Monads, Cellular Automata and Neural Nets

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Leibniz's *Monadology*, written toward the end of his life as a summary of his metaphysics, is both one of the shortest and the least clear works of modern philosophy. It has been said to have "an aura of strangeness"[1] and called "a kind of fantastic fairy tale, coherent perhaps, but wholly arbitrary."[2] We might therefore be inclined to dismiss the *Monadology*, in spite of the author's earlier contributions to logic and mathematics.

In this paper, I would like to suggest that such a negative view of the *Monadology*, by treating Leibniz's metaphysical system separately from his logical and mathematical systems, fails to understand what Leibniz was attempting to do. The trend in this century has been, as Leibniz intended,[3] to see these two aspects of his thought as intrinsically related.[4] I would therefore like to consider the monad in a new way, as a logical or mathematical entity.

Leibniz tells us in the *Monadology*[5] that:

(1) Monads are simple substance, without parts [*Mg*, #1] but which can aggregate into collections. [*Mg*, #2]

(2) They also lack extension, figure and divisibility. [*Mg*, #3]

(3) They are neither created nor destroyed, but are eternally existent. [*Mg*, #4-6]

(4) "They have no windows." [*Mg*, #7] They are completely self-contained, can not be altered or changed by any external entity and nothing "goes out" from them. Therefore, all change must come from within. [*Mg*, #11]

(5) They have qualities, as they can be differentiated, [*Mg*, #8] and each is unique. [*Mg*, #9]

(6) They can change state. [*Mg*, #10] These changes of state have to do with perception. [*Mg*, #14] The passage from one perception to another is called 'appetition.' [*Mg*, 15] Future states are dependent on previous states, as each monad is "pregnant with its future." [*Mg*, #22]

(7) They may also be called entelechies "as they have within themselves a certain perfection." [*Mg*, #18]

(8) Each monad "is a perpetual living mirror of the universe." [*Mg*, #56]

(9) There are three types of monads, those "bare monads" which have only perception, animal souls which have clearer perception and some memory, [*Mg*, #19] and rational souls or spirits, which have both memory and apperception. [*Mg*, #14]

Taken as written, it would be hard to decide what sort of entity Leibniz had in mind. It seems to me that the first problem in understanding Leibniz lies in viewing monads as somehow "things," as "res extensa." His use of the terms "substance" [*Mg*, #1] and "atom" [*Mg*, #3] at the beginning of the text may lead the reader to this expectation. However, an examination of Leibniz's theory of substance toward the end of his life makes it clear that this is not what he intends.[6] If one must choose one aspect of Descartes' dualism, it appears that monads should be understood as "res cogitans."[7]

This being the case, it seems that we should seek the monad in the area of entities that can be thought, and further, within the realm of logical abstractions. Leibniz, as is well known, had a considerable interest in what we would today call cognitive science.[8] Based on this and on the way he uses the term 'substantial form,'[9] it seems to me that we should visualize a monad as a logical abstraction, an entity which exists not in the physical universe, but in the mind and, in our own day, perhaps in a computer system.

Several mathematical theories have been developed which have as their basic element something that resembles a monad. These elements are variously called a cell, logical neuron, or sometimes simply, a box. Among the more interesting theories are the cellular automata of John von Neumann,[10] the work of McCulloch and Pitts,[11] the perceptron of Minsky and Papert,[12] and the most recent development, neural network theory recently developed by a number of mathematicians into a valuable heuristic tool for computer science.[13] For the sake of simplicity, I will combine these theories, and consider only those elements which the theories have in common and which seem to be applicable to Leibniz.

In order to understand the basic idea, let us begin by considering the simplest possible network; that is, one having only two cells, (or boxes or neurons) or to use Leibniz's language, monads (A and B). Each cell will have only one characteristic or quality, in this case that of color, and each quality will have only two states, white and black. We can then define the system by one of two formulations, rules of combination or algorithm.

(1) The two monads must be in the same state; i.e., if A is white, then B is white and if A is black, then B is black.

(2) The two monads must be in different states; i.e., if A is white, then B must be black and if B is white then A must be black.

Obviously, both rules can not be simultaneously true, so each system is a universe, at least of discourse.

If you wish to expand the system to involve five monads (or cells) you could keep your desktop PC busy for quite a while developing the functions (or rules) for the possible systems. Clearly, some aggregates of functions would be internally inconsistent, and therefore a system could not be developed using such combinations. However there might very well be more than one consistent system.

If you make the quality five-stated (white, black, red, green and yellow, for example), you will have to arrange to use a major, mainframe computer at some scientific laboratory to develop the system. Continue to increase the dimensions and eventually you will reach the point of mathematical incomputability.[14] Since Leibniz states that the monads are infinite,[15] we clearly have infinite possible universes indeed.

