

# COMPLEXITY AND PEIRCEAN RELATIONISM

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## ABSTRACT

The "sciences of complexity" have recently revealed a variety of singular characteristics and relationships in far-from-equilibrium physical systems, in living organisms, and in their complicated associations. These are features such as **emergence, self-organization, autonomy, circular causality**, etc. No synthesis able to connect them all into a single explanatory matrix has yet been found, notwithstanding the conceptual wealth and suggestive power of these conceptions. Nor is there a consensus on how to define the term "complexity" so as to take into account all of these ideas.

Here we propose a diagnosis of the source of these deficiencies and also some ways to remedy them. A parallel is drawn between the difficulties encountered by quantum physics and those facing the sciences of complexity. They are similarly rooted in implicit assumptions underlying basic concepts of classical physics. We briefly outline the evolution of these presuppositions, some reasons for their success and entrenchment in modern science, and various alterations and generalizations they must undergo to transcend their limitations in wider domains.

We also offer an analysis of different kinds of simplicity and complexity, partly inspired by Peirce's ideas, aimed at integrating and rendering intelligible the new notions arising from the study of complexity.

## Towards a synthesis

This Second International Seminar is one of many meetings that demonstrate a great and growing interest in the research on complexity and its implications. The ideas and problems that concern us here arise within diverse disciplines and their exploration tends to transcend ordinary interdisciplinary barriers. In these times of narrowly specialized and fragmented research, the discoveries brought to light by the investigation of complex systems offer much promise. We hope they will yield the benefits of a new theoretical and methodological integration of the sciences by means of novel explanatory schemes applicable across the board to physical, chemical, biological, economical and social phenomena.

Problems inherent in the nature of interdisciplinary studies may partly explain why we have failed to reach a recognized theoretical synthesis or even a consensus on how to define some of our key terms, starting with "complexity" itself<sup>1</sup>. Nevertheless,

intriguing logical connections have been discovered among some of these notions (e.g., **emergence**, **self-organization**, **autonomy**, **circular causality**, **criticality**, etc.), which point to some clues in the search for a comprehensive synthesis. Ideally, such a synthesis will allow us to trace all of these novelties to a common origin, identifiable by the traits that define the concept of complexity. As a modest contribution to this venture, this paper attempts to reach two goals:

- To identify an important obstacle in the path to the desired integration, and
- To suggest some means to overcome the obstacle's effects.

To attain these goals, we will repeatedly seek support from some ideas and discoveries advanced by the great American thinker Charles Sanders Peirce (1839 – 1914). Peirce was a philosopher, physicist, and mathematician, as well as one of the founding fathers of mathematical logic and contemporary semiotics. Due to complicated and unfortunate events, his work did not receive its merited exposure until very recently<sup>2</sup>. Consequently, an additional goal of this contribution is to make complexity researchers aware of the writings of this philosopher, which offer a rich vein of ideas that are ripe for discovery and application.

### **Simplicity and complexity**

The notions of complexity and simplicity are strictly correlated and it is reasonable to expect that a satisfactory definition of one should lead directly to a concomitant definition of the other. Remarkably, most works in this area tend to directly approach the characteristics of complex systems, taking for granted the correlative notion of simplicity as if it were not in itself problematic. Nevertheless, in attempting to draw a formal explication of simplicity, one is immediately confronted with a difficulty: Simplicity shows a **self-referential** character—a feature associated with logical and mathematical paradoxes, and that has also been encountered in other studies of complex systems.

In contrast with ordinary scientific terms (e.g., “mass,” “genome,” “molecule,” etc.), the concept of simplicity has the peculiarity of being already involved and employed in the cognitive operations we apply to display its meaning. This is

because the role played by this notion in scientific research is by no means confined to its methodological applications—such as those in which Ockham’s razor is brandished in the culling of hypotheses and theories. Scientific research tacitly appeals to considerations of simplicity, in its quest to uncover an underlying unity behind the manifold variety of phenomena. The achievement of this goal is usually interpreted as the **reduction** of a large plurality of data and processes into the interaction of just a few basic elements and relations. The paramount epistemic virtue of these basic elements lies precisely in their self-evident and acknowledged simplicity. It will suffice at this point to observe that both notions, simplicity and complexity, are applied to features of phenomena, as well as to theories devised in order to explain those phenomena.

