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Complexity, network theory, and the epistemological issue

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Abstract

Purpose – The purpose of this paper is to contribute to refine the conceptual framework of complexity. For such a purpose, a number of epistemologically oriented remarks are provided, arguing about the relevance of second-order considerations for complexity and the importance of pluralism in scientific research.

Design/methodology/approach – At first, the paper focuses on one of the topical areas of complexity research, i.e. network theory, but uses this for drawing the attention to more general issues. The underlying assumption is that scientific and philosophical research might complement each other, and that this is especially crucial for the advancement of complexity.

Findings – The paper suggests three ways for refining the scheme of complexity: analyzing it at the right level, i.e. not focusing on single principles or theories (e.g. network theory), but rather on the overall frame; including both ontological and epistemological considerations; and recognizing how the epistemological implications of complexity foster the adoption of a pluralist stance in scientific research (and beyond).

Social implications – The way in which science (complexity) is portrayed, i.e. as "perspectival" and inclined to pluralism, could impact on how it is thought, designed and socially perceived.

Originality/value – Complexity is one of most promising fields of contemporary science, but still lacks of a coherent frame of analysis. This requires an investigation from different point of views, as an object of interdisciplinary cooperation. The main paper's value consists of providing second-order considerations which puts scientific findings in perspective and can contribute to a better understanding of their meaning from a philosophical standpoint too.

Keywords Epistemology, Complexity science, Network theory, Scientific pluralism

Paper type Viewpoint

1. Introduction

Complexity is one of the most promising research areas and a highly debated topic of contemporary science, which transcends disciplinary barriers and has implications at multiple levels. Investigating it from different point of views, as an object of interdisciplinary cooperation, is important for reaching a fuller understanding.

Nonetheless, an agreed account of complexity is not available (Alhadeff-Jones, 2008; Israel, 2005; Morçöl, 2001). Its historical development itself, which covers a wide time span (from dynamical systems theory founded by Poincaré by the end of the nineteenth century to the most recent developments), is fragmentary and branched.

Complexity could be portrayed as a multifaceted space where different research pathways (e.g. chaos theory and complex adaptive systems (CAS) theory, just to mention two of them), originating in diverse historical and theoretical settings, come to merge. Such a merging is, however, only partial. Complexity is still an "amalgam" of principles, methods and concepts, which do not form a real coherent framework (Heylighen *et al.*, 2007).

On the other hand, others (e.g. Chu *et al.*, 2003) pointed out that a common ground can be found, and that such a ground would form the basis for the development of a new way of conceiving science based on a "post-Newtonian" paradigm (e.g. Morin, 2008; Nicolis and Nicolis, 2009; Ulanowicz, 2009). For example, there is a shift in the preferred focus of analysis, pointing towards complex relational patterns and non-linear phenomena, which are basically neglected by Newtonian science. Besides,

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there is an attempt to overcome the shortcomings of scientific reductionism. Anyway, what is not shared is which idea or level (i.e. ontological, epistemological or methodological) of reductionism is contrasted.

This work begins by outlining the limitations of reductionism as a methodological procedure. Next, it illustrates network theory, i.e. one of the theoretical approaches developed under the frame of complexity science, which is frequently advocated to move beyond reductionism. In spite of appreciation of this approach, a number of critical remarks are made for integrating the view provided by its proponents (mostly mathematicians and theoretical physicists). Finally, some considerations on complexity research taken as a whole are supplied. The paper argues on the importance of taking into account epistemological arguments about complexity, and how this could foster the adoption of a pluralistic stance in scientific research.

2. The limitations of reductionism

Reductionism is at the root of modern science. It was above all Descartes, who conceived the world as a clockwork mechanism, to credit it as one of the key components of the scientific method, together with logical deduction and quantification, and to formulate a reductionist view of science.

Reductionism has proved to be a powerful heuristic device, leading to a long history of scientific achievements. There is, however, a rather large consensus that while on the one hand it is still a necessary research strategy in contemporary science, on the other only rarely it is sufficient (e.g. Mazzocchi, 2008; Mitchell, 2009).

