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LEIBNIZ'S MATHEMATICAL AND PHILOSOPHICAL APPROACHES TO ACTUAL INFINITY A CASE OF CULTURAL RESISTANCE

The notion of cultural resistance, as introduced by Raymond L. Wilder in his treatment of the history of mathematics, is a reliable guide in any pursuit of the history of ideas. A trouble which afflicts historians of ideas is that they find inconsistencies where a perfect logic is expected, to wit with great thinkers. However, after a while of reflexion, rather something contrary to that should be expected, if a cultural resistance is taken into account. Let us dwell a while on that phenomenon.

1. Creative thought and cultural resistance

1.1. Greatness of one's creative thought consists in surpassing the bounds of that cultural system in which one happened to be born and to live. But even the greatest mind is no supernatural being that would be able to easily overcome such confines. There must ever arise a tension between the existing paradigm and the drive of new original visions being characteristic of a genuine philosopher. This is a struggle which cannot end without victims, that is, uncertainties, changes of mind, even inconsistencies in the output of any original thinker.

Thus, what a philosopher's contemporaries firmly believe has to affect his mind, even most original and bold. Moreover, not only the beliefs which a philosopher encounters in the time he lives modify his original vision. There is even a more important factor, namely the invincible ignorance shared by him with his contemporaries. When seeing the views of our ancestors from the point of advanced knowledge of ours, we hardly can imagine how much different their way of thinking must have been. Let me mention two historical examples related to Leibniz's intellectual struggles: that of the theory of infinity and that of the idea of cosmic evolution.

Since Aristotle, people distinguished between actual and potential infinity, and they asked, as Aquinas did, if there might exist infinite actually number of things. Aquina's answer in the negative is characteristic not only of the theological but also of the mathematical mode of thinking since the ancient Greeks up to the end of the 19th century.

Aquinas relies on that maxim of the Book of Wisdom, which impressed also Augustine and Leibniz, that God ordered all the things according to a number: *omnia in numero disposuisti*[1]. It seemed obvious for anybody since Greeks up to the appearing of modern set theory that the term "number" had to denote a *finite* number, so to speak, ex definitione. For, it was rightly believed that numbers are those objects on which operations of addition, multiplication, etc. should be defined. No such definitions were even in a remote field of vision, hence nobody could seriously think of infinite numbers. Only when precise definitions of operations in various domains of infinite numbers have been given in modern set theory, the term "infinite number" started to have a sense.

Thus, when the Holy Scripture declared that the world was created "in number", this must have meant for Aquinas and other heirs of the ancient thought that the world was not infinite. This was the picture of the universe with which Leibniz's vision of the infinite multitude of monads must have clashed. He proved not discouraged by this cultural resistance. However, on the other hand, he had no conceptual devices to incorporate his vision into a reasonable mathematical scheme; in such a sense he incurred losses because of the limitations of the cultural system in which he happened to live. This is why *Monadology*, the main work to develop his idea of the actually infinite universe, does not contain any reference to mathematical approaches to infinity.

1.2. Another conceptual abyss between Leibniz's time and that of ours may be hinted with the following Teilhard de Chardin's remark: *the greatest event in the evolution of human race is that it once learned about its evolution.* This gretest event was among those things in the earth and heaven which were not even dreamt by the philosophers in the 17th century.

I do not mean Darwin's idea of the evolution of plants and animals which was just a small step when compared with what Hubble's discovery and the

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[1] See Summa Th., Pars Prima, q. 7, a. 4). The text in question mentions also weight and measure as the principles of ordering (*in pondere et mensura*). However, according to the typical biblic style these terms seem to be added just for emphasis, not as carrying a new content; hence "number" renders the concept in question.

general relativity theory disclosed to the people of the 20th century. The idea of the evolving universe was so puzzling, so unbelievable, that even Einstein rejected it in his first version of general relativity at the cost of distorting the theory. Only after Hubble's empirical discovery of the expansion of the universe, in 1923, Einstein returned to the non-distorted version, ashamed of his previous mistake.

