

The very complex journey of complexity: a short note.

Pietro Terna, August 2020 (rev. October 2021)

Imagine a world correctly described in mathematical and logical terms, in any detail, and at any level. In this way, it would be possible to realize the dream of Leibniz (Gottfried Wilhelm von Leibniz, 1646-1716), that we read in *Opera philosophica*, xi. *De scientia universali seu calculo philosophico*¹:

*Quo facto, quando orientur controversiae, non magis disputatione opus erit inter duos philosophos, quam inter duos computistas. Sufficiet enim calamos in manus sumere sedereque ad abacos et sibi mutuo (accito si placet amico) dicere, calculemus.*²

Unfortunately (fortunately?), two hard constraints preclude the actual achievement of a world so entirely known to allow such exciting solutions.

Leibniz was not aware of the existence of:

- (1) the so-called *chaos*, due to the presence of dynamical systems, whose apparently-random states of disorder and irregularities are often governed by deterministic laws (that are highly sensitive to initial conditions);
- (2) of the phenomenon of complexity, due to the emergence of entirely new properties at any new level of aggregation.

We focus here on the second barrier.

THE DAWN OF THE COMPLEXITY IDEA

From where to start? Maybe, from the Latin construction of the word *complexus*. In Morin (2000), the great philosopher advocating the knowledge of complexity for the education of the future, we read that in Latin “complexus signifie ce qui est tissé ensemble”. Is that explanation sufficient to understand what complexity is?

Ancient Greek philosophers seem to help very little. In Aristotle, complexity seems opposed to simplicity as a matter of lifestyle (Wong, 2011). My beloved Spinoza wrote about the complexity of the mind (Sangiaco, 2011), without defining complexity.

In the 40s of the last Century, von Neumann was working with automata and their complexity, but (McMullin, 2000): “he described his own concept of complexity as «vague, unscientific and imperfect».”

If we jump to the 60s of the last Century, we have the Kolmogorov complexity, defined as a measure: given an object, e.g., a piece of text, the length of the shortest computer program (in a predetermined

¹ https://fr.wikisource.org/wiki/Page:Leibniz_-_Opera_philosophica,_ed._Erdmann,_1840.djvu/38.

² In the future, when an issue is controversial, it will not be necessary to dispute between two philosophers but between two subjects able in computations. It will suffice them to keep the abacus into their hands, sit down, and say each other –in a friendly way–start making calculations.

programming language) that produces the same object as output. Beautiful, but again it is not a reply to our search about what complexity is.

The concept was there, but missing a clear interpretation and definition, confused with the ascientific and antireductionist holism, i.e., the idea that we should view many systems (physical, biological, social, our body, etc.) as wholes, not merely as collections of parts. Sure, but then what?

In Simon (1962), we have an attempt to clarifying the concept, but with an example of dangerous compromise (*italic is mine*):

Roughly, by a complex system I mean one made up of a large number of parts that interact in a nonsimple way. In such systems, the whole is more than the sum of the parts, not in an ultimate, metaphysical sense, but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole. *In the face of complexity, an in-principle reductionist may be at the same time a pragmatic holist.*

Simon adds a note to the paragraph, but the lack of an explicit picture of the complexity definition is there:

See also John R. Platt, Properties of large molecules that go beyond the properties of their chemical sub-groups, *Jour. Theoret. Biol.* 1. 342-358, 1961. Since the reductionism-holism issue is a major *cause de guerre* between scientists and humanists, perhaps we might even hope that peace could be negotiated between the two cultures along the lines of the compromise just suggested. As I go along, I shall have a little to say about complexity in the arts as well as in the natural sciences. I must emphasize the pragmatism of my holism to distinguish it sharply from the position taken by W. M. Elsasser in *The physical foundation of biology*, New York, Pergamon Press, 1958.

THE MANIFESTO

With an interesting introduction, Goldstein (2014) has newly brought to our attention the crucial article of Anderson (1972). Goldstein quotes the original title, "*More is different - Broken symmetry and the nature of the hierarchical structure of science*" underlying the decisive elements of reduction, construction, and emergence: the real manifesto for complexity science.

With the title "In memoriam: Philip Anderson,"³ the Santa Fe Institute, on March 20, 2020, wrote:

Philip Anderson, a theoretical physicist who wrote rules that dictate the strange behavior of condensed matter and lent his deep intuition to problems beyond physics, died on March 29, 2020. He was 96 years old.

"It is hard to overstate the importance of the ideas of Phil Anderson to the science of SFI and complexity in general," said Santa Fe Institute President David Krakauer. "His 'More is Different' article from Science in 1972 was the most important and rigorous refutation of the foolishness of reductionism for complex systems yet published. Not only did Phil

³ <https://www.santafe.edu/news-center/news/memoriam-philip-anderson>.

articulate why confusing parts for the whole was a problem, but in the process, he explained why different fields of inquiry – from genetics to economics – needed to exist. This was a supreme act of intellectual modesty and generosity."

(P. W. Anderson, Nobel prize in 1977, participated in 1984 in the founding workshops of the Santa Fe Institute, but the co-founder of the Institute was Herb Anderson.)

Quoting the 1972 original paper:

(p.393) The reductionist hypothesis may still be a topic for controversy among philosophers, but among the great majority of active scientists I think it is accepted without questions. The workings of our minds and bodies, and of all the animate or inanimate matter of which we have any detailed knowledge, are assumed to be controlled by the same set of fundamental laws, which except under certain extreme conditions we feel we know pretty well.

