systems

Review

Universal Complexity Science and Theory of Everything: Challenges and Prospects

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Abstract: This article argues that complexity scientists have been searching for a universal complexity in the form of a "theory of everything" since some important theoretical breakthroughs such as Bertalanffy's general systems theory, Wiener's cybernetics, chaos theory, synergetics, self-organization, self-organized criticality and complex adaptive systems, which brought the study of complex systems into mainstream science. In this respect, much attention has been paid to the importance of a "reductionist complexity science" or a "reductionist theory of everything". Alternatively, many scholars strongly argue for a holistic or emergentist "theory of everything". The unifying characteristic of both attempts to account for complexity is an insistence on one robust explanatory framework to describe almost all natural and socio-technical phenomena. Nevertheless, researchers need to understand the conceptual historical background of "complexity science" in order to understand these longstanding efforts to develop a single all-inclusive theory. In this theoretical overview, I address this underappreciated problem and argue that both accounts of the "theory of everything" seem problematic, as they do not seem to be able to capture the whole of reality. This realization could mean that the idea of a single omnipotent theory falls flat. However, the prospects for a "holistic theory of everything" are much better than a "reductionist theory of everything". Nonetheless, various forms of contemporary systems thinking and conceptual tools could make the path to the "theory of everything" much more accessible. These new advances in thinking about complexity, such as "Bohr's complementarity", Morin's Complex thinking, and Cabrera's DSRP theory, might allow the theorists to abandon the EITHER/OR logical operators and start thinking about BOTH/AND operators to seek reconciliation between reductionism and holism, which might lead them to a new "theory of everything".

Keywords: reductionism; holism; emergence; theory of everything; complexity science; systems theory; cybernetics

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1. Introduction

The search for a single, all-encompassing systems theory goes back at least as far as the first half of the 20th century (e.g., Bertalanffy's General Systems Theory (GST), Wiener's cybernetics) (see [1–8]). Later theories dealing with complex systems, such as chaos theory [6], synergetics [9–11], self-organization [12,13], self-organized criticality [14], and complex adaptive systems [15,16], also followed this monistic way of thinking. Admittedly, much of the relevant work on complexity follows the ethos of rejecting the Newtonian paradigm built on Cartesian reductionism and turning to holism [17–19]. In this regard, some authors sought to end "reductionist complexity science" (RCS) and, with it, perhaps, efforts to create a "reductionist theory of everything" [20,21]. Despite this severe setback for RCS, many reductionist-oriented scientists have not lost faith in a universal theory for all complex systems.

On the other hand, holism and the theory of emergence have been integral to systems theory and "complexity science", at least since von Bertalanffy's GST. However, some authors hold that emergence has made it possible to extend the narrow scope of systems theory beyond the natural sciences to the field of social and socio-technical sciences [8,22–26].

This paper generally defends the view that the founders and advocates of the significant theories of complex systems uninterruptedly insisted on a single "theory of everything". This search in itself entails reductionism–monism, a doctrine(s) that reflects the logical empiricism's search for linguistic or nomological unity through a "theory of everything" [27,28]. Reductionism generally states, "One can explain some object by reducing it to a different, usually simpler object or a thing" [29] (p. 5). According to the reductionists, therefore, all specific theories dealing with various complex systems should be replaced by a set of powerful algebraic expressions or a few computer models that predict the whole system's behavior based on the behavior of the components that lie at a lower level.

The problem is that these reductionist attempts fail to recognize the emergence-related hierarchies often observed in complex systems. But even those who accept ontological holism and emergence in natural and social realities believe that the theory of emergence can somewhat explain the gap between the micro and macro worlds. Yet even in their efforts to explain all kinds of world phenomena, there is a trace of the reductionist–monistic notion of a single theory or explanatory framework that unites most, if not all, sciences. Paradoxical as it may sound, this holistic-oriented theory is also reductionist–monist to a certain extent, as it is consistent with the belief that there is a single overarching theory that can replace other, more specific theories of particular sciences such as biology, psychology, economics, etc. However, it seems that the theory of emergence cannot explain the transition from the micro-world of physics to the macroscopic phenomena of the higher sciences, at least not for now. Therefore, it cannot be straightforwardly appreciated as a "theory of everything". At least, that is what I suggest in this paper. However, based on current empirical and philosophical knowledge, the "holistic theory of everything" has much more potential to take precedence in the search for a theory of everything than the reductionist theory.

The thesis of two theories of "everything" in "complexity science" and their same reductionist–monistic denominator is not new. However, I offer a fresh argumentation for it. Unfortunately, the discussion of the conceptual framework underlying systems or complexity-related "theory of everything" is somehow ignored and not discussed as it should be. It is noteworthy that this paper does not discuss other field-related attempts to establish a "theory of everything", such as the one advocated by Steven Hawking [30] in physics or psychology, such as the semantic general theory of everything discussed by Samsonovich et al. [31] or the algorithmic "theory of everything" in computer science discussed by Schmidhuber [32].

This article is structured as follows. First, Section 2 briefly overviews GST and cybernetics as precursor theories of contemporary "complexity science". It also discusses the holistic and reductionist threads that run through these theories. Section 3 briefly discusses chaos theory, synergetics, self-organization, and complex adaptive systems. Section 4 then sets out the convergence between systems theory, cybernetics, and complexity and shows how this convergence supports the notion of "complexity science", which promotes either reductionist or holist "theory of everything". Then, Section 5 examines the viability of the reductionist "theory of everything" in the era of holism and emergence and the limitations of the holist "theory of everything". A critical analysis of the arguments in these sections will ultimately help us recognize the perils and promises of the "theory of everything" inspired by complexity and, in the concluding section, point out possible new paths toward it.

2. The Doctrinal Aspects of General Systems Theory, Cybernetics, and Chaos Theory

Many authors, inspired by the results of a paper by Naomi Oreskes and colleagues (1994), perhaps consider reductionism and RCS dead or at least banished from current research practice. Of course, this assumption could be valid because it is becoming increasingly clear that reductionism fails when confronted with emergent phenomena in complex systems [18,33–35]. However, as I will discuss, reductionism in some forms was never excluded from systems and complexity research efforts to create a "theory of everything". In this context, the hypothesis I wish to discuss, and test here is that the long-stated scientific goal has been, and continues to be, to provide a general framework for a unified or integrative explanation of various complex systems (e.g., natural, social, or engineering systems). In other words, I am sympathetic to the idea that efforts to develop a complexity-inspired "theory of everything" based on either reductionism or holism have survived to this day. Does the history of systems and complexity theory support this contention?

First, GST, which is one of the direct roots of these theories [36], was developed initially in biology by the Austrian biologist Karl Ludwig von Bertalanffy, who emphasized the central importance of "systems" to biology and other sciences [1–3,37,38]. However, it is debatable whether he is the only one responsible for the origin of systems theory. As Gunter [8] suggests, some authors cite the biologist Paul Weiss and his dissertation published in 1912 and even R. I. Williams as significant figures in the development of systems theory. However, von Bertalanffy made the most important conceptual and mathematical contributions to the further development of systems theory or what he called "systems science".

Von Bertalanffy [3] recognized the disadvantages and limitations of the mechano-reductionist approach and the advantages of holism in investigating the incredible complexity of the living world. This doctrinal shift helped establish the paradigm of biological systems as "ultimate realizations of complex systems" [39] and "probably the most complex entities to study in their natural environment" with multiple chains of interacting causalities [40] (p. 546). Von Bertalanffy also sharply criticized the unscientific character of 19th- and 20th-century neovitalism advocated by Driesch, Bergson, and others [3]. Instead, he proposed holism as a promising scientific alternative to vitalism [41]. He vividly maintained that life appeared to contradict the fundamental law of thermodynamics because living organisms, as open, dynamic systems of matter in a steady state and not in equilibrium as their change over time, can absorb and release material and energy from and to the environment to maintain their particular organization [2,41] (p. 248).