While Einstein was not able to free himself from the century long habit of conceiving the universe as eternally stable, should we wonder that Leibniz did not manage it? Though his metaphysical vision included a presentiment of the eternally evolving universe as due to God's eternal activity, there was no remotest idea of that in the world picture of his time. Here we encounter another case of resistance; a fruitful idea did not bring fruits which it would offer in more favourable cultural circumstances.

Leibniz's vague intuition of the infinitely developing universe is implicit in his idea that the world is incessantly becoming — due to God's computing, and setting his thoughts in motion: *cum Deus calculat and cogitationes exercet, fit mundus.* Now, one faces the question, whether God may stop his computing and thinking. Provided the answer in the negative, and provided that God's intellectual activity makes the world ever better (and not ever worse), one has to endorse the idea of the universe ever getting better. Thus *the best of possible worlds*, as Leibniz used to call the existing one, in not the one in which we presently live but the one to evolve from that of ours in an infinitely remote future (this would make Voltaire's known satire rather pointless).

However, while so expressing his most intimate vision, Leibniz was not capable of working it out towards an idea of cosmic evolution. Among the reasons of that inability there was that he had no conceptual means to guess what kind of numbers might be involved in God's eternal computing.

2. Uneasiness about mathematical infinity

2.1. Georg Cantor used the phrase 'horror infiniti' coined on the pattern of 'horror vacui'. The latter was to be a property of Nature, while the former was to mean one's being afraid to face the abysmal infinity of infinite collections. The word 'fear' may be too dramatic to call Leibniz's attitude, but such words as 'disquiet' or 'uneasiness' truly render the state of mind both of him and his contemporaries.

The first well known sign of such a disquiet, extensively referred to by Leibniz in his *Accessio ad arithmeticam infinitorum* appears in Galileo's

Discorsi [...] (*Dialogues Concerning Two New Sciences*). The passage in *Discorsi* is worth quoting as a historical landmark in the human way to apprehending infinity. The text runs as follows (p. 32 in Engl. version).

> If I should ask how many squares there are one might reply truly that there are as many as the corresponding number of roots, since every square has its own root and every root its own square, while no square has more than one root and no root more than one square.
>
> But if I inquire how many roots there are, it cannot be denied that there are as many as there are numbers because every number is a root of some square. This being granted, we must say that there are as many squares as there are numbers because they are just as numerous as their roots, and all the numbers are roots.
>
> What then must we conclude under such circumstances? We can only infer that the totality of all numbers is infinite, and that the number of their roots is infinite; neither is the number of squares less than the totality of all numbers, nor the latter greater than the former; and finally *the attributes "equal", "greater", and "less", are not applicable to infinite but only to finite, quantities.* — [Italics W.M.]

The last sentence (italicized) makes evident the enormous distance between mathematical thinking in those times and in the period after the establishing of set theory. Until the power set axiom and the diagonal reasoning were introduced, nobody could reasonably speak of greater and smaller infinite totalities. Thus, in a sense, Galileo was right when he restricted applicability of these predicates to finite numbers; their meaning had not been defined for infinite numbers, hence their scope must have been restricted to the domains in which they originated, that is, the finite ones.

2.2. Leibniz's approach was more ambitious. He tried to handle the problem within a research programme concerning mathematical methods, and in connexion with some mathematical tasks which he was occupied with in 1672. It was the year which Leibniz spent in Paris waiting for an opportunity to carry out a diplomatic mission. The opportunity delayed (with no final success), hence he got a fair amount of time to engage himself into various research projects.

One of them started from a talk with Christian Huygens whom Leibniz regarded as his master in mathematics. This meeting is by Leibniz reported in an extensive letter to Gallois written by the end 1972, entitled *Accessio ad arithmeticam infinitorum*.

According to that report, Huygens suggested that Leibniz should try to solve a demanding (in that time) mathematical problem, namely to find the sum of a series of rational numbers. This series is listed as item [3] below. The remaining items exemplify akin results achieved by him after he generalized Huygen's problem. To wit, he defined a whole class of arithmetic series, the class being constructed in a systematic way to lead to the solution being looked for. It is that construction which Leibniz combined with the problem of infinity in arithmetic.