The fact that the idea of simplicity is involved beforehand in every scientific investigation—in roles that cannot be eliminated—could initially be perceived as an obstacle to every attempt to characterize it in an objective manner, independently of the cognitive operations that are deployed to explicate its import. But this is not so. On the contrary, we will attempt to show that the consideration of this peculiarity may lead to a precise elucidation of the concepts of simplicity and complexity in their mutual interrelation.

### **Different simplicities**

The fact that the idea of simplicity is implicitly at work in the conception and selection of hypotheses suggests that we can find a point of departure for its examination—specifically in its actual employment by scientists throughout the historic evolution of scientific theories. While analyzing the origin of modern science in the works of Galileo and his contemporaries, Charles Peirce detected the application of a new kind of simplicity, which we may call **natural simplicity**. It has attributes that go beyond those of traditional **logical simplicity**, which are here understood as mere economy of components or rules of transformation.

Its application was a decisive factor in the unification of mathematical reasoning and experimental work that laid the foundations for classical mechanics and its future developments. This natural simplicity becomes manifest in a phenomenon that Galileo recurrently designates as *il lume naturale*, the “natural light of reason.” This is a faculty of the mind capable of suggesting the correct hypothesis because of our congenital tendency to guess it, after proper analytical activity eliminates the physical or conceptual impediments that tend to obscure it<sup>3</sup>. This tendency of the mind (which seventeenth-century thinkers were inclined to justify with recourse to theological arguments) finds a strictly naturalistic explanation in Peirce’s evolutionary epistemology. Our cognitive faculties developed as the result of a protracted biological evolution. This leads us to assume that we are equipped with an instinctive propensity to understand and predict, with some degree of success, the consequences of mechanical actions and sequences of movements which are pervasive in our experience and the actions we exert upon the world. From a purely logical point of view, it is always possible to posit an unlimited number of hypotheses compatible with the limited set of observations we are able to perform. Our tendency toward a correct explanation rather than toward an incorrect one is an extra-logical element. This is the element needed to propel in the proper direction the chain of hypotheses and experimental tests that characterize the course of scientific activity.

In this paper we would like to suggest that the application of natural simplicity is not limited to the generation and selection of hypotheses. On the contrary, its main role appears in the process of **idealization**, a *sui generis* variety of **simplification**, whose employment is one of the dominant traits by which modern science distinguishes itself from its precursors in antiquity and medieval times. Under the influence of the atomistic tendencies of the “mechanical philosophy,” natural simplicity dictated which aspects of experience were to be retained and which were to be discarded, in fashioning the idealizations that have since guided the theories of classical physics. These theories are aimed at “reducing” the apparent complexity of the phenomena revealed in our experience, by means of idealized representations of the behavior of physical systems. They are based on the application of simple rules of interaction (i.e.,

laws) upon restricted classes of components (e.g., particles, planets, etc.), which are endowed with properties chosen by virtue of their well-known intelligibility.

The requirements of natural simplicity lead thus to two types of simplification—one concerning the components of a physical system, and the other concerning the rules that constrain their behavior. The components are characterized by a few quantifiable features, represented by their space-time coordinates and, generally, by a minimum of intrinsic properties. For their part the rules must be encoded into simple algorithms, which can compute output quantities (to be corroborated by future measurements) from input quantities obtained by measurements performed on the components,

### **Classical simplicity and iconic intelligibility**

Some essential characteristics of these idealizations, which were adopted to meet the demands of natural simplicity, remained veiled for a long time. They were only clearly disclosed to scientific reflection after a protracted scrutiny, during the early decades of the twentieth century<sup>4</sup>. This long and laborious examination was compelled by sustained, yet failed attempts to reconcile surprising experimental findings about subatomic structures with the theories and concepts of what has since been labeled “classical physics.” As anticipated by Peirce much before these discoveries, “When we come to atoms the presumption in favor of a simple law is very slender...”<sup>5</sup>

At present the philosophers of physics often employ the neologism “classicality” to summarize the traits that define objects of ordinary experience, in contrast to those that characterize quantum entities. With respect to the components of a physical system, the features of classicality include **sharp spatial localization** at every instant, perfect **individual re-identification**, complete **separability**, and the **simultaneous observability** of their diverse properties. Both the components and their interactions enjoy another characteristic feature, their **visualizability**. This can be defined, *grosso modo*, as a property that endows them with **iconic intelligibility**. With this last expression we indicate the result of

faithfully modeling the relational structure of the physical system by means of a one-to-one mapping onto corresponding structures of our innate **pictoric space**. This is the realm in which we congenitally and automatically organize the logical relations interlinking the data of our visual experience. The operations of Boolean logic, for example, are faithfully visualizable in the relations of inclusion and intersection of simple geometric figures (e.g., Venn diagrams).