Nevertheless, acquiring the biological organization, in principle, cannot contradict the fundamental laws of physics. As von Bertalanffy stated in his book The Problems of Life [37], systems science is not about contradicting the laws of physics but about using them to analyze individual parts and processes in living things on the basis of which we can understand the relationship between the individual components that produce the organism as a whole [41]. He [3] (p. 409) even praised Descartes' comparison between man-made machines and life (Descrates' bete machine and the homme machine of Lamettrie) and Darwin's idea of natural selection as a crucial mechano-reductionist contribution to the understanding of order and organization in the biological domain. Clearly, GST or systems science owes much to centuries-old Cartesian reductionism, which modern complexity theorists are unfortunately quick to reject. Paradoxically, one might rhetorically ask if we would even understand the meaning of holism if it were not for such mechanistic attempts to understand life. However, what is holism in the context of systems theory?

Historically, "holism" can be traced back to the ancient Greeks and Aristotle's principle that "the whole is greater than the sum of its parts", which refers to the unity of the whole or "wholeness", but the South African Jan Smuts coined this term in 1926 [42]. It can be viewed from at least three philosophical perspectives: epistemological; methodological; and ontological. Epistemological or confirmation holism (Duhem–Quine thesis) is the view that a single model, theory, or hypothesis cannot be tested in isolation [43]. For example, it is essential for understanding the explanatory value of complex and global climate simulation models [44]. On the other hand, methodological holism, which goes hand in hand with epistemological holism, underscores that "Systems have to be studied by considering the things that are their parts in the context of the whole" [45] (p. 110). This is an appropriate heuristic approach to studying other non-complex systems as well. It is worth noticing that methodological and epistemological holism coincide in many aspects. For example, in social sciences, methodological individualists and methodological holists debate whether individualist explanations can do holist explanations' explanatory job [46]. In other words, the disagreement is whether individual actions can account for the explanation of social phenomena or whether we need explanations of the social whole and their actions.

On the other hand, ontological holism runs profoundly through the heart of complexity and its predecessor theories, such as GST. It states [45] (p. 110), "Holistic systems are such that their constituent parts have some of the properties that are characteristic of these things only if they are organized in such a way that they constitute a whole of the kind in question". Nevertheless, many ideas and concepts that have emerged over the centuries have contributed to the development of systems science, "In a sense, one can say that the term "system" is as old as European philosophy" [3] (p. 407).

Although von Bertalanffy openly advocated holism, I believe he was a reductionist–monist in terms of his ideas about the transformative and revolutionary impact of GST on the advancement of science. In his numerous texts and books, he argued that GST had already proved its superiority over other scientific theories by enabling the scientific and mathematical formalization of many on-first-sight unscientific concepts such as whole, wholeness mechanization, centralization, hierarchical order, stable and stationary states, equifinality, and shows their applicability to various systems [1–3]. Although he did not directly engage with logical positivism or other perspectives on science, to my knowledge, he pretty much agreed with the positivists' search for a "theory of everything", albeit under the conditions imposed by his theory. Positivists often regarded physics as a fundamental science that should be admired and aspired to by all other sciences. In von Bertalanffy's view, GST, which builds on physics, is a "new science" that explains the living, non-living, social, and technical realms and man's place in the universe. In an early formulation of GST, expressed orally in the 1930s and later printed in 1947 and reprinted in 1955, 1968, and 1972, von Bertalanffy writes [3] (p. 411),

"There exist models, principles, and laws that apply to generalized systems or their subclasses irrespective of their particular kind, the nature of the component elements, and the relations or "forces" between them. We postulated a new discipline called General Systems Theory. General Systems Theory is a logico-mathematical field whose task is the formulation and derivation of those general principles that are applicable to "systems" in general".

It seems that he envisioned GST as a "theory of everything", which he called systems science. Systems science is the "Scientific exploration and theory of "systems" in various sciences (e.g., physics, biology, psychology, and social sciences) [3] (p. 414). Not only did he hold that interdisciplinary GST aimed to explain complex phenomena in nature and society, but in his 1972 paper [3], he openly discussed the possibility of establishing a systems technology, a systems philosophy, and a systems ontology. Thus, by proposing a new philosophical paradigm based on the "systems" concept and a "model of certain general aspects of reality", GST aims to provide a transdisciplinary synthesis of knowledge. Here, it becomes clear that von Bertalanffy, instead of physics, demands GST as a unifying force that would replace the role of physics as a fundamental and paramount science. Obviously, GST would become a sort of "new philosophy" anticipating the further progress of civilization.

All these suggest that von Bertalanffy was a kind of reductionist or monist who paved the way for the "theory of everything" and a figure who simultaneously wholeheartedly accepted the matters of holism in his long life's work. This shared vision and mission of systems-complexity-oriented "theory of everything" was later reiterated and emphasized by Richardson and Cilliers [21] (p. 6) when they said that RCS aspired to take over the role of the physical sciences by attempting to reduce and explain all of reality through "A handful of powerful, all-encompassing algebraic expressions". Unfortunately, instead of interdisciplinarity and transdisciplinarity, GST took the path of specialization [47].

However, von Bertalanffy is not the only one among the great names of science to advocate a single theory capable of explaining diverse and complex natural and social phenomena. Inspired by messaging in the technical field, mathematician and philosopher Norbert Wiener, America's second Leibniz, invented the inter-scientific discipline of cybernetics that studies the theory of communication and control in the animal and the machine [4,5,48]. He writes on this general scope of cybernetics, which will later be called first-order cybernetics [5] (p. 267):

"As a means of controlling machinery and society, the development of computing machines and other such automata, certain reflections upon psychology and the nervous system, and a tentative new theory of scientific method".

First-order cybernetics, which deals with the complex entity (innate complexity) (see [49]), was systematically introduced into many sciences, including biology (biocybernetics), thanks to Norbert Wiener [4], Ross Ashby [50,51], Hans Drischel [52] and some philosophical reflection on it [53]. Later, in the 1960s, Heinz von Foerster [54] proposed second-order cybernetics, which focused on cognitive complexity (the term used by Fereidunian et al. [49]) and emphasized the cognitive limits of the observer when observing complex or simple systems [55].

3. The Progress in the Systems Theories from the Mid-20th Century Onward

In the second half of the 20th century, chaos theory, synergetics, self-organized criticality, and complex adaptive systems further carved the landscape of today's systems theory and "complexity science". These theories furthermore expanded the classic range of systems and cybernetic thinking. Nonetheless, they cemented the search for a "theory of everything" to erase the boundaries between the various sciences and explain processes and structures as diverse as cells and the stock market. I will briefly outline these theories in order to understand the seeds of the "theory of everything" that lie within them.

The chaos theory, which, in addition to quantum theory, challenges determinism, emerged relatively later than GST and cybernetics [7]. Although its roots can be traced back to Henri Poincaré [56] and Andreï Nicolaïevitch Kolmogorov [57], Edward Lorenz [6] is considered the official father of chaos theory [58]. Lorenz discovered and described the chaotic behavior of a non-linear system and attractors. Worth noticing here is that the term "chaos theory" was later coined by mathematician James A. Yorke in 1975—chaos theory itself underwent a significant change after the introduction of the concept of "fractal analysis" by Benoît Mandelbrot proposed in 1973 [58]. The invention and mathematical formulation of strange attractors by the Belgian physicist David Ruelle, which states that trajectories in phase space never intersect but form cycles that are not exactly concentric, also contributed to the rapid development of chaos theory in the last quarter of the 20th century [58] (pp. 283–290).

From the 1980s onwards, chaos theory, in its various formulations, particularly fractal analysis, permeated many specific research areas, including geology, climatology, and neuroscience [59–63]. The attractors and equations of fractal analysis are capable mathematical formulations that explain chaotic and non-chaotic behavior in natural and socio-technical systems. A simple process can become complex because of repeating in time "https://fractalfoundation.org/resources/what-are-fractals/ (accessed on 20 November 2023)". In principle, the behavior of complex systems constituting components might be known (predictable or deterministic) or unknown (unpredictable or stochastic) [49]. This observation holds for creating macroscopic complexity, but biological systems require antichaos; as Lansing [64] pointed out, both self-organization and complex adaptive systems are, in some sense, reactionary to chaos theory since both focus on antichaotic behavior and nontrivial interactions between lower-level constituents that produce system as a whole. In this considerable effort by chaos theorists to explain, model, and predict various phenomena in nature, society, technology, and economy, one can recognize an apparent reductionist–monistic aspiration for the "theory of everything".