Leaving aside that method of construction (which would require a rather comprehensive exposition), let us just notice that in every next series the diferences between denominators of any adjacent terms become greater. Here are examples of the series (starting from [2], not from [1], for a reason to be seen later).

[2] $\quad \frac{1}{1} + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5} + \frac{1}{6} + \frac{1}{7} +$ *etc.* $= \frac{1}{0}$

[3] $\quad \frac{1}{1} + \frac{1}{3} + \frac{1}{6} + \frac{1}{10} + \frac{1}{15} + \frac{1}{21} + \frac{1}{28} +$ *etc.* $= \frac{2}{1}$

[4] $\quad \frac{1}{1} + \frac{1}{4} + \frac{1}{10} + \frac{1}{20} + \frac{1}{35} + \frac{1}{56} + \frac{1}{84} +$ *etc.* $= \frac{3}{2}$

Note that in [2] the difference equals one in any case; in [3] it equals two between the first two terms, three between the 2nd and the 3rd term, and so on. In [4] such differences are still greater than in the preceding series. Leibniz lists, moreover, series [5], [6], [7] as examples, each obeying the same law of increasing (with each next series) the differences between adjacent denominators.

At the same time, in the fractions being the sums of series, numerators and denominators increase in such a way the they form the sequence (from [2] to [7], respectively):

$$\frac{1}{0}, \ \frac{2}{1}, \ \frac{3}{2}, \ \frac{4}{3}, \ \frac{5}{4}, \ \frac{6}{5}, \ etc.$$

Now we come to the point in which Leibniz's argument concerning infinity can be traced. We should complete the above list of series with the lacking item [1] in which denominator differences would be lesser than 1 (as occurring in [2]). This should equal zero, while the sum should equal the fraction $\frac{0}{0}$ (for it should have the numerator less than that in [2]). Thus we obtain the following series.

[1] $\quad \frac{1}{1} + \frac{1}{1} + \frac{1}{1} +$ *etc.* $= \frac{0}{0} = 0$

Leibniz's comment concerning this series requires a bit of discussion since its meaning does not seem clear to a modern reader. The comment runs as follows (p. 15 in the edition mentioned in References).

> [...] audacter concludo numerum istum infinitum sive numerum maximum seu omnium unitatum possibilium summam, quam et infinitissimum appellare possis, sive numerum omnium numerorum esse 0 seu nihil. Et demonstratio nova vel ex eo suppetit, quod numerus maximus est summa omnium unitatum sive numerus omnium numerorum. At summa numerorum necessario major est numero numerorum (ut 1+2+3 etc. majus quam 1+1+1 etc.). Ergo numerus maximus non est numerus maximus seu numerus maximus est 0, *etsi non ideo infinitas partes continuo aut infinitam magnitudinem tempori ac spatio protinus negem.* [Italics – W.M.]

The passage italicized by myself is worth utmost attention as it displays that uneasiness which I hint at in the title of this section. The scientists and rationalist philosophers in the 17th century claimed that the new science must be entirely mathematical if it is to succeed in explaining the world. Leibniz belonged to most ardent followers of that programme. However, he must have admitted that mathematics does not fully reflect the structure of reality. While time and space possess infinite magnitudes, these magnitudes, unfortunately, cannot be rendered with mathematical concepts.

Before trying to find out a possible source of that failure of Leibnizian mathematics, some comments are in order to interpret the previous part of the quotation. Leibniz makes use there of the equality listed above as [1], where the left side represents an infinite magnitude, as the ones are being added and added without stopping, while the right side amounts to zero (that it is obtained with dividing zero by zero may be here disregarded as a minor point). Thus Leibniz feels entitled to emphatically conclude that *the infinite number of all numbers amounts to zero, or nothing.*

It does not seem clear how to understand the identifying of zero with nothing. As for the series [1], '0' denotes a mathematical entity in it, but no mathematical entity deserves to be called nothing. Moreover, in the next argument ('demonstratio nova') being like a reductio ad absurdum, Leibniz seems to blame the concept of an infinite number as lacking consistency. For, he argues, such a number (as the sum of all terms in series [1]) would be both the greatest one, as being infinite, and not the greatest one, since the series of all natural numbers (as 1+2+3, etc.) would be greater yet. According to Leibniz, the self-contradictory phrase 'the greatest number is not the greatest one' denotes zero, and here again he identifies zero with nothing; however, zero is an object undoubtedly free from being self-contradictory while nothing is defined by an inconsistent expression, indeed.