Although often instigated by ontological assumptions, most discussions are focused on reductionism as a methodological procedure: the best way of scientifically investigating a system is focusing on its component parts (often, although not necessarily, at the lowest possible level), which are usually obtained by the well-known reductive method of decomposition, and then studied in isolation, i.e. under laboratory conditions or in other settings different from *in situ* (e.g. Kaiser, 2011).

Investigating a system in this way implies to believe that the explanatory power attributable to its parts is sufficient to understand the whole system, and that the properties of such parts are basically unaltered by their context. However, this approach works only for systems that are closed or isolated, i.e. interactions with the environment are minimal or absent – in studying them one can focus exclusively on internal factors – and that are highly decomposable (Bechtel and Richardson, 2010), i.e. interactions between parts occur in a linear fashion and the relational setting do not play a primary role in determining how these parts function.

This same approach, if not complemented by others, shows severe limitations for studying systems (e.g. biological and ecological systems) that are open, i.e. basically non-separable from their environment, and "minimally decomposable" (Bechtel and Richardson, 2010), i.e. the properties of their component parts are co-determined by the organization of the whole.

Reductive procedures could also be supplemented by a synthesis stage, aiming to reaggregate the system's parts to examine how they function in the whole. However, this resynthesis frequently fails. If decomposition has wiped out the systemic organization, it is implausible to believe that such an organization will be rebuilt by simply putting the component parts together once again. Even if we come to know some organizational constraints (on which basis the parts are held together), one cannot expect to easily reconstruct how these parts, through their coworking, create the behaviour of the system as a whole (e.g. Kell and Welch, 1991). Such a behaviour is usually the result of a long "history" of complex interactions and adjustments, which occur in nature and cannot be fully reproduced outside of their original context. This is especially relevant in biological research (Williams, 1997), where the limitations of reductionism have become particularly evident.

Many *in vivo* properties or behaviours (e.g. robustness in organisms) are not shown by isolated molecular components, and therefore not detectable (or depictable in quantitative terms) *in vitro*. Besides, *in vitro* experimental observations often cannot be extended to the physiology of the system (Bruggeman *et al.*, 2002).

This has led to a rediscover of more holistic research strategies, i.e. non-invasive experimental methods by means of which structures and behaviour in cell and organisms under physiological conditions can be studied.

This has also led to the surfacing of systems biology, which can be seen as an attempt to broadening the molecular biology scope and approach. If the focus of the latter is usually restricted to isolated phenomena one at a time, e.g. a single gene or few proteins, systems biology aims at seeing how many levels of biological information are interrelated and understand their significance in the wider context. Kitano (2002, p. 1662) expressed this metaphorically: "Identifying all the genes and proteins in an organism is like listing all the parts of an airplane. While such a list provides a catalog of the individual components, by itself it is not sufficient to understand the complexity underlying the engineered object. We need to know how these parts are assembled to form the structure of the airplane".

More generally speaking, novel approaches are searched in science to investigate the relational and organizational aspects, including the dynamics between the system, its component parts and the environment (Juarrero, 2002). Here complexity theory enters the scene.

3. Progressing complexity through network theory

Complexity is often advocated as a means for overcoming the limitations of reductionism (Mazzocchi, 2008). With its set of revolutionary theoretical ideas (e.g. chaotic dynamics and self-organized criticality), it is contributing to transforming and improving science.

Some scholars have, however, underscored how research on complexity has not yet totally expressed its potential. The theoretical ideas have not always been translated into a real progress: "We learned a lot, but achieved little: our tools failed to keep up with the shifting challenges that complex systems pose" (Barabási, 2012, p. 14).

Barabási (2012) argues that this could depend on the abstract nature of complexity, which has been developed more from toy models or mathematical anomalies than from real-world observations. And yet, he claims, this situation is changing due to technological advancements. In different fields of research, from biological sciences to economics, huge and complex bodies of data have become available in electronic form. Such an unprecedented data deluge, coupled with the fact that computer processing power allows them to be analyzed efficiently and much more rapidly than in the past, offers new opportunities for accounting the structure and dynamics of large networks.

