach, von Stillfried, Roemer 2009; Slowik 2016).

Conclusion

Scientific ideas usually arise and evolve over time in the pattern of spirals, ebbs and flows, and if they are not categorically rejected for mathematical reasons or by appropriate experiment, they are gradually enriched and “condensed” with content, becoming much more consistent and scientifically convincing. From “shadows of consciousness” abstractedly extracted, they follow their path to solidly theoretically grounded and empirically proved facts and theories. This is also the case with Leibniz’s *Monadology*, a philosophical work that generates remarkable scientific ideas that subsequently “seep” into modern physical theories and find (or are about to find) their experimental confirmation. At the same time, we cannot disagree with the statement that “Leibniz’s clairvoyance into the future is explicable only on the basis of his universal information, universal interests, and universal genius” (Wiener 1934, 482).

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