2.3. Why did Leibniz prefer to deprive his philosophy of mathematical support than to admit infinite numbers? An explanation can be found in the same *Accessio*, where he sketches a project for what would be nowadays called 'foundations of knowledge'. This project included derivation of Euclidean axioms from mere definitions of the terms involved. This seemed to him the safest way of ensuring the truth of the first premisses of mathematics. When announcing the subject of *Accessio* in its introductory passage, he puts on the same footing arguments against infinity and arguments for the possibility of proving mathematical axioms. This declaration, serving both as a title and an abstract, runs as follows.

> Accessio ad arithmeticam infinitorum, ubi et ostenditur numerum maximum seu numerum infinitum omnium numerorum impossibilem esse sive nullum; item ea, quae pro axiomatis habentur, demonstrabilia esse evincitur exemplis.

Among those most venerable axioms whose proofs, as Leibniz believed, were supplied by him on the basis of definitions alone, there was that a whole is greater than any part of it:

Omne totum est majus sua parte.

At the last pages of *Accessio* Leibniz offers examples of such proofs, including a demonstration of the above principle (the course of reasoning is not relevant to the present subject). Leibniz was so earnestly engaged in that methodological project that he most appreciated what he regarded as its results. This should explain why he was so sensitive to anything what seemed to endanger the whole-part principle; and the idea of a set of numbers whose part equals the whole appeared to him destructive.

There is a moral to be drawn from this story, which may be instructive for students of the history of ideas. Let me express this lesson in the familiar metaphor of hardaware and software. Imagine, you have to choose between (1) a computer which due to the hardware has enormous computational power (as consisting in speed, memory size, etc.), but no software is supplied with it, and (2) a computer with less giant hardware parameters but richly endowed with useful software.

Now compare (A) a genius of old times, enjoing a wonderfull brain but devoid of knowledge and skills which came later in the historical development, and (B) a less gifted brain but equipped with advanced knowledge and sophisticated problem-solving methods. Obviously, A is the counterpart of 1, while B is the countepart of 2 in the hardware-software parable.

The moral is as follows. When admiring the intellectual power of people like Leibniz, we should be prepared to take into account their limitations of knowledge, methods, and conceptual equippment ('software') which are overcome with later achievements, those inherited by our generation. It is historian's task to sharply analyze our ancestors' failures. Thus he wins a starting point to trace the progress owed to next generations.

3. Is it possible for a modern mind to understand *Monadology*?

3.1. One's understanding of other one's view involves either agreeing or disegreeing with it, or else refraining from both with being aware of why one refrains. Does it often happen that this criterion is met by Leibniz scholars with respect to strange ideas of *Monadology*?

There are at least two prerequisities for Leibniz scholars to realize these ideas. (1) A scholar is bound either to recognize an infinite set of monads, at least as being possible in one of scenarios admissible for nowadays science, or to state that there is no chance of such a scientific exemplification. (2) He should decide whether he admits the view of the universe as having infinitely many levels of complexity. The dealing with these questions should be aided by an awareness which infinity is at stake: that of denumerable sets (aleph zero) alone, that of continuum, or else a higher one. The innocent ignorance of our ancestors who did not distinguish among infinities is no longer available to a modern researcher; he may refuse, like Leibniz, to connect metaphysics with set-theoretical notions but, unlike Leibniz, he would be obliged to account for the disregarding of set theory.

In what follows, I shall attempt at a rational reconstruction of Monadology in terms of modern science, treating that procedure as a means to understand Leibniz's thought; when suggesting one from among many possible intepretations, one approaches to understanding. One should notice that such reconstruction may involve counterfactual assumptions — in order to free oneself from accidental historical facts.