In order to discover whether this theory is indeed something like the idea that Leibniz had in mind, let us compare each of the characteristics of monads to those of a cellular automata system or a neural network. First, neural cells or automata are simple and cannot be divided, but can be aggregated into groups or systems.[16] This seems to be one of their basic characteristics. Indeed, I cannot imagine how one would go about dividing a logical cell. Likewise, logical cells clearly lack parts, extension and figure. Their existential state is as difficult to discuss as that of any mathematical entity, but cells certainly cannot be created or destroyed in the way that objects are. If we must classify a cell in terms of Cartesian dualism, it is certainly more a "res cogitans" than a "res extensa." As we have seen, cells can have qualities or states and thus are capable of change.

How this change occurs is, I think, the crucial key to understanding Leibniz, and also one of the aspects of the *Monadology* that has most confused scholars. In terms of the system as a whole, no cell need communicate with any other. Given the rules of combination and the state of only one cell, in a closed system, it is possible to determine the state of all the other cells, although, as we have seen the computation involved may be monumental.[17] Thus, if one cell changes, all the others will also change in a pre-established fashion, but information does not need to pass directly from one cell to another. Indeed, in current neural net theory, the processing is done in parallel, that is, all at once, so that causation as we usually understand it does not operate.[18] Thus, each cell "mirrors" all the others, but "has no windows" and is "pregnant with its future." Leibniz's pre-established harmony is not some sort of odd, ad hoc system held together by God, but the necessity which derives from the principles of the logical system itself.

Leibniz tells us that this passing state (change) is called 'perception' [*Mg*, #14] and the internal principle which occasions the change or passage is called 'appetition.' [*Mg*, #15]. At this point, I must admit that I am forced to make an assumption which is not contained in the *Monadology*; to wit, that perception is to be understood as something like a formulation, algorithm or rule of combination, but this seems consistent with his doctrines.[19] A position like this, in contemporary cognitive theory, is termed 'functionalism'[20] and is a widely held view among those who think that mental processes can be explained in terms of mathematical principles. A common way to put the basic principle of functionalism is that the mind is the "software" of the brain. If I am correct in this reading of Leibniz, then he should be freed from the labels "dualist" or "occasionalist," which have never really suited his theory and be hailed as the first functionalist.

Leibniz then discusses those monads which have memory and apperception. This would add yet another dimension to the system, i.e., that of past and future, or in computer terms, a timestep. The state of a cell would be dependent not only on all the other cells and the functions of the system, but also on all previous states of the system, and would thus be logically reflexive, which is one way of interpreting the concept of consciousness.[21] Timesteps are a problem that is still being worked out in the technical world, and I trust I will be forgiven if I do not lead the reader off into yet another technical wasteland.[22] Suffice it to say that while it adds to the complexity of

the problem, this characteristic is certainly a possible, if not actual, part of neural net theory.

Last, Leibniz tells us that the monads are entelechies. I associate this with his earlier comment that perceptions change through appetition. In both cases, he seems to be saying that changes in monads are a result of goal-directedness and further that this goal-directed quality is internal to the monad.[23] This is precisely the characteristic, according to cognitive science, that differentiates the merely mechanical from the living.[24] Monads are "information processing systems," to use the current terminology.

Thus, it seems to me that we can best understand Leibniz's idea of a monad if we view it as the unit of a particular type of logical system. His theory is, however, not a perfect one. It would, after all, be most surprising if Leibniz had successfully anticipated by almost three hundred years the current cutting edge of cognitive science. Unfortunately, like most theories developed ahead of their time, the *Monadology* suffers from a basic flaw.

The astute logician will have noticed that I spoke of a closed system, that is, one in which the state of a cell or monad can be definitely determined. I described a system in which a cell is black or it is not; there was no state of "sort of black." This is the way early theories, such as that of von Neumann,[25] were developed and this is, of course, required for Leibniz by the law of non-contradiction. However, the current success of neural net theory is dependent on abandoning this most basic principle of Western logic and allowing what is termed "fuzzy logic."[26] In fuzzy logic not all sets have precise boundaries, and a quality can be predicated of an object statistically (or "sort of").[27] The effect of this on neural net theory is to push the complexity to yet a higher level, and insure that no mere human understands "the works" of the system.[28] However, if you want something that could truly be called "perception," that can really recognize and interpret patterns, you must add fuzzy logic to neural net theory.

Leibniz perhaps hints at a recognition of this principle when he discusses differing degrees of perception, [*Mg*, #22][29] but in the end, he could not free himself from his view of a "clockwork universe," perfect but sterile. In accepting the law of non-contradiction, Leibniz, like Laplace (in another context), closed the universe to the messiness that is reality.[30]

Notes

1. Nicholas Rescher, *G.W. Leibniz's "Monadology": An Edition for Students* (Pittsburgh, Penn., University of Pittsburgh Press, 1991) p. 11.

2. Bertrand Russell, *A Critical Exposition of the Philosophy of Leibniz* (London: Allen and Unwin, 1937) p. xiii.

3. G.W. Leibniz, "Letter to Samuel Masson on Body (1716)," in *G.W. Leibniz: Philosophical Essays*, ed. and trans. Roger Ariew and Daniel Barber (Indianapolis: Hackett, 1989) p. 229.