(...) The main fallacy in this kind of thinking is that the reductionist hypothesis does not by any means imply a "constructionist" one: The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe.

The constructionist hypothesis breaks down when confronted with the twin difficulties of scale and complexity. The behavior of large and complex aggregates of elementary particles, it turns out, is not to be understood in terms of a simple extrapolation of the properties of a few particles. Instead, at each level of complexity entirely new properties appear, and the understanding of the new behaviors requires research which I think is as fundamental in its nature as any other.

This is the core of complexity.

THE ECONOMIC SIDE

From Friedrich von Hayek 1974 Nobel Lecture (Hayek, 1989):

Organized complexity [...] means that the character of the structures showing it depends not only on the properties of the individual elements of which they are composed, and the relative frequency with which they occur, but also on the manner in which the individual elements are connected with each other.

In a June 2020 discussion⁴ about the modern monetary theory (use money to push growth in presence of unemployment) prof. Steve Keen⁵ wrote "More is Different—the Class Economists Failed to Attend" and "Microfoundations is garbage, predating understanding of complex systems. See Anderson (real Nobel Prize winner!) for a total putdown [link to Goldstein 2014 here]. This criticism is like Ptolemaic astronomers criticizing Copernicus for not having epicycles."

A bit strong, but ... nice.

⁴ <https://twitter.com/MichalakisCon/status/1276353140451708928?s=20>.

⁵ https://en.wikipedia.org/wiki/Steve_Keen.

Anderson's conclusions were related to economics, also with a dialogue⁶:

In closing, I offer two examples from economics of what I hope to have said. Marx said that quantitative differences become qualitative ones, but a dialogue in Paris in 1920's sums it up even more clearly:

FITZGERALD: The rich are different from us.

HEMINGWAY: Yes, they have more money.

A very important book from Santa Fe Institute: Arthur *et al.* (2020).

Finally, the three 2021 Nobel Laureates in Complexity fields. From <https://www.santafe.edu/news-center/news/sfi-applauds-first-nobel-prize-complex-systems-research> we read:

SFI researchers cheered this October when the Nobel Prize in Physics was awarded to Syukuro Manabe, Klaus Hasselmann, and Giorgio Parisi "for groundbreaking contributions to our understanding of complex systems."

Spanning disciplines and notoriously difficult to define, complex systems science has struggled to achieve the mainstream recognition of older, more established fields. But the acknowledgment from the Nobel Committee, arguably the most prestigious award-granting assembly in the world, has emphasized its importance and beauty.

REFERENCES

P. W. Anderson. More is different. *Science*, 177(4047):393–396, 1972.

https://www.tkm.kit.edu/downloads/TKM1_2011_more_is_different_PWA.pdf.

W. B. Arthur, E. D. Beinhocker, and A. Stanger, editors. *[Complexity Economics] Dialogues of the Applied Complexity Network I - Proceedings of the Santa Fe Institute's 2019 Fall Symposium*. Santa Fe Institute Press, 2020.

J. A. Goldstein. Reduction, construction, and emergence in P. W. Anderson's "More is different". *Emergence: Complexity and Organization*, 16(3):117–134, 2014.

https://www.researchgate.net/profile/Jeffrey_Goldstein/publication/308012273_More_is_different_Broken_symmetry_and_the_nature_of_the_hierarchical_structure_of_science/links/5877f21008ae329d622833bd/More-is-different-Broken-symmetry-and-the-nature-of-the-hierarchical-structure-of-science.pdf.

F. v. Hayek. The pretence of knowledge (Nobel Lecture, 1974). *American Economic Review*, 79(6):3–7, 1989. <https://www.nobelprize.org/prizes/economic-sciences/1974/hayek/lecture/>.

A. Sangiacomo. Adequate knowledge and bodily complexity in Spinoza's account of consciousness. *Methodus*, Volume 6(Issue 6.1):77–104, 2011. doi: <https://doi.org/10.5771/0718-2775-2011-6.1>. <https://philpapers.org/archive/SANAKA>.

⁶ The dialogue never happened, see <http://www.quotecounterquote.com>.

B. McMullin. John von Neumann and the evolutionary growth of complexity: Looking backward, looking forward... In *Artificial Life*, volume 6, pages 347–361. MIT Press, 2000. <http://www.eeng.dcu.ie/~alife/bmcm-alj-2000/bmcm-alj-2000.pdf>.

E. Morin. Les sept savoirs nécessaires à l'éducation du futur. Seuil Paris, 2000. https://unesdoc.unesco.org/ark:/48223/pf0000117740_fre.

H. A. Simon. The architecture of complexity. In *Proceedings of the American Philosophical Society*, volume 106, pages 467–482. American Philosophical Society, 1962. http://homes.sice.indiana.edu/jbollen/I501F11/readings/week3/simon_H_The_architecture_of_complexity.pdf.

D. B. Wong. Complexity and simplicity in Aristotle and early Daoist thought. In King, Richard AH and Schilling, Dennis, editor, *How should one live? comparing ethics in ancient China and Greco-Roman antiquity*, chapter 13, pages 259–277. Walter de Gruyter, 2011. <https://pdfs.semanticscholar.org/b211/03a07e3422ab9eb8ecae14d7c01de00c3e35.pdf#page=267>.