The development of new models for these networks and the surfacing of a new theoretical approach based on graph theory, namely network theory (e.g. Barabási, 2003; Watts, 2004), played a crucial role. Importantly, key notions of the latter are seen as being derived directly from data and observations. For example, the theory of evolving networks is upheld by considerable empirical evidence substantiating the scale-free nature of the degree distribution. For Barabási and other scholars, this "data-inspired" approach represents the reason behind a noteworthy shift in research on complex systems, if compared with earlier studies on the same subject.

Network theory is an important and highly reputable field of research which studies complex interacting systems – from biological systems to social systems and World Wide Web – focusing on the patterns of relations between the component parts forming them. The interconnectedness of these parts is seen as causing network effects, which is a crucial issue to be studied for understanding complex systems[1].

The structure of complex systems is represented in term of a web of nodes and links connecting the nodes to one another. From a mathematical standpoint, this corresponds to a graph. Regardless of the dissimilarities concerning the nature of the nodes and the interactions between them, a limited number of basic laws is believed to rule and constrain the behaviour of most networks (Butts, 2009; Newman, 2010).

Network theory provides us with a mathematically based (and methodologically holistic) approach, which is particularly apt to study highly non-decomposable systems (Rathkopf, 2015). It allows, in fact, to avoid the use of methods like decomposition, as well as of "idealized" models, i.e. simplifying, tractable versions of many-elements systems (networks models involve, however, another type of "idealization" by neglecting the empirical nature of the individual nodes). As Barabási (2012, p. 15) puts it, "Reductionism deconstructed complex systems, bringing us a theory of individual nodes and links. Network theory is painstakingly reassembling them, helping us to see the whole again".

Besides, its proponents believe that network theory is capable of linking together models of network structures and notions rooted in statistical physics literature, such as phase transition, criticality and self-organization. So, for example, the fact that a power law distribution is found in complex networks would show that they self-organize into a scale-free pattern (Barabási and Albert, 1999). These outcomes provide the hope we are close to discover some new fundamental principles existing in nature, and that by means of them the universal patterns of complexity will be fully explained. For Barabási (2012), the development of a general theory of complexity seems at hand. But can we say that it is true?

It comes as no surprise that physicists search for new fundamental principles or laws, which would be able to grasp the underlying unity of the natural world, and theories acting as new unifying frames. This is a typical tendency of modern physics research. The sole novelty here resides in the fact that the searched laws or theories concern "connectivity". On the other hand, a critical reflection should be made about some of the above mentioned claims on both the scientific and philosophical ground, considering contrasting arguments too.

For example, one thing is to recognize that notions derived from the physics of phase transitions can provide useful insight for developing mathematical models of complex network structures; quite another would be to assume that the "real" networks (e.g. Internet) have genuine critical points (see, e.g., Willinger *et al.*, 2002) or exhibit phenomena as those observed in particular physical systems.

A more detailed discussion on this topic can be found in Fox Keller (2005)[2]. This paper takes, however, another look at the matter, focusing on some (realist and objectivist) assumptions that seem to underlie network theory. It will attempt to demonstrate how, by pondering these issues, one gets the chance to reflect on the overall status of complexity and what really counts for its progress.

4. Remarks on network theory

First, it is emphatically claimed that the development of network theory derives directly from data, kind of assuming that it is gathered directly from the reality of things, bypassing the distortions of the human, limited mind. Nonetheless, considering data as a simple reflection of the real-world risks to be an epistemological oversimplification. Data are not simply or neutrally "given", and their collection is not a merely empirical activity. Rather they result from a certain way of looking at phenomena. Even the instruments we use to get data have been designed (and are applied) according to some theorical assumptions, which indicate what has to be investigated and the possible meaning of what they detect (Mazzocchi, 2015).