4. See for example:
Louis Couturat, *La Logique de Leibniz d'apres des Documents inedits* (Paris: Alcon, 1901) p. x.
Bertrand Russell, "Recent Work on the Philosophy of Leibniz," in *Leibniz: A collection of Critical Essays*, ed. Harry G. Frankfurt (New York: Doubleday, 1972) pp. 366.
Paul Schrecker and Anne Martin Schrecker, "Introduction" to Leibniz, *Monadology and Other Philosophical Essays* (Indianapolis: Bobbs-Merrill, 1965) p. ix.
E.T. Bell, *Men of Mathematics: the Lives and Achievements of the Great Mathematicians from Zeno to Poincaré*, (New York: Simon and Schuster, 1937) pp. 121-122.

5. All references to the *Monadology* are taken from:
Gottfried Wilhelm von Leibniz, *Monadology and Other Philosophical Essays*, Schrecker and Schrecker, *op. cit.*, henceforth indicated by *Mg* with the number of the passage in question given in brackets within the text.

6. Leibniz, "Letters to Des Bosses, (1712)," in Ariew and Garber, op. cit., pp. 198-203.
Since I do not have time in this short work to consider Leibniz's later views on substance, please see:
Stuart Brown, *Leibniz* (Minneapolis: University of Minnesota Press, 1984) pp. 139-143.
Ian Hacking, "Individual Substance," in Frankfort, op. cit., pp. 143-151.
C.D. Broad, *Leibniz: Introduction*, ed. C. Lewy (Cambridge: University Press, 1975) pp. 88-89.

7. An excellent treatment of the relationship between Leibniz's idea of the monad and Descartes's formulation of "thinking things" can be found in:
Montgomery Furth, "Monadology," *Leibniz: A Collection of Critical Essays*, ed Harry G. Frankfurt (New York: Doubleday, 1972) pp. 99-135.

8. Stuart Hampshire, *The Age of Reason* (New York: Mentor, 1956) pp. 143-144.

9. Gottfried Leibniz, "Sec. 11," *Discourse on Metaphysics*, trans. Philip Wiener in Steven M. Cahn, *Classics of Western Philosophy* (Indianapolis: Hackett, 1977) p. 444.
For a discussion of this interpretation see:
Brown, op. cit., pp. 137-139.

10. John von Neumann, *Theory of Self-Reproducing Automata*, ed. A.W. Burks, (Urbana: Illinois University Press, 1966).

11. Warren S. McCulloch and Walter Pitts, "A Logical Calculus of the Ideas Immanent in Nervous Activity," *Bulletin of Mathematical Biophysics* (1943) 5:115-133.

12. M. Minsky and S. Papert, *Perceptrons* (Cambridge, Mass.: MIT Press, 1969).

13. Among the many available texts are:
Bart Kosko, *Neural Networks and Fuzzy Systems: A Dynamical Systems Approach to Machine Intelligence* (Englewood Cliffs, N.J.: Prentice Hall, 1992).
Marilyn McCord Nelson and W.T. Illingworth, *A Practical Guide to Neural Nets* (Reading, Mass.: Addison-Wesley, 1991).

14. Personal communication, Jerry Stauffer, Intelligent Systems Division, Sandia National Laboratories, Jan. 7, 1993.

15. Leibniz, "Letter to Volder (1704)," in Ariew and Garber, op. cit., p. 179.

16. For a description of a logical neuron see:
Nelson and Illingworth, op. cit., pp. 43-52.

17. Kosko, op. cit., p. 22.

18. Nelson and Illingworth, op. cit., pp. 60-61.

19. Benson Mates, *The Philosophy of Leibniz: Metaphysics and Language* (Oxford: University Press, 1986) p. 199.
Broad, op. cit., pp. 120-123.

20. Alvin E. Goldman, *Philosophical Implications of Cognitive Science* (Boulder: Westview, 1993) pp. 74-75.

21. For a consideration of this definition of consciousness see:
Roger Penrose, *The Emperor's New Mind* (New York: Penguin, 1989) p. 410.

22. Kosko, op. cit., p. 45.

23. Broad, op. cit., pp. 101-102.

24. A. Rosenblueth, N. Wiener and J. Bigelow, "Behavior, Purpose and Teleology," *Philosophy of Science* (1943) 10: 18-24.

25. von Neumann, op. cit.

26. Actually, fuzzy logic sees the law of non-contradiction as a special case much as Quantum mechanics views Newtonian mechanics.
Kosko, op. cit., p. 271.

27. Kosko, ibid.

28. I observed this fact at the International Conference of the American Optical Society on Maui in 1992, which I was fortunate enough to attend. While neural nets are extensively used in optical pattern recognition, virtually no optical scientist considers how the nets do what they do. They are "black boxes."

29. Broad, op. cit., p. 97.

30. Joseph E. Hofmann, *Leibniz in Paris 1672-1676: His Growth to Mathematical Maturity* (Cambridge: Cambridge University Press, 1974).

Steve J. Heims, *John von Neumann and Norbert Wiener: From Mathematics to the Technologies of Life and Death* (Cambridge, Mass.: MIT Press, 1981).