In a certain sense, the fact that quantum phenomena are not visualizable summarizes many of the characteristics that render them counter-intuitive by their lack of the classicality traits enumerated earlier. The naturalness of natural simplicity appears in this light as a feature of the system of logical relatedness that was “wired in” to the neural connections of our brains and retinas during the course of biological evolution.

### **Lessons from history**

In spite of serious difficulties of interpretation that still plague quantum theories and in the light of the preceding observations, we can extract from the explanatory successes of these theories an important lesson which we may be able to extend to the sciences of complexity. Quantum physics has been able to endow the components of atomic systems with new properties, contrary to those suggested by natural simplicity, by placing their description within abstract spaces specially created in imagination (e.g., Hilbert space and Fock space). These relational structures cannot be mapped one-to-one onto the screen of our pictoric space, except within partial contexts and perspectives constrained by complementarity relations.

The development of this capacity for extending the reach of our experience and of our inferential processes seems to indicate that we are endowed with the power of transcending our congenital capacities for knowledge when they show themselves insufficient for exploring new territories. Furthermore, everything seems to indicate that such extension is a **prerequisite** to opening, for the first

time, those new horizons of experience. The new instruments of modern technology are continuously expanding the reach of our senses (e.g., electron microscopes, infrared telescopes, etc.) and of our action (e.g., nanotechnology tools, particle accelerators, etc.). In a similar way, the use of diagrams, symbolic notations and mathematical devices (computers) expand our abilities for understanding and transforming relational structures that were not foreseen in our biological organization. We would like to explore the possibility that, as in the case of quantum physics, it may be possible to overcome some conceptual difficulties in the study of complex systems through the creation of new cognitive instruments for dealing with novel relational networks.

It is important to observe that the acquisition of notions, which are alien to those suggested by natural simplicity, does not authorize us to discard the classical notions and simply replace them all with the new conceptions. On the contrary, it is necessary to convert them into platforms for departing and returning in our excursions, when we venture beyond the limited realm of phenomena that are made directly accessible through the exercise of natural simplicity. As Bohr repeatedly remarked, it is impossible to make do without the concepts of ordinary language and the idealizations of classical physics. These notions are the only available route to the quantum realm because only through their application are we able to describe and communicate the experimental procedures and their results. Furthermore, these results represent the sum total of the evidence on which we postulate the reality of quantum phenomena.

A new kind of simplicity, which we may call **compositional**, characterizes the quantum entities in their role as components of ordinary objects. With respect to this role the properties of macroscopic objects appear in turn as **emergent properties**, arising out of the **complexity** of interactions between quantum entities, in processes such as decoherence, which are induced by quantum coupling and entanglement with the environment.

As in the case of quantum processes, it seems interesting to speculate on the possibility that complexity phenomena offer a similar resistance to being understood because they realize new types of relatedness that were not incorporated into the idealizations of classical physics. Our task may then require the invention of new idealizations. If history repeats itself, once we discover these new forms of simplicity we will find it necessary to retain the classical idealizations and to combine them with the new ones.

### **Complexity and relatedness**

It is pertinent to recall that classical idealizations were created under the auspices of an atomistic philosophy based on a nominalist and dualistic metaphysics. Under its influence the representation of physical bodies was sought in terms of aggregates of ultimate components with a minimum of internal structure and whose behavior was reducible to mere changes in spatial relations. As a consequence, the ultimate components enjoy both natural and compositional simplicity.

A related feature of this philosophical orientation was the prohibition of appealing to final causes in the explanation of phenomena. Specifically, it had a preference for explanations based exclusively on a form of efficient causality which is built-in to its central explanatory scheme. This scheme is based on distinguishing between contingent data (initial conditions) and necessary rules (laws of nature). With anachronistic hindsight we can now consider this scheme as an anticipation of the workings of digital computation, where initial conditions play the role of input and the laws of nature are represented by the programmed algorithm. The taboo against final causes exerts its influence to the present date. This is despite the work of such early thinkers as Euler and Leibniz, who already saw that efficient and final causes are somewhat complementary, and the fact that final causes find rigorous application in the variational principles of classical and quantum mechanics<sup>6</sup>.