Second, what appears to be also questionable is the kind of (uncritical) realism which characterizes the network approach to complex systems (Baker, 2013). This is typified by assumptions at both ontological and epistemological levels. The former concerns how the world is arranged, i.e. there is a unique (network) structure underlying given real-world phenomena or systems (or the world itself as a whole), whose existence is independent of our epistemic structures and interests. The latter implies to assume that such a structure can be fully and objectively accounted by graph-theoretic models, something that, in turn, is possible only if the scientific investigator is able to reach a neutral and observer-independent place of observation by which discerning the world as it is. Particularly, this latter point needs to be further explored.

One thing to clarify is that mathematical networks are models for real-world complex systems. They are constructed to represent network structures existing in these systems, but their unquestionable scientific value does not legitimate their reification, i.e. referring to them as if they were "real" networks. Think about how nodes or connections from one node to another are drawn. Not only on the system's features depend such an operation but also on the modeller's vantage point, background and purpose: "A link in a network is a connection, and almost any relation can count as a connection under the right circumstances" (Baker, 2013, p. 704).

In order to demonstrate how the modeller's influence could lead to model differently the same situation, Baker (2013) makes the example of a community of mobile phone users. There are many different ways to pass from data (concerning the phone calls) to the network model: a choice has to be made about the type of phone communication that functions as the basic link or about the threshold that determines when it is legitimate to draw a link between two nodes (e.g. a given number of calls per week): "even if there is such a thing as the underlying network for this mobile phone community, this does not imply that the given [mathematical] network is the only, or even the best, way of representing that network. Doing this requires defending the various decisions that are made in fixing on particular relations as *proxies* for the underlying connections of interest" (Baker, 2013, p. 702, emphasis added).

One could argue that the problem here resides precisely in the fact that a mistaken notion of "connection", which relies on proxy links, is used. These links are supposed to stand in for what are the (presumed) "real" connections, but there is no guarantee that such connections are rightly reflected by them. Once resolved this issue, the possibility to construct the right network model will be at hand. In many other circumstances, e.g. dealing with neatly definable physical systems, things are in fact less uncertain, i.e. nodes and connections can be established more easily and univocally. However, to make choices, to select what is most relevant is not a prerogative of particular circumstances in which a (graph) model is constructed from data. Rather it is part of the modelling process itself. Given situations can make the task easier, but this won't change the nature of the process.

Another argument that further complicates the matter regards real-world systems themselves (and the network structures they might include). We have inherited from Greek philosophy (i.e. the philosophical tradition beginning with Parmenides) the view that the world is populated by distinct and isolated items, which show stable and permanent (because "essential") features, differently from "accidental" ones which are subject to change. Newtonian science and its objects (i.e. closed and isolated systems) fit well with this worldview. But most complex systems do not (Juarrero, 2002).

How a system is identified? By drawing boundaries, i.e. separating what is part of the system and what is not (Cilliers, 2005). However, in given circumstances, e.g. when complex systems are concerned, this is far to be a trivial operation. Apart from any explicit, constructivist considerations (see next section), there are at least two issues to be considered, which are connected to the fact that complex systems are embedded in their environment and history.

First, no clear distinction between complex systems and environment can be made, because they constantly interact with one another and are strongly entangled (Cilliers, 2005). The environment (which often includes other systems, or their parts, that may also interpenetrate among themselves and with the target system, as frequently occurs in the bioecological and social realms) participates in forming their identity, and its role should be seriously taken into account to fully account them.

Second, complex systems are "structures of processes" (Juarrero, 2002), i.e. highly dynamical items that change and evolve, together with their boundaries (their nature seems to reflect the "everything flows" of Heraclitus' philosophy). Unpredictable directions can also be taken by such systems, owing to the richness of feedback loops and non-linear relations typifying them.

Under these conditions, what normally appears as uncontroversial, i.e. the possibility to establish univocally and permanently the boundaries of a system (or the elements of a real-world network structure), is called into question. As argued by Cilliers (2005, p. 612): "If one acknowledges the complexity of a system, it becomes more difficult to talk about 'natural' boundaries […]. A complex system has structure and patterns that would render some descriptions more meaningful than others, but the point is that we do not have an a priori decision procedure for determining when we are dealing with something 'more meaningful'. The contingent and historic nature of complex systems entails that our understanding of the system will have to be continually revised. The boundaries of complex systems cannot be identified objectively, finally and completely"[3].