As an interdisciplinary field of research, synergetics attempts to decipher general principles that regulate the self-organized formation of macroscopic structures through cooperation between individual parts of a system. It was founded in 1969 by Herman Haken [9–11]. Basically, synergetics assumes that every complex system is a multi-agent system with synergetic effects that can lead to chaotic and disorderly behavior or to orderly and predictable behavior. Synergetics can facilitate the transition from chaotic to orderly, antichaotic behavior to understand the inner workings of life and its evolution. Indeed, a wide range of biological phenomena, such as morphogenesis, qualitative macroscopic changes in animal and human behavior, population dynamics, evolution, neural networks, and electroencephalographic (EEG) signals, can be successfully studied by synergetics [10]. Recent neuroscience research further supports synergism and synergetics' relevance in explaining complex systems' spatio-temporal dynamical behavior. For instance, Varley et al. [65] recently reported that highly synergistic subsystems widely distributed in the human brain might play an integrative role in the brain's functioning.

Furthermore, it seems that scientists and philosophers consider the concept of "complexity" as particularly relevant in relation to "self-organization", "emergence", and "nonlinearity", all of which are typical features of complex systems [66]. While nonlinearity, which is essential to chaos theory, states that minor influences on the system can significantly change the state of the system on a large spatial scale [67,68], self-organization refers to an evolutionary process in which new, complex structures occur primarily within and by the system itself [69]. In other words, scientists recognize that self-organized systems exchange matter, energy, and information with their environment but achieve their organization without environmental instructions thanks to many components whose non-trivial interactions produce structural and dynamical order [12,70,71]. In terms of emergence, self-organization refers to the results of the collective interactions of the constituent components that produce ordered emergent behavior, such as the spontaneous formation of patterns, nonlinear coupling of reactions, bistable switches, waves, and oscillations in time and space of a given system—and it may well be true that it is a fundament of cell biology [71].

Self-organization entered the scientific arena within first-order cybernetics in the 1940s–1950s and was later extended to physics, biology, and neuroscience [50,54,72]. Additionally, it can be defined by the notions of system autonomy. Whether as a stand-alone theory explaining complex patterns in the world (see below self-organizing criticality) or as part of other theories, such as the autopoiesis theory of Varela and Maturana, self-organization points to the autonomous systems that are "Organizationally closed, so that the network of processes is recursively interdependent in the generation and realization of the processes themselves" [72], (p. 2), [73] This closure in production and space, the two premises of autopoiesis, seriously challenges reductionist efforts to explain the higher organization of matter in biological systems solely in terms of component interactions with lower levels. Why?

Both self-organization and autopoiesis hold that the organization and production of these lower-level components depend on the system's higher levels. This general observation implies that the phenomena of the lower level cannot be explained without taking into account the phenomena of the higher level(s) because higher levels help produce and maintain lower-level components. This understanding is a joker card for antireductionism and holism in biology. In other words, two-way causality (reciprocal causality) or interactions between "top–down" and "bottom–up" causalities plays a central role in explaining the inner workings of complex biological systems [35,74,75]. Some, like Pete A.Y. Gunter [8], Fritjof Capra, and Pier Luigi Luisi [76], claim that systems theories should be reframed to include autopoiesis because it has been now extended beyond the boundaries of biology and delve deep into social sciences. A particular extension of autopoiesis had already occurred when it was applied to computer science and the study of artificial life [77].

Furthermore, Wendy Brandts in 1997 [39] also referred to Horgan [78] and Bak et al.'s self-organized criticality [14] to suggest that research on complex systems is fueling enthusiasm for a unified theory of complexity from nature to society [21]. Self-organized criticality is a particular computational model introduced by Pearl Bak in 1987. This mathematically excellent attempt to formulate self-organization considers an attractor that arises by moving far from equilibrium to create a footprint of the complexity of 1/f noise and fractal structures that are prevalent in nature [14,79]. The central claim of self-organized criticality is that all observed natural dynamic objects can reach a self-organized critical point, which is necessary to generate complex (self-similar) fractal-like structures in space and time if the condition of spatial degrees of freedom is met [14]. However, SOC has some limitations. The most recognizable is that it only recognizes two-time activity scales and interactivity across local spatial connectivities or captures only a single fractal or "monofractal" pattern [79]. In contrast, general cascade computational models inspired by Alan Turing's cascading instability, among others, can explain the perceptive-action system's multifractal nonlinear behavior (multifractal nonlinearity) [79]. For these reasons, self-organized criticality should be considered outdated, superseded, or perhaps updated by other theories, including complex adaptive systems (CAS) theory, which has gained traction in the social and natural sciences.

CAS is one of the most recent, but not the last, of the theories that have developed on the wings of GST, cybernetics, and chaos theory. CAS, a subgroup of nonlinear dynamical systems, assumes that a large number of interacting adaptive agents perform a simple task individually but that their mutual interactions result in complex collective behavior in natural or socio-technical systems [15,16,80–82]. These nonlinear dynamical systems share commonalities and general principles, even if they appear very different to observers [64,83]. Holland [16] (pp. 1–2) enlisted four major features of complex systems applicable to research areas as diverse as encouraging innovation in dynamic economies, providing for sustainable human growth, predicting changes in global trade, preserving ecosystems, controlling the internet, strengthening the immune system, etc. The first is parallelism, which suggests that many agents interact simultaneously by sending and receiving simultaneous signals (protein-related positive and negative feedback cascades in cells). The second feature is the principle of conditional action, which states that the agent's actions usually depend on the signals they receive. The third feature of modularity suggests that group rules can be combined as "subroutines" to deal with each new situation. For example, eight proteins forming a loop are essential for the citric acid cycle (Krebs), a fundamental component of all aerobic organisms, from bacteria to elephants. The final feature is adaptation and evolution, which illustrates that the players in a CAS change over time regarding adaptations that improve the system's performance.

These later theories of complex systems seemingly shared the same undivided vision of Bertalanffy and Wiener's universal "theory of everything" that can successfully deal with many natural and socio-technical macroscopic phenomena. They contributed significantly to strengthening the reductionist and monistic stream within complexity research without, however, abandoning the idea of holism. For this reason, Gunter's [8] list of shared assumptions of all systems theories, which are emergence, holism, hierarchical organization, and "bottom–up" and "top–down" causality, should be updated to include a reductionist–monistic search for all-inclusive systems theory or universal "complexity science". It is worth noting that, unlike GST, these later theories could better deal with all kinds of complex and non-linear phenomena in nature, society, and technology, bringing them much closer to today's understanding of "complexity science". This conclusion is in line with the conclusions of Gunter [8], Turner, and Baker [26] about the failure of Bertalanffy's theory to deal with complexity and nonlinearity and especially Turner's and Baker's arguments about why we should distinguish complexity theory or "complexity science" from systems theory. However, this in no way diminishes the historical importance of GST for developing holistically-based systems thinking, which inspired further scientific advancements.

The search for one all-powerful theory for complex systems has never ceased and continues to permeate research practice and meta-scientific reflection on it today. Even if this is not clearly emphasized in some of the new mathematical and computational formulations of the new generation of systems theory, the beliefs and actions of many scientists support this claim. For example, Ochoa [84] points out that different systems can be modeled based on the exact mathematical framework that current systems science provides. Similarly, Hipólito et al. [85] (p. 7) define complexity science as "Composed of an array of different techniques, which together aim to capture the unifying common features of the behavior of multi-system interactions".

Also, in a recent topical article by Wong et al. [86] (p. 1), which is already resonating beyond the scientific community, the authors propose a unifying evolutionary framework for the development of living and nonliving complex systems based on three remarkable features: (1) the existence of many components that can adopt a large number of different configurations; (2) the existence of processes that can drive these different configurations; and (3) the selection process that can choose these different configurations based on their function. According to these authors, the "law of increasing functional information" suggests that "universal concepts of selection—static persistence, dynamic persistence, and novelty generation—drive systems to evolve through the exchange of information between the environment and the system". These recent attempts to formulate unifying "laws" that drive complexity in the universe are pretty much in line with what early systems and complexity theorists were trying to achieve.

We should look at the following example as further proof that the reductionist "theory of everything" inspired by systems and complexity theory is taken seriously across sciences, including physics. Lukyanenko et al. [38] (p. 5) nicely illustrated this point:

"Stephen Hawking treats "system" as a fundamental constituent of reality... Hence, both in Feynman's formulation, as well as in the rendition by Hawking and Mlodinow, everything in the universe, from elementary particles to the entire universe, is a system, and furthermore, it is the objective of modern physics to predict the properties of these systems".