3.2. Let me start from assuming that Leibniz's rejection of infinity in mathematics was just a historical accident. Had he been born, say, in the 20th century, he would have willingly agreed that there are as many even numbers as all natural numbers, and so on. For, owing to the achievements of set theory, he would have accepted the distinction of two kinds of the whole-part relation, one valid for finite collections, the other for infinite collections. Certainly he would have enjoyed Cantor's diagonal argument

to the effect that the set of natural numbers, being a part of the set of reals, has to be smaller than the latter (because of the lack of one-to-one corespondence), in accordance with his favourite principle[2].

When making use of such counterfactual considerations, I claim thereby that Leibniz's rejection of mathematical infinity is logically independent from the rest of his philosophical thinking (depending solely from too narrow interpretation of the whole-part axiom in that time mathematics). Should we reject that rejection, the rest of the intellectual edifice would remain intact. If someone affirms the opposite, it is up to him to demonstrate a logical nexus between the denial of infinite numbers and philosophical principles.

The historical, and not logical, dependence of Leibniz views on infinity, connected with the cultural circumstances of his time, has been noticed by Hans Poser who reports on most influential rationalist thinkers as well as most renowned mathematicians of that time, all of them denying reasonabless of the idea of infinity, and then concludes: "Dies ist die Situation die Leibniz vorfindet". Had he found a different situation, his views on mathematical infinity would have been likely to be different, without any significant change in his philosophical vision.

It should be distinguished between, so to speak, downword and upword understanding of older ideas. The former relies on knowing those historical antecedents which account for the content and the appearance of the idea or theory in question. The latter consists in an attempt to render this idea in modern conceptual framework, to make it reasonable within this framework; this does not mean its acceptance, rather a mere possibility of acceptance if certain conditions prove satisfied. Such interpretational hypothesis in a way resembles an empirical hypothesis in science; even if not accepted in the moment, it may be seriously considered owing to its well-defined content.

3.3. Let me start from a conjecture to interpret the notion of monad. It seems that neither elementary particles of physics nor human minds can pretend to be monads. Though in the moment no commonly acceptable candidate is in view, a situation is better for Monadology now than it was in the framework of classical physics. For in various ways physics becomes to be permeated with the concept of information.

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[2] There is an inspiring Friedman's essay on analogies between Monadology and set theory. He notices Leibniz's refusal to acknowledge actual infinity in mathematics, but a historical explanation of the divergence in question is not intended in his essay. The problem appears more sharply when one takes into account Leibniz's view on mathematics as the most powerful device for philosophy. Then the question arises why did he give up applying this tool to the foundations of his own philosophical system.

The uncertainty principle somehow connects physical processes with activities of the human mind. This was the first departure from the paradigm in which mind (as well as information) and matter were absolutely separated. It is commonly known how far we are from a satisfying interpretation of the uncertainty principle. Hence no reliable path leading from such ideas to monadology can be imagined in the present state of science. Nevertheless, a rift in the old picture has been made, and clima for connecting matter with information gets more favourable. This is why there could appear a popular book on quanta entitled *The Ghost in the Atom: a discussion of the mysteries of quantum physics.* It includes interviews with most prominent representatives of eight, competing with each other, interpretations of quantum physics.

Among these interpretations there is one, developed by David Bohm, having been initiated by Louis de Broglie, which should suit Leibniz in a particular way. Contrary to the mainstream interpretation by Bohr and Heisenberg, which suggests an influence of the mind on physical phenomena, Bohm's view is free from such subjectivist approach. Instead, the famous uncertainty is being explained as resulting from researcher's lack of knowledge as to a deeper, more complex, level of phenomena; because of this emphasis on the objective reality, Bohm's interpretation is called *ontological.*

The whole point of ontological interpretation is to claim that there may be an *infinity of levels* in nature. Ever new kinds of entities and processes may appear at a deeper level. Bohm (1957; 133) characterizes the qualitative infinity of nature in the following way[3].

> A systematic and consistent analysis of what we can actually conclude from experimental and observational data leads us to the notion that nature may have in it an infinity of different kinds of things.

Popper (1977; 33) when approvingly discusses Bohm's ideas, summarizes them as follows in the context of complexity of particles deemed earlier as elementary (here the Leibnizian anti-atomism would be triumphant).