The idea of network as relational patterns could also be understood in the light of philosophical views which follow more refined versions of realism. One of the more interesting has been advanced by Ladyman *et al.* (2007) and Ross (2000), who developed Dennett's thesis (1991). The former are sustainers of (ontic) structural realism, a philosophical position which is committed to the structural or mathematical content of scientific theories rather than to their empirical one. Ladyman *et al.* (2013, p. 63) assert that "The scientific study of naturally occurring patterns requires both a suitable means for formally representing patterns and a method of inferring patterns from data that picks out objective features of the world".

The strategy to achieve an ontological account of patterns is built on two items: identifying patterns on the basis of their predictive utility (in terms of computational efficiency); and appealing to the fact that to determine whether a pattern is predictively useful depends on a certain state of affairs, i.e. "if it is possible to build a computer to accurately simulate the phenomena in question by means of said pattern, and if doing so is much more computationally efficient than operating at a lower level and ignoring the pattern" (Ladyman *et al.*, 2013, pp. 64-65). Since computation is not other than a physical process, to settle on if a given computation can occur, and therefore whether the involved pattern is really existing, are ultimately the laws of physics.

This argument, which relies on a mathematical (and computational) view of the world, has been advanced for supporting a realistic reading of complexity. In point of fact, it fits rather well with the standard reading of complexity science, but does not move too far away from objectivism (and mathematical reductionism). Now the question is: does such a reading provide a thorough portray of complexity?

5. The epistemological side of complexity

In his piece Barabási (2012, p. 14) puts forward other important questions about complexity: "what should a theory of complexity deliver? A new Maxwellian formula, condensing into a set of elegant equations every ill that science faces today? Or a new uncertainty principle, encoding what we can and what we cannot do in complex systems?"

His response is that complexity should supply a theoretical approach (i.e. network science), which is able to make sense of today's data deluge and provide a new unifying frame, and that scientific research (and our understanding of the world) will be transformed by these findings.

According to the opinion expressed in this paper, the argument that complexity research has not yet entirely expressed its full potential is correct. Much of its innovation power waits to be unlocked. However, the formulation of a new unifying theory cannot be a solution here. Besides, in order to fully grasp complexity, focusing solely on individual theories or principles would be profitless as well.

Scientists are usually so immersed in their field of activities that they risk missing the general (and historical) perspective. Nevertheless, a prerequisite for understanding complexity is having a picture of it as a whole, i.e. investigating how an inclusive framework is formed by the interplay of several theoretical and conceptual items. As mentioned before, some scholars (Morin, 2008) speak of the "paradigm of complexity" which, in contrast with the Newtonian paradigm, is more apt to describing a world characterized by non-linearity and self-organizing processes. The image suggested here is a polyphony of many voices, each contributing to create an overall theme. It is a kind of multiplicity which, however, coexists with an all-embrancing unity.

We cannot ignore that not all the theories or approaches forming complexity are in harmony with each other. Think, for example, about the debate between complexity scientists more inclined to a reductionist view (e.g. Gell-Mann, 1994) and those recognizing emergence, seeing it essential, for instance, to explain life (e.g. Kauffmann, 1995). From an emergentist perspective, nature is able to transcend the physico-chemical level, giving raise to something qualitatively different, i.e. living systems, which co-evolve with their environments and whose properties cannot be reduced to the properties of their parts.

A less acknowledged fact is another kind of internal tension characterizing complexity: on one hand there is the tendency to depict the world in post-Newtonian terms, on the other hand the epistemological approach is generally still the same of the Newtonian science (Morin, 2007). The latter presumes a clear distinction between object and subject. Objectivity and universality in knowledge are searched.