Furthermore, a fresh article by Poudel et al. [87] published as part of the theme issue "Thermodynamics 2.0: Bridging the natural and social sciences" in Philosophical Transactions A uses an area of physics called thermodynamics, a universal and unifying science, to bridge the sciences of matter (natural science) and of life (social science). In the same thematic issue, Swenson [88] has argued that the fourth law of thermodynamics (the law of maximum entropy production), alongside the first law of time-translation symmetry and the self-referencing circularity of the relational ontology of autocatakinetic systems, are the critical ingredients for a grand unified theory unifying physics, life, information, and cognition (mind). These more recent efforts to explain the complex world in terms of the fundamental laws of physics are an offshoot of the long-standing positivist reductionist tradition that saw physics as the only fundamental science that should replace the other sciences. They also support the assertion that the positivist way of thinking in science is still very much present in today's postmodern age. Whether it is complexity research or physics research in question, all of these reductionist-tinged accounts follow and rely on the offerings of reductionism and monism to legitimize the quest for the "theory of everything".

4. On the Convergence between Systems Theory, Cybernetics, and Complexity

What is complexity? What is "complexity science"? How does "complexity science" relate to systems theory and cybernetics? More importantly, why should we waste our time asking these questions? At least I have a prompt answer to the last question, "The natural world can be generalized to a complex system, and a "science of complexity" would provide us with the knowledge to control just about everything" [21] (p. 10). To be able to provide at least partial answers to these other questions, we should first discuss the relationship between GST, later theories of complex systems, and cybernetics.

From the 1950s on, there was a tendency to merge von Bertalanffy's GST and Wiener's cybernetics [89]. However, as Heylighen and Joslyn [89] (p. 156) aptly put it, "GST studies systems at all levels of generality, whereas cybernetics focuses more specifically on goal-directed, functional systems that have some form of control relationship". Cybernetics also have a specific relationship with the postmodern understanding of knowledge's contextual and subjective nature. In this context, second-order cybernetics, which takes the strict view that knowledge about complex systems must include the relevant role of an observer who observes the system as such, showed that knowledge is intrinsically subjective [7,54,90–95].

This realization further suggests that the scientific knowledge of "mind-independent" complexity does not directly represent an external or "mind-independent" reality; the subject who perceives complexity actively interprets and adds to its true meaning. In this Kantian-inspired epistemology, our scientific descriptions of the complex world, obtained through various methods, measures, explanations, and representations, should be viewed as "world versions", even if the "world itself" exists independently of our existence.

On the other hand, first-order cybernetics focuses on universal phenomena of control and communication, learning and adaptation, self-organization, and evolution [95–97]. The rough classification of cybernetics into first-order and second-order cybernetics would look like this. Today, however, at the latest, this subdivision is perhaps artificial, as researchers are increasingly pushing for the unification of objective and subjective components in treating complex systems. For example, physicists increasingly use entropy to approach the interplay of subjective and objective components in studying complexity. In this regard, Fagerholm et al. [98] argue that entropy is a property of both a system and an observer, as it can measure hidden information in a system that arises due to the constraints of an observer.

What are the differences between systems theory and broader complexity theory, sometimes called "complexity science"? There is no straightforward answer to this question. However, there are some valuable pushes in this direction. For example, Turner and Baker argue that systems theory, as conceptualized by Bertalanffy, does not account for the nonlinear dynamics of complex systems [8]. However, we must admit that nonlinearity emerged later within chaos theory and has now been incorporated into the new generation of systems theory. It seems that GST, together with cybernetics, chaos theory, synergetics, self-organized criticality, and complex adaptive systems, enabled the development of what we now call "complexity science" and the second generation of general systems theory recently presented by Minati, Pessa, and Licata [99]. Gunter, on the other hand, argues that systems theory and complexity theory share the same foundations and conceptual apparatus [8] (p. 15):

"The terms used by complexity theorists are identical with those used by proponents of biological systems theory: nonlinearity, emergence, uncertainties in prediction, self-organization, bottom-up causality, chaos. Equally significant, complexity theorists attack the mechanistic standpoint in exactly the same way as systems theorists".

In contrast to Gunter, I, along with other authors, see another critical point of difference between systems theory and complexity theory or "complexity science". Unlike the latter, which seeks to explain the emergence and emergent patterns in systems, early cybernetics, and systems theory focused on "positive and negative feedback loops" [22,25]. Indeed, complexity theory, which has changed considerably in light of recent scientific discoveries, particularly in the biomedical field, now focuses on the "leveled ontology" central to 19th and 20th-century British emergentism [18,100]. "Leveled ontology" assumes that the levels in question are not only levels of description or explanation but "levels of reality or ontological levels" [100] (p. 853). These ontological levels are instances of strong emergence or, namely, the understanding that "A high-level phenomenon is strongly emergent with respect to a low-level domain when the high-level phenomenon arises from the low-level domain, but truths concerning that phenomenon are not deducible even in principle from truths in the low-level domain" [101] (p. 244). Besides being focused on the emergence, today's "complexity science" tries to understand the relationship between the micro and macro properties of complex systems and the practical importance of emergence and holism for science (see [102]). However, I agree with Gunter [8] and many others, such as Medd [21,24], in their advocacy of complexity theory or "complexity science" as a comprehensive systems theory that deals with natural socio-technical and organizational systems.

The critical question is, what is “complexity science”? Does it follow the idea of the “theory of everything”? In the special issue of A Journal of Complexity Issues in Organizations and Management, a publication of the Institute for the Study of Coherence and Emergence (Volume 3, Issue 1, 2001), edited by guest editors Kurt Richardson and Paul Cilliers, a group of renowned philosophers and scientists or “gurus” in the field of complexity set themselves the task of answering the thorny question of what complexity is. Is complexity perhaps a science or a narrative? If it is a science, is it postmodern or postpositivist? As expected, they all give unique answers to the same question, and each gives us clues for further attempts to define the complexity and its science. Moreover, I find their answers still relevant more than 20 years later. I will not go into all the works on this topic but only mention a few relevant to this paper.

In the introductory article, Richardson and Cilliers classify complexity, or “complexity science”, into hard, soft, and somewhere between. Reductionism plays an integral part in this division. Hard complexity science (reductionist complexity science, RCS) “Mimics the aim of the physical sciences in trying to reduce the wide richness of reality to a handful of powerful, all-embracing algebraic expressions” [21] (p. 6). Unfortunately, RCS seems to rely on a seductive syllogism that Naomi Oreskes and her collaborators refuted in a 1994 article in which they warn us of the impossibility of validating and verifying numerical models of natural systems [21,78].

On the other hand, soft complexity science recognizes that the complexity inherent in socio-technical organizations, characterized by language and meaning, differs from the natural world [21]. Therefore, some believe that theories of complexity developed in the natural sciences are not directly applicable to social systems but can provide some insight and illumination into the behavior of these systems. Hard complexity science, which promises a universal language and principles applicable to any natural and perhaps social context, unlike soft science, is a real science. The social sciences are considered soft complexity sciences because physical theories such as quantum mechanics have no value to the social sciences [21,103]. To worsen the situation, some hold soft complexity sciences as pseudoscience. For example, Phelan [103] thinks that pseudoscience includes soft complexity sciences (resemblance thinking). Similarly, Edgar Morin [104] distinguishes between “generalized complexity”, which refers to the human condition, and “constrained complexity”, which enables fundamental advances in formalization and modeling in science.

Nevertheless, both “hard” or “soft” complexity aims at contextual, “non-objective”, and “non-static” knowledge. Stated differently, our knowledge of reality is limited, subjective, and context-dependent [55,105,106]. It depends on the subject matter’s stability and requires stable boundaries, which do not exist in complex nonlinear dynamical systems. By changing the context, we change the understanding and, thus, problematize the learning process as an essential aspect of complexity [21] (p. 13), “We can never have complete knowledge of a complex system; we can take advantage of the various alternative representations (including our own subjective models) and synthesize more robust approximations allowing more informed decision-making”. Even informational–functional approaches to evolving complexity suggest that the context of a system alters the outcome of a calculation in systems with increased functional information defined by static persistence, dynamic persistence, and novelty generation [86].