> More recently, the subatomic particles have in their turn been diagnosed as complex structures; and David Bohm (1957) has discussed the possibility that there may be an infinity of such hierarchic layers.

Leibniz in the frequently mentioned passage 64 of *Monadology* speaks of living bodies as being structures *in the least of their parts ad infinitum.*

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[3] The quotations below from Bohm's texts are given after Pylkkänen 1992.

Here Bohm and Popper seem to be more monadologist than Leibniz himself as the latter restricted the infinite structural complexity to organic bodies alone. However, would he have sticked to this restricted view, if he had possessed our modern knowledge of matter? Then he should have known that parts of organic bodies may be isolated and exist outside a living body. Should they lose their structure then? If not, Leibniz's notion of infinite structural complexity of living matter, down to ever deeper layers, should be extended to any matter at all. As if continuing this line of thought, Bohm (1990; 283f) claims the following.

> In some sense a rudimentary mind-like quality is present even at the level of particle physics, and as we go to subtler levels, this mind-like quality becomes stronger and more developed. Each kind and level of mind may have a relative autonomy and stability. One may then describe the essential mode of relationship of all these as *participation*. [...] Through enfoldment, each relatively autonomous kind and level of mind to one degree or another partakes of the whole. Through this it partakes of all the others in its "gathering" of information. And through the activity of this information, it similarly takes part in the whole and in every part.

This seems to be akin to Leibniz's idea which in passage 63 is expressed as follows. *Every monad is in its way a mirror of the universe, and since the universe is regulated in a perfect order, there must also be an order in that which represents, that is to say in the perceptions of the soul.* Bohm's notion of gathering information is worth comparing with that of perception, while participation seems to be like Leibnizian mirroring.

These and other analogies do not mean that Bohm's theory is something like Monadology resuscited. There are differences to be discussed, for instance, the notion of substance (which is very rigid in Leibniz while in Bohm is more relative), and the claim of determinism (which with Bohm is combined with a kind of indeterminism). However, what I intend is not to vindicate Monadology within the frame of modern science but just to hint at the possibility of reasonably discussing it in modern terms.

3.4.   There may be still another modern approach to Monadology. I mention it very briefly here as the subject requires more size and a separate discussion.

Ever more popular with phycists and information scientist becomes the idea that the universe is like a giant computer. On the other hand, within a view due to Richard Feynmann, even single elementary particles may be viewed as computers. Between these two extremes there are in Nature

innumerable systems — included in the universe and including particles — which also may act like computing devices.

If we try to imagine monads on the pattern of computing automata, belonging to Nature, hence *automata naturalia* (as called in *Monadology*, 64), then we obtain a picture not very far from that drawn by Leibniz. If, moreover, we emphasize the role of software, treating hardware as a secondary element which may be produced if a suitable software (to control production) is available, then the analogy with monads gets even closer.

Let us go further. *Essentiae rerum sunt sicut numeri* — says Leibniz in his juvenile dissertation *De principio individui*, and develops this thought throughout later writings. At the same time, each Turing machine, hence each computer, can be defined with a single number, owing to the ingeniuos coding procedure invented by Turing. Analogically, monads might be represented by single numbers. While computers, ex definitione, are coded with computable numbers, there is no obstacle to believe that what Leibniz called divine or natural machines might be coded with non-computable numbers (an idea close to Penrose's contention), and so known to God alone.

After thus arriving at God's calculating powers, we reach a fitting finale to sum up the argument with the saying: *cum Deus calculat, fit mundus*. This seems to disclose the essence of Leibniz's thought. Therefore, contrary to all the arguments he had against infinity of numbers, and in spite of the cultural resistance, there was a moment when he could not help expressing a faith in the infinity of numbers. *Neque enim negari potest, omnium numerorum possibilium naturas revera dari, saltem in divina mente, adeoque numerum multitudinem esse infinitam.* (Letter to Des Bosses, 11 March, 1706.) Let me say it once more, in English. "One cannot deny that the natures of all possible numbers do exist, at least in the mind of God, and this is why the set of numbers is infinite."

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