The unprecedented success of classical physics, both in its explanatory power and in its technological applications, can be partially explained by the unusual historical situation that directed its efforts from the onset toward the study of mechanical phenomena, both terrestrial and planetary, which are so immediately intelligible in the light of classical idealizations.

All this leads us to consider the possibility of finding new kinds of idealizations, which may reduce the processes that characterize complex systems to new forms of simplicity. If that should be the case, they may turn out to be quite different from those that were created to understand mechanical phenomena. In complexity research we deal with processes that find their most familiar instantiation in the behavior of living organisms. The structures we naturally regard as components of these systems (e.g., cells, organelles, macromolecules, etc.) display attributes that contrast greatly with the passivity and lack of internal relations characteristic of ideal mechanical components. They behave as agents endowed with internal degrees of freedom, self-propelled through their own reserves of energy, and capable of deploying a variety of different behaviors in answer to changes brought about by their environment or other similar agents. The study of processes generated by the interactions of these components spontaneously leads us to explanations that invoke **functional relations and final causes**, in order to do justice to the kind of relatedness embodied in their interactions.

### **Complexity and hierarchical organization**

It is commonly observed in complexity studies that the natural world seems organized in a hierarchy of levels of increasing complexity. Following Peirce and other thinkers, we may envision this organization as reflecting the history of cosmic evolution—from the creation of the elemental particles, through the biological evolution of organisms and ecosystems, to the recent emergence of human societies and languages.<sup>7</sup>

Some of the characteristics by which we recognize organisms as complex systems (emergence, self-organization, etc.) are already present at the mesoscopic scale, which lies between the level of atoms and that of macroscopic objects<sup>8</sup>. These features are displayed in phenomena such as ferromagnetism, superconductivity, and superfluidity. As is well known, the explanation of these processes involves ideas related to phase transitions and symmetry breaks, which allow the derivation of rules capable of explaining the behavior of the system **without recourse to the details of its composition**.

In classical physics the laws of phenomenological thermodynamics are similar to these rules. They arise out of processes of stochastic averaging, which effectively erase the details of the individual behavior of the system's particles. Peirce recognized this kind of process as the origin of a **new kind of simplicity** in his reflections on the structure of protoplasm, some 100 years ago:

“...it is the law of high numbers that extreme complication with a great multitude of independent similars results in a new simplicity.”<sup>9</sup>

These considerations lead us to hypothesize the emergence of new types of simplicity, in accordance with the ascending levels of hierarchical organization. In the same manner we are led to expect the existence of new and correlative types of complexity.

Our preceding reflections may be summarized in the following points.

- Complexity and simplicity are logically and epistemically correlated.
- They have the peculiar property of applying both to phenomena and to our theories about those phenomena.
- There are different kinds of simplicity and complexity, including logical, compositional and natural varieties.
- Natural simplicity plays an essential role in the processes of idealization and modeling that characterize modern science.
- New types of idealization may be needed to deal with complex systems, where new kinds of components and forms of relatedness seem to demand the introduction of functional and final causality.

### **Peircean relatedness and complexity**

In the preceding paragraphs we had occasion to refer more than once to some Peircean ideas, which seem extremely relevant to our subject and have the peculiarity of anticipating some of our new conceptions. Several other similar

such references can be found in his writings. We think that the main point regarding these ideas is the fact that they are part of a great and tragically unfinished philosophical synthesis, from which they issue systematically through logical and conceptual analyses.

This is not the place to sketch, even superficially, Peirce's vast system of thought. Instead, I would like to conclude these reflections by briefly stating one of Peirce's central principles in the expectation that it may be of great programmatic interest for those of us who may consider applying his ideas to complexity studies.