Considering that there could be scientific appropriations of complexity, the question is what constitutes this “science” more precisely. No uniform definitions of “complexity science” or “complex” exist. Even the RCS with some of its proposed laws, e.g., that complex systems are incompressible (principle of incompressibility), i.e., that “Any description claiming to be complete must be as complex as the system itself”, does not seem to be very helpful in the search for a unified definition of complexity science [21] (p. 9). However, Richardson and Cilliers [21] make a point that researchers’ personal preferences are critical in determining which definitions of complexity are considered. Likely, these subjective preferences undermine efforts to elevate “complexity science” to the status of a science.

One such definition of complex systems, “Complex systems are comprised of a large number of entities that display a high level of nonlinear interactivity”, is pushed forward by Richardson and Cilliers. In defense of the vagueness of attempts to crown complexity as science, we must not forget that the definition of science and scientific knowledge is a centuries-old, still elusive problem of which Richardson and Cilliers are well aware. Indeed, apart from the difficulty of defining a novelty like “complexity science”, there is surprisingly no universally accepted definition of what science is.

Scientists and philosophers informed and raised in the positivist tradition assume that an absolute reality exists, regardless of the observer’s role in acquiring knowledge about that world [21]. They also believe in mathematically expressed “laws of nature”, in the nonsubjective nature of knowledge generated by the scientific method(s), and in reductionist methodology, which asserts that knowledge of the whole can be gained by analyzing the parts of the system and putting them together to understand the whole (the whole is equal to the sum of its parts) [21]. All these criteria are often used to distinguish science from pseudoscience. However, as we have seen above, “complexity science” does not meet these formal requirements. If we strictly adhere to them, there can be no “complexity science”. Or is a positivist understanding of what makes science a science perhaps too narrow, Richardson and Cilliers ask? Opinions on this issue are divided. For example, Morçöl [107] holds that “complexity science”, while rejecting the Newtonian notion of universal laws, nevertheless uses generalizations often abhorred by postmodernism.

On the other hand, “complexity science” is postpositivist because postpositivism represents a “Compromise between the extremes of positivism and radical postmodernism, in which the contextuality of (local) knowledge is recognized as well as the existence of universal principles (scientific knowledge)” [21] (p. 18) [107]. It seems that complexity science is a “grey” science for the “stuff in between”, which, on the wings of postmodernism, warns us to be cautious when uncritically adopting any “black and white” theoretical position [108]. Phelan [103] is critical of Morçoel and others who deny “complexity science” the ability to distinguish science from other types of knowledge. In other words, scientific inquiry is inconceivable without the notion that science is the “supreme arbiter of truth, objectivity, and rationality”. Examination of the disciplinary and/or interdisciplinary scientific status of complexity will continue to challenge our ability to distinguish between science and non-science and between different paradigms of scientific rationality (e.g., Newtonian, quantum-mechanical, etc.).

Another valuable line of argumentation about the scientific status of complexity comes from the theory of emergence and self-organization. For example, some authors, such as Medd [24], argue that “complexity science” should emphasize “emergent and self-organized phenomena” from a social science perspective, which are seen as central to defining complexity and overcoming “theoretical complexity science” through a “top–down” and “bottom–up” analysis. In this context, scientists must explain the gap between microscopic diversity and macroscopic order using the theory of emergence and “complexity science”. This science deals with order, which is often mistakenly characterized by a relative end state and complexity [23]. In other words, in addition to laws of physics, such as motion, gravity, electromagnetism, and thermodynamics, we need an additional unarticulated law to describe the macroscopic phenomena of our complex, evolving universe [86]. Gunter [8], Turner, and Baker [26] seem right when arguing that complexity theory or the “complexity science” goes beyond the scope of GST and contemporary systems theory, which is closely related to biology. In other words, “complexity science” aspires to the pedestal of theory or science about almost everything, from the atom to the dynamics of ecosystems to society and the stock market.

5. Reductionism, Holism, Emergence, and Theory of Everything

In the previous chapters, we have given some indication of holism and emergence. Here, we will say more about ontological holism and reductionism and their relation to the emergence in the context of systems theory and “complexity science”.

First, I will discuss Elder-Vass's version of an influential argument supporting ontological holism that builds upon ontological emergence. This argument, which was put forward by Elder-Vass in 2010 [109], was discussed and reconsidered by Julie Zahle in 2014 [110]. Elder-Vass [109], similar to Robert Rosen [111,112], considers natural or socio-technical systems ontologically or "inherently" complex. To digress, Robert Rosen, a renowned systems thinker, theoretical biologist, and biology's Newton (see [17]), most clearly and forcefully articulated the idea of complexity as a system property, reflecting the need for many different methods to study and representation to describe such systems [111,112]. However, what is whole? Is this concept easy to define, or is it susceptible to relativization?

Any system of interest or entity "Is a relatively enduring whole composed of parts standing in certain relations to each other" [109] (p. 17). As Zahle noticed, "These parts may be entities too, and hence they may themselves be persistent wholes made up of parts standing in certain relations to each other, and so on" [110] (p. 179). Elder-Vass and Zahle see biological reality as "Containing various entities, both combining and dissolving into yet other entities". As expressed by Mario Bunge [113], emergence leads to new entities, while submergence leads to their disappearance. Indeed, Elder-Vass and Zahle are talking about the vertical multilevel stratification of things in nature, for instance, in a living world. Every "whole entity" possesses specific "intrinsic" ontic properties, but the parts also may have their own properties, and in the end, we have numerous properties to deal with.

This line of reasoning quickly leads Elder-Vass to consider what properties have whole that the parts do not have. He gave many examples, and one is very simple: the physicochemical differences between water, hydrogen, and oxygen. In isolation, a prominent property of water is to be a liquid at certain temperatures not possessed by its parts(hydrogen and oxygen atoms). Zahle calls these emergent properties of wholes proper. She cites Elder-Vass and writes [110] (p. 180), "The emergent properties of a whole are ones it has in virtue of, or because of, its parts standing, at that moment, in certain relations to each other". Here, "at that moment" is meant to signal that the relationship between the emergent properties of a whole and its parts is synchronic and non-causal rather than diachronic and causal". By contrast, the emergent properties of the parts Zahle and Elder-Vass hold "Are really a property of the whole that happens to be localized in some respect within the part" [109] (p. 27).

Famous Robert Rosen's distinction between living organisms and machines can demonstrate "whole" and "wholeness" anticipated by ontological holism. The argument, recently restated by De Bari et al. [114] (p. 3), is as follows: while there is an isomorphism between the structure of a machine and the function of its components (the idea that machines are fractionable), organisms are so far not fractionable. In other words, machines comprise man-made and assembled parts or components, each performing a specific function. These assembled machine parts are allopoietic, meaning that they are not self-produced but engineered by humans and other machines. In contrast to machines, there are no clear boundaries between the components of biological organisms. De Bari et al. [114] give examples of the integration of the nervous and vascular systems and of the dependence of the functional role of a particular component on a changing internal and/or external context (e.g., the function of a muscle in different postures or in the context of different activities). This difference between machine and biological systems suggests that analysis in the engineering domain leads to synthesis. This means we can take apart machines to figure out how they work and then learn how to build them, according to De Bari et al. [114]. However, although we know a lot about cell biochemistry and molecular biology, we still do not know how to make cells (synthesis), which underscores the uniqueness of the self-organization of living matter. Now, let us discuss reductionism more specifically.

In his seminal book, published in 1974, Francisco Ayala [115] explained the differences between philosophical modalities of reductionism. Respectively, ontological reductionism questions whether physical–chemical processes are responsible for phenomena on a higher level, e.g., in biology. It rejects non-material principles, such as life force, entelechy, radical energy, etc., as unscientific. Epistemological reductionism is concerned with whether theories formulated in one branch of science are exceptional cases of theories and laws of another branch of science. Epistemological reductionists may claim, for example, that the theory of evolution is a particular case of some physical theories, which is difficult to prove.

On the other hand, methodological reductionism refers to the issue of research strategies, methods, and methodologies that scientists use in research. In this context, for example, it is interesting whether living processes are best studied at the molecular or higher levels of organization or whether both are necessary to unravel the complexity of life processes. Today, many scientists and philosophers consider both "bottom–up" and "top–down" research strategies equally appropriate for capturing interacting causalities coming from both directions, thus highlighting the fact that there is no privileged level of causation in biology [35]. For instance, it appears that genetic information (bottom–up) intermingles with epigenetic information (top–down) in generating quantitative and qualitative phenotypes, suggesting that both research strategies are needed to define genes and to reflect on the role of genetic processes in physiology and evolution [74]. This argumentation makes physiology again a central field of research within biology, as recently argued by Noble [116].

In my opinion, the reductionist's main line of attack is to refute strong emergence and ontological holism or to show that they are an illusion created by the limited cognitive capacity of our brain when confronted with complex systems. In other words, to win the battle against antireductionism, reductionists focus their attack on criticizing the scientific soundness of strong (ontological) emergence. In this direction, it is worth noting that most philosophers today agree with most scientists in rejecting ontological emergence and accepting ontological reductionism [102]. Indeed, the ontological antireduction is questionable because to defend strong emergence scientifically requires a successful computational and mathematical formalization and characterization of emergent phenomena, about which there is still considerable dispute in the scientific community (see [102,117]).

Some authors, such as Forestiero [118], hold that the low effectiveness of mathematics in solving biological problems in situations when the effects of the whole on the parts are taken into account. This "whole-parts" causality is essential in proving the validity of the autopoietic closure of production assumption. For the success of empirically motivated ontological emergence, scientists must prove that computational systems biology can answer the question of how emergent collective behavior appears on the biological macroscale [119]. On the conceptual level, however, emergence and computability align pretty much [120].

Furthermore, many ontological reductionists, in principle, do not support epistemological and methodological reductionism. However, some go one step further, aiming at epistemological and methodological reduction in specific sciences such as biology to physics as their ultimate goal. Their aim is not only to refute strong emergence but also to show that the theoretical–epistemological–semantic elements of specific sciences (e.g., Nagel's special sciences, Rosenberg's instrumental sciences, or Mayr's provincial sciences) are reducible to theories of physics. These are eliminativists [121]. However, their quest is doomed from the start. Why? Eliminativism fails simply because it does not recognize the uniqueness of the language of higher strata sciences, conceptual frameworks, generalizations, methodological settings, etc. Stated differently, even metaphysical reductionists, such as Alexander Rosenberg [121,122], do not take the idea that biology and psychology's methods, specific theoretical frameworks, such as the theory of evolution, and language biologists and psychologists use daily should be reduced or replaced by physics. The reductionists merely claim that biologists must come to terms with the fact that biology "needs a systematic and complete anchoring in the physical" without disallowing its conceptual and methodological settings, as noticed by Rosenberg [122] (pp. 124–125):

"Of course, the reductionist must recognize the indispensability of the theory of natural selection to biology. Anything else would turn reductionism into an untenable eliminativism".

Incidentally, Rosenberg's understanding of sciences dealing with complex systems is consistent with Richardson and Cillier's notion of the reductionist principle of incompressibility we mentioned in the previous section. This principle is more than crucial to understanding the limited cognitive capacity of humans to explain and investigate complex systems holistically. It also raises concerns about the success and scope of epistemological and methodological holism in complexity research. Unfortunately, some examples from practice also speak for epistemological holism's failure. For example, Lenhard and Winsberg's [44] fear of climate model pluralism suggests skepticism about the value of confirmation holism in real-life science settings. At least the epistemological holism seems to be in an empirical and perhaps intellectual crisis. Any failure to describe or explain complex phenomena holistically through synthesis or integration of system components is equivalent to reductionism [123] or a reductionist, mechanistic view of science à la Newton [17]. Therefore, not only does complexity in biology and other higher-strata sciences challenge the limits of reductionism and determinism, as Mazzocchi (2008) prophetically noted, but the scope and promise of holism also may reach its limits in science these days.

Why do eliminativists fail in the case of epistemological and methodological reductionism? To put it another way, why cannot epistemological emergence die so quickly? Let us discuss the following example. Rosenberg [121] considers the sciences dealing with complex matter, such as biology, to be instrumental sciences. Metaphysically–nomologically speaking, these sciences have no laws of their own and rely on the fundamental laws of physics, but we often mistakenly perceive them as having their laws. In other words, we view the behavior of natural and social systems as if they defy the fundamental laws of physics or are subject to other "emergent laws" because our cognitive limits have been reached in studying, modeling, and explaining complex systems by experimental, computational, and mathematical means. Perhaps this imperfection in our minds leads us wrongly to account for the strong emergence and claim that biology deals with laws and processes that physics cannot explain. Pigliucci [102] (p. 263) summarizes the essence of epistemological or weak emergence accepted by most philosophers and scientists of our time,

"There are no true emergent phenomena, only phenomena that cannot currently (or even ever) be described or understood in terms of fundamental physics, and yet are, in fact, only complex manifestations of the microscopic world as understood by fundamental physics".

Because of the intricate "inherent" complexity of life and the limited cognitive ability of humans to deal with it, we perceive or confuse, for example, weak emergence with its ontological counterparts. Therefore, given the complexity of matter assigned to biology, reductionists are forced to admit, at least in the short term, the impossibility of rejecting epistemological antireductionism and weak emergence. Overall, given the fact that eliminativism is untenable, most reductionists are unwilling to refute the heuristic and pragmatic significance of both epistemological and methodological antireductionism in sciences dealing with higher layer "realities" whose theories are formed conceptually and experimentally in a way quite different from the physical. In this way, they are, in my opinion, in some ways on the same line as the anti-reductionists. As nicely summarized by Nagel [124] (p. 3):

"Epistemological antireductionism holds that, given our finite mental capacities, we would not be able to grasp the ultimate physical explanation of many complex phenomena even if we knew the laws governing their ultimate constituents. Therefore, we will always need special sciences like biology, which use more manageable descriptions".

This rise in epistemological antireductionism coincidence with the fall of eliminative reductionism or the abandoning of some forms of epistemological reductionism in the post-genomic era of biology [125] (p. 359):

"All we can say for sure at the present time is that a specific form of reductionism is starting to disappear from biology, a form in which complex structures and functions could directly be explained by the properties of a limited number of gene products".

Of course, there are other ways to argue in favor of antireductionism and the theory of emergence in "special" sciences, such as the multiple realizability argument (see [126,127], Maturana and Varela's autopoiesis (biological autonomy) [91,93,94] Whitehead-inspired process ontological view of life [128], etc. Of these mentioned theories, special attention has recently been paid to the process-based ontological view of life, which emphasizes the dynamic rather than the stationary dimension of life functioning. This promising perspective, which is difficult to interpret, "derives" at least in part from ideas such as Bohm's "holomovement" concept of "unbroken and undivided totality" [129] (p. 575). By taking into account the self-organization of an autopoietic system and process-based ontology, emergence can be explained very simply, with minimal assumptions about the properties of the underlying physical processes. This idea is elaborated in recent essays by Heylighen [130,131].

The arguments from the system-related revolutions in the "special" or "instrumental" sciences can also benefit the anti-reductionist efforts. The revolutionary orientation of genetics and genomics toward systems holistic research at the beginning of the 21st century is seen by many as a solid foundation for the justification of anti-reductionism [36,125,132,133]. Echoing François Jacob's book Logic of Life, Michel Morange [125] argues that reductionism cloaked in molecular biological garb seemed to win the battle against holism at the end of the 20th century by explaining the properties of life and genetic control of life's functions in terms of the molecular structural properties and enzymatic capabilities of macromolecules. However, this joy lasted only briefly as holistic models of what life is and how it works emerged on the eve of the 21st century on the wings of what is known today as the post-genomic era.

Now, is it possible to understand the meaning of the expressions "science is holistic" or "science is reductionist" without assuming the relativity of these positions? In other words, is the determination of these scientific perspectives problematic, and if so, are the concepts of reductionist or holistic "theories of everything" also relative? In the book Holism and Reductionism in Biology and Ecology, Rick C. Looijen [134] argued for a relativistic understanding of scientific fields and subfields' holistic or reductionist character and mutual dependence between holism and reductionism. Basically, he claims that a scientific theory, a research program, or even an entire science or sub-discipline can be holistic in relation to a lower level of organization but reductionist in relation to a higher level. He provides illustrative examples to support this idea [134] (p. 121). For example, ecology is holistic compared to physiology, genetics, or molecular biology. Physiology is also holistic compared to molecular biology. Ecology can be considered holistic and reductionist, depending on its sub-disciplinary structure. Population ecology, which studies the relationships between groups of organisms of the same or different species, is holistic compared to auto-ecology, which studies the relationships between individual organisms and the environment.