There are two prominent conceptions that bestow unity to the various branches of Peirce's system of ideas. One is the concept of mathematical continuity and the other his distinction of three universal categories. These categories discriminate three basic components in all forms of reality and its representation by thought. The first one is an element of original simplicity, characterized by its entire lack of relatedness. The second one represents dyadic relatedness and the third one triadic relatedness. The three are always co-present in all phenomena, although in different degrees, and are **mutually irreducible**. Genuine triadic relations, in particular, are **totally irreducible to any dyadic combination of dyadic relations**.<sup>10</sup>

On the other hand, all systems of relations, no matter how complex, are always reducible to combinations of dyadic and triadic relations. Dyadic relations are prominent in mechanical interactions and correlation. Triadic relations are especially manifest in actions that generate meaning (i.e. in semiotic operations). Peirce seems to be the first thinker to have clearly realized that semiotic operations are not confined to the signs of human languages. And now contemporary biology is beginning to study them in the workings of the organic codes (e.g., genetic code, sugar code, etc.) and in intercellular and intracellular signaling<sup>11</sup>.

## In Conclusion

Peirce's extensive writings, many of which remain unpublished, contain innumerable suggestions which, from a contemporary perspective, lead us to consider the various kinds of complexity that may be generated by interlinking the elements of a system through combinations of dyadic and irreducibly triadic relations. They also lead us to search for how the different effects of dyadic and triadic interactions may affect the scope and powers of digital and analog computation, and of efficient and final causality<sup>12</sup>. This is a project that we are just beginning to envision. We sincerely hope that this brief communication may have succeeded in showing some of the attractions of this approach and in extending an invitation to future participants in its development.

## Notes

<sup>1</sup> A very good summary of the present status of these issues in biological systems, from a philosophical point of view, may be found in Vand de Vijver *et al.* (2003). On how to define and measure complexity see also Standish (2001) and references therein. The point of view of algorithmic information theory as reflected in the work of Wolfram and Chaitin was recently summarized in Chaitin (2003).

<sup>2</sup> The Arisbe web page, URL = <http://members.door.net/arisbe/>, offers a wealth of information on Peirce, writings by and on him, and links to other Peirce study centers; an article found there, "The singular experience of the Peirce biographer" by Joseph Brent, tells the sad and shameful story of the neglect and suppression of Peirce's papers.

<sup>3</sup> See McMullin (1983) and Nowak (1995).

<sup>4</sup> This story is the subject of a voluminous bibliography. A good introduction is Darrigol (1992).

<sup>5</sup> Paragraph 6:11, vol. 6 of Hartshorne (1931– 1935 ;1958). For Peirce's anticipations of some quantum conceptions see my paper Fernández (1989).

<sup>6</sup> On Leibniz and the variational principles see the recent work of Gale (2002).

<sup>7</sup> This view was popular at the beginning of the 20<sup>th</sup> century (Peirce, Bergson, Alexander, and others) but it declined until very recently under the ideological influence of neo-Darwinism. It has lately undergone a revival under the combined impact of new ideas in complexity theories, developmental and ecological biology, biosemiotics, etc. See Salthe (1999) and other contributions to the same volume.

<sup>8</sup> A guide for the exploration of new organizing principles at work at a scale intermediate between atomic and macroscopic levels is given in Laughin (2000).

<sup>9</sup> Paragraph CP1:351 in vol. 1 of Hartshorne (1931– 1935 ;1958).

<sup>10</sup> On Peirce's irreducibility thesis see Burch (1991) and his contributions to Hauser (1997).

<sup>11</sup> In Barbieri's thesis of the ribotype the emergence of new kinds of organic codes marks the major transitions in evolution. Cells are triadic structures combining genotype, phenotype, and ribotype. See a very readable presentation of his findings and theories in Barbieri (2003).

<sup>12</sup> The work of Hava Siegelmann and her collaborators shows that analog computation in neural nets can in principle transcend the limitations of digital computers. See Siegelmann (1999).

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<sup>1</sup> A very good summary of the present status of these issues in biological systems, from a philosophical point of view, may be found in Vand de Vijver *et al.* (2003). On how to define and measure complexity see also Standish (2001) and references therein. The point of view of algorithmic information theory as reflected in the work of Wolfram and Chaitin was recently summarized in Chaitin (2003).

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<sup>5</sup> Collected Papers 6:11. For Peirce's anticipations of some quantum conceptions see my paper Fernandez (1989)

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<sup>8</sup> A guide for the exploration of new organizing principles at work at a scale intermediate between atomic and macroscopic levels is given in Laughlin *et al.* (2000). Laughlin, R.B., Pines, D., Schmalian, J. Stojković, and Wolynes, P.

<sup>9</sup> Collected Papers CP1:351

<sup>10</sup> On Peirce's irreducibility thesis see Burch (1991) and his contributions to Hauser (1997).

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