Above these subfields are systems ecology and landscape ecology, which deal with the complex interactions between all organisms and their environment in a given geographical area and the influences of different landscapes on the diversity and richness of species and communities. Global ecology is holistic concerning all of the above research areas, as it examines global energy and material flows, the influence of global hydrology, atmosphere, and lithosphere on the biosphere and, conversely, the biosphere on these other earth spheres. Although this relativism forces us to be cautious in determining the theoretical perspective we adopt in certain areas of scientific research, the emergence that leads to hierarchies and the hierarchical organization of the sciences and forms the basis of a holistic "theory of everything" holds well as long as we are at the macroscopic level of insights. Whatever level we look at is holistic until we reach the elementary particles, for which other laws seem to apply. With the help of "top–down" and "bottom–up" causality, the same emergence theory should explain the structure and dynamics of the organizational levels of different systems across time and space. In the case of the reductionist "theory of everything", it all boils down to the essential structural components of physical reality and the laws that govern them. For it, there is no fear of relativization. The following discussion will help us more closely understand the relationship between reductionism and emergence (holism) across sciences.

By finding their way into systems and complexity research, holism and emergence gave a new meaning to the attempts to reduce theories, research programs, and sciences. They may have shifted this discussion into the realm of ontology. For example, referring to famous Anderson's paper [135], Elena Castellani [33] gives a much clearer picture of the relationship between reductionism and emergence when reflecting on the connections of these concepts with the scientific understanding of current quantum field theories as effective field theories. Accordingly, Castellani argues that Anderson opposed the reduction or supremacy of "high-energy physics" over "low-energy physics" (solid-state physics or condensed matter physics) by postulating basic anti-reductionist notions, which I will interpret briefly here [33] (p. 255):

(a) The way down/way up distinction or "top–down"/"bottom–up" distinction, which basically says that research should start with a "top–down" reduction in everything to fundamental laws (reductionist hypothesis) and then use those laws to reconstruct the entire universe (constructionist hypothesis).

However, this thesis actually accounts for and supports reductionist causes since it does not assume emergence and emergent properties and the hierarchical structure of science. Therefore, Anderson [135] (p. 393) and Castellani [33] (p. 255) introduced two other theses, which I find relevant to our cause;

(b) The fact of emergence. The constructionist hypothesis is rejected because of the emergence of new properties, "At each new 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";
(c) The hierarchical structure of science. The entities of X are emergent in the sense that, although obedient to the laws of the more primitive level Y (according to the reductionist hypothesis), they are not conceptually consequent from that level (contrary to the constructionist hypothesis).

Having described these notions, let us draw the consequences of this understanding to reach a "theory of everything". It is now worth noting that, with respect to (b) and (c), antireductionists claim that the higher-level phenomena are irreducible to low-level strata. Reductionists, on the other hand, argue that they are reducible. As indicated earlier, antireductionists firmly believe in stratified (layered) ontology in which a higher stratum or layer presupposes lower strata but not vice versa. This reasoning has substantial implications for the disciplinary organization of sciences, as discussed by Sayer [29] (p. 5):

"The strata usually cited are the physical, the chemical, the biological, and the social, but further strata may be invoked within each of these. The plausibility of the idea that the world is stratified arguably provides a warrant for the existence of different disciplines: the physical, the biological, and the social deal with different strata of reality".

Sayer's powerful claim is straightforward: we have different disciplines for the different parts of reality. For example, molecular biology deals with DNA and proteins, while autecology deals with the relationships between individual organisms and the environment. Psychology studies the mental life of humans.

Having said all these about reductionism in light of holism and emergence, the prospects for one all-encompassing reductionist systems theory or complexity theory capable of explaining phenomena across vertical levels of organization of complex systems are not so bright. Simply stated, scientists and philosophers involved in complexity studies must refute ontological emergence to defend one reductionist theory for all systems successfully. Otherwise, their idea of explaining all hierarchies with the laws of the atomic and molecular world would have to be reformulated to include some new macroscopic laws, if not laws, then at least exceptional cases of the same physical laws that govern molecular interactions. As far as the reductionist/antireductionist dispute is concerned, if reductionists fail to refute emergence, then they must admit their defeat and accept new metaphysics [102].

Even if reductionists are correct and there is no strong emergence in nature, or that emergence is an epistemic phenomenon, scientists should take it seriously because it shows us "Current methodological or theoretical deficiencies that make straightforward reductionist accounts unfeasible in practice, if not in principle" [102] (p. 265). Surprisingly or not, as I already discussed, it is much more difficult for them to justify epistemological and methodological reductionism. It seems neither practical nor pragmatic, for example, to reduce biology's concepts and research programs to physics, systems theory, or "complexity science". This does not exclude that many concepts from systems theory or physics, such as "synergetics", "nonlinearity", and "self-organization", help search for the explanation of evolutionary changes in living organisms. Alternatively, ontological antireductionists rely on strong emergence to build one "holistic theory of everything". They are not convinced that these emergent laws are special cases of fundamental laws of physics.

Whatever path one chooses, the consequences are the same: a theory of everything hits the walls, at least for now. In the first scenario, if one proves that strong emergence is real, one would find it difficult to describe it by mathematical or computational characterization of the interactions of lower-level components, except in sporadic cases [35,117]. This is because current mathematical modeling tools and computational power are limited in describing, modeling, and predicting strong emergent phenomena in the "bottom–up" and "top–down" directions, as philosophical and scientific studies on biological complexity suggest [117,118,121,122,136,137]. Even if one can somehow prove that there is no strong emergence, contemporary science must accept that it has not succeeded in providing a reduction model in which weak or epistemological emergence disappears from the table, either for pragmatic or substantive reasons. This conclusion is supported by the above discussion of Rosenberg's notions of reductionism and eliminativism. A reductionist "theory of everything", at least in its eliminative form, has, thus, come to a standstill because scientists or philosophers have not succeeded in formally proving strong emergence by applying the known mathematically expressed laws of physics on the one hand and disproving weak or epistemological emergence on the other.

In the second scenario, if we show and prove that strong emergence and theory of emergence holds once forever, then the question arises whether it is possible to apply the same theory developed for the macroscopic world to the microscopic world of physics and chemistry. This would be a challenging task whatsoever. But why do both scenarios end with skepticism? Or better say, does one of the above theories of everything take precedence when confronted with the existing scientific and philosophical knowledge?

Let us perform a thought experiment here. As said in a few lines above, the "theory of everything" can be based either on physicochemical laws or the theory of emergence. In the first case, it is reductionist; in the second, it is anti-reductionist. We have already demonstrated skepticism in explaining emergent phenomena utilizing physicochemical macromolecular interactions on more than one occasion. To elaborate on this matter, I will discuss the following example further. Focusing on non-technical ontological emergence in the biosphere suggests that life and its science are built upon the functional integration of parts (e.g., proteins) as part of a broader "Kantian whole upon which selection acts" or better say, "Living things are Kantian wholes where the parts exist for and by means of the whole. Humans are Kantian wholes" [19] (p. 2). In other words, as Kauffman and Roli [19] (pp. 1–2) explain, the Pythagorean dream that "all is a number", taken up by Newtonian physics, suggests that evolving biospheres and ecology lie outside the Newtonian paradigm, thus ending the search for a "reductionist theory of everything" as part of what these authors call the "third major transition in science" that follows the first transition inspired by Newton and the second led by quantum physics.

Nevertheless, Kauffman and Roli's skepticism poses a significant challenge to the idea of the "theory of everything" in the realm of complexity, forcing researchers to abandon their dream of a mathematically expressed "reductionist theory of everything" [19] (p. 6):

"The diachronic evolution of our or any biosphere is beyond entailing law and beyond any mathematics based on set theory". The troubles with the mathematization of biology and biomedicine, applications of analytical and statistical mathematical methods, and atomic and energetic physical models to explain structural and functional properties across multiple levels are long-lasting, even traced back to Edmund Husserl and without to be resolved soon [136,137]

Therefore, we are left with the theory of emergence. Besides the fact that this theory is not clearly mathematically or computationally articulated, the problem is that it cannot be applied in a "top–down" direction to all levels of organization of matter. In living systems, perhaps by means of closure of production, it is possible to argue that higher levels or higher emergent phenomena affect those on lower levels.

It is hard to make such a claim in an inorganic world. In other words, if we use this theory to explain the properties of water that emerge from the fusion of hydrogen and oxygen, we can hardly explain the properties of hydrogen and oxygen with the theory of emergence. Thus, the "holistic theory of everything" would only partially explain the world; primarily, it will be suitable for life sciences, psychology, and social sciences. From this reasoning, we would need other theories to explain the physical and chemical properties of elements such as oxygen and hydrogen and their microstructural organization and interactions unless someone successfully applies the theory of emergence to the subatomic world. Whether this will happen and when I am not sure. One might object that we need a plurality of theories, at least two, to account for the vertical nomological structure of the universe, as thought experiment suggests.

Moreover, a theory of emergence that focuses on the vertical hierarchical structure of the world would not solve the problems of horizontal nomological pluralism that Nancy Cartwright [138] discusses, namely, that there are no universally valid laws of physics in the universe. The early conclusion here is that both attempts to formulate the "theory of everything" have shortcomings. However, this conclusion does not mean we cannot draw new lessons from their shortcomings, direct our intellectual efforts to reconcile them, and arrive at a new promising "theory of everything".

Perhaps the skepticism about both "theory of everything" I have expressed seems premature in light of new trends in systems thinking. Indeed, some new moments in developing the universal complexity theory challenge my skepticism. There are already some signs in this direction. In recent years, systems scientists and thinkers have developed theoretical positions based on solid empirical evidence to explain the universal denominators underlying complexity in mind, nature, and society [81,86,139–141]. In this connection, "complexity science" began to recognize that different systems have similar ways of generating complexity that concretize uniquely across space and time. This is an important step forward toward the "theory of everything" in the field of complexity. Chu et al. [81] (p. 22) mention the following contributors of complexity:

1. Internal inhomogeneity of the system (i.e., it consists of many classes of autonomous agents);
2. Adaptivity of agents in the system;
3. Nonlinear interactions between parts of the system;
4. Net-like causal structure of the system (high connectivity).

The following example demonstrates some of these generators, such as nonlinear interactions and high connectivity. In neuroscience, brain complexity is associated with dynamic instabilities as a precursor for pattern formation and self-organization. No less critical is the homostatic balancing between "the dialectic dynamics of regional functional segregation and global coherent integration" [142]. Although this example concerns the brain, I believe that homeostatic balance, dialectics, and integration can also be found in other organs, organ systems, and entire ecosystems, no more and no less. Homeostasis and integration are, thus, at least features of the biological domain and perhaps also drive other complex inorganic systems, such as the atmosphere, the hydrosphere, the lithosphere, and socio-technical systems. So, these are some characteristics of organized systems that are more or less universally distributed on different scales.

Nonetheless, there have been significant developments in the search for structural and dynamic universals in nature and mind in the last 25 years in the form of DSRP Theory (DSRP stands for Distinctions, Systems, Relationships, Perspectives), which describes four patterns and their underlying elements [139–141]. In a series of papers, Cabrera and his collaborators hold that universality is structural and dynamic, not informational. Despite the fact that the superficial details of the two systems differ, it does not mean that their fundamental structure or dynamics differ. These empirically supported structural and dynamic universals can be predicted and modeled. DSRP Theory, which highlights how thinking and knowledge evolve, identifies four patterns and their underlying elements—identity (i) and other (o) for Distinctions (D), part (p) and whole (w) for Systems (S), action (a) and reaction (r) for Relationships (R), and point (ρ) and view (v) for Perspectives (P) [141]. These are universal existing in both cognitive complexity (mind) and material complexity (nature), making them grasp between mind and nature (systems thinking or cognitive complexity and material complexity (systems science)) [141]. At some point, if the "theory of everything" becomes a reality, scientists will better understand how these universals drive the domain-specific complexity.

6. Discussion and Conclusions

This paper concludes that reductionism and holism have their share in the search for the "theory of everything". In this context, at least two forms of theories of "everything" appear at the outskirts of systems and complexity research. One is reductionist, the other is holistic. Both ways of explaining phenomena and processes, from atoms to cells, societies, and stock markets, have shortcomings, at least if we carefully analyze mathematical, computational, and philosophical attempts to capture strong emergence and apply the theory of emergence to the subatomic world. One falls short when it comes to recognizing a "leveled ontology" based on emergence. At the same time, the other could, in principle, be successful in better understanding macroscopic physical, biological, psychological, and social phenomena. It is hard to tell whether the "holistic theory of everything" might account for physical forces operating on a subatomic level. The theory of emergence in the subatomic realm does not sound implausible because even subatomic particles have their hierarchical vertical structure, from the Higgs boson to electrons, protons, and neutrons. Particles such as bozon, meson, quarks, etc., which comprise electrons, protons, and neutrons, have different physical properties such as mass, charge, etc. However, the atomic world functions according to the laws of quantum mechanics, and the perceptibility of quantum mechanical effects decreases as the complexity of macroscopic systems increases [113]. Thus, macroscopic and emergence driving subatomic world probably could not align for this reason.

Despite this uncertainty, many other authors are becoming more optimistic that a "holistic theory of everything" is possible after all. I share their empirically grounded optimism. For example, based on everything discussed in this paper, one of the reviewers is very optimistic in this direction and states that "Such a theory, of course, would not be able to explain every single property of every single system, but it may allow for explaining even the laws governing physical particles. The last reflections of Stephen Hawking with his collaborator Thomas Hertog [143] go in this direction, proposing that the properties of the different particles and fields are the result of a historical process of cosmological evolution in which particular values for the physical constants emerged as "frozen accidents", resulting from the symmetry breaking that is characteristic of self-organization". However, we must be cautious here because, as Cabrera and Cabrera noticed [144], what physicists call "theories of everything" refer to the attempt to unify the fundamental physical forces and important theories within physics, such as String Theory or M-Theory. However, this "theory of everything" does not apply across all disciplines and cannot strive for the "unity of all knowledge" [144]. Therefore, the "theory of everything" inspired and led by "complexity science" and "systems science" has much more credentials to call itself "theory of everything" than those conceived and nourished by physicists.

In the meantime, until a complexity-inspired "theory of everything" emerges, scientists and philosophers should instead focus on scientific pluralism, which is epistemologically and perhaps ontologically compatible with complexity, to advance research practice further [39,145,146]. "Pluralism reflects complexity", Sandra D. Mitchell famously said [146] when discussing and justifying different scientific approaches to studying the same complex phenomenon.

An adequate understanding of the complex world built on pluralistic assumptions would require complementary theories, explanations, and research programs coordinated jointly. Above all, "complexity science" should find ways to reconcile reductionism and holism. Biology can serve as an example and inspiration here. Some philosophers and scientists, such as Walker and Cloete [147], openly discuss and advocate biology as a two-faced science: reductionist and holistic. This dualism is not only some theoretical or speculative things from the pencils of armchair philosophers and scientists. The very research practice supports it. For example, a more experimental systems approach to biological complexity inspired by the post-genomic revolution in biology, the so-called "pragmatic systems biology" adopted and practiced by "molecular systems biologists", contains in a hidden way the remnants of a reductionist methodology and epistemology [18,117,125,132]. On this behalf, Morange [125] has pinpointed that biologists in the post-genomic era, unlike philosophers of science, remain committed to reductionism but with some hints of holism.

On the other hand, systems-theoretical biological thinking, with its applications to biology and medicine (systems biology and systems medicine), tends to build on variants of holism, including ontological holism, holistic modeling, and explanations [18,132,133]. However, this division is somewhat artificial, as molecular and systems biology are interdependent and complementary [148]. Perhaps Morin's Complex Thinking, Bohr's complementarity, and Cabrera's DSRP theory can help reconcile reductionist and holistic "theories of everything". Bohr's complementarity, for example, has already proved helpful in mediating between opposing views or doctrines in physics and neurobiology [149,150] and is quite promising when applied to biological complexity to link theoretical and practical problems both at the local level (organism) and at the global ecological/economic level [151]. All these enlisted conceptual tools could guide and advise the future "theory of everything" in terms of BOTH-AND and not EITHER-OR logical operators. The ideas discussed in this paper certainly need further discussion and theoretical-empirical support to confirm or, in the latter case, reject them.

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