Think about CAS, which is characterized by the same epistemological position of network theory and represents one of today's leading research programmes in complexity. CAS is basically a "first order" science, whose approach is based on formalism and modelling tools such as cellular automata or multi-agent simulation (Miller and Page, 2007), and makes use of advanced computational techniques. On one hand, CAS introduces genuine novelties on the methodological grounds and in the way of seeing the world, making sense of how observable global phenomena arising in (physical, biological and social) complex systems are due to simple local rules of interaction of their component parts (e.g. Holland, 1995). On the other hand, the modelling process as such (which, as said, depends also on the modeller's choice criteria), is not problematized. Apart from any possible lack of information, what is searched is still an objective and factual "representation" of the external world, i.e. the target system.

A more inclusive description of complexity should take into consideration both the ontological and the epistemological level. Complexity should not only be seen as a field of research investigating the systems populating the world (i.e. the "observed systems"). Rather it should be concerned also with the kinds of systems which study the former (i.e. the "observing systems"), being, however, strictly intertwined with them. In this sense, it cannot be fully accounted if second-order issues are not taken into consideration. The epistemology of complexity can be seen as a "second-order" science, i.e. a meta-reflection on science and knowledge which is based on scientific findings themselves (although not only on them).

Admittedly, such a position is not reflected in the mainstream complexity research. But this can be understood easily as scientists are still trained to investigate an objective world which is clearly separated from the subject doing the investigation. Only rarely science has problematized this distinction, as occurred with quantum physics, for example. And yet this was also the case of second-order cybernetics (von Foerster, 1974, 1982) and autopoiesis theory (Maturana and Varela, 1980, 1987) that should be considered as an integral part of the complexity tradition. Knowledge is seen here as generated by the interaction between the world and the subject who experiences it (which is still part of the world). It involves a process of mutual specification between a living system and its world-environment, which co-emerge all jointly.

It is precisely by accounting the observer as an autopoietic system that deconstructs the ideal of a scientific investigator who would be able to explore the natural world from an absolute vantage point.

Such an investigator, instead, approaches nature from within and from a situated vantage point.

Other complexity theorists expressed similar concerns. Prigogine and Stengers (1984), for example, advanced an "endophysical" notion of scientific knowledge, arguing that the scientific investigator is embedded in the same physical world she/he is studying. Thinking to the features of complex systems themselves, Cilliers (1998) put forward, instead, a philosophical reading of CAS, finding parallel between complexity and postmodern philosophy, and recognizing the situatedness of knowledge as well. Morin (2007; also see Malaina, 2015), on his turn, distinguished two different types of complexity, depending on the adopted epistemological approach: namely, "general" complexity (following an epistemological approach based on second-order cybernetics' insight) and "restricted" complexity (basically following the epistemological approach of Newtonian science).

6. Complexity as a pathway towards pluralism

Taking into account the role of the observer in the process of knowledge gathering, which is perfectly in line with Baker's concern against the objectivist stance of the network approach (see Section 4), means pointing towards a pluralistic view of science too. Although scientific pluralism has been philosophically understood in different ways – as an epistemic thesis, e.g. "perspective pluralism" (Giere, 2006) or "integrative pluralism" (Mitchell, 2009), or as a metaphysical thesis, e.g. "promiscuous realism" (Dupré, 1993) – it is frequently associated with an understanding of scientific knowledge as intrinsically "situated", precisely because observer-dependent.

Santos (2013), for example, in the introduction to a special issue devoted to the philosophy of complex systems, highlights how complexity needs of a pluralist, pragmatic, interdisciplinary framework, which pays attention to the role of the observer. Rosen (1987), on his turn, described complexity as the property of a system corresponding to the difficulty in describing and modelling it. There is no single formalism which is able to capture all its properties. The fact that investigating complex systems from a single approach or mode of description, or focusing solely on a single organizational level, is often not sufficient, is increasingly recognized. In order to gain a broaden picture or more fully grasp a particular phenomenon, multiple different (not necessarily consistent or integrable) accounts could be needed: each (observer-dependent) account has its own limitations but, by combining them together, they may complement one another.

It is also pluralism in the scientific research itself, especially in dealing with complex systems, to motivate pluralist claims in the epistemology of science. Consider, for example, this quote from the introduction of the multi-author book *Scientific Pluralism:* "The case studies in this book indicate that science provides good evidence that […] some parts of the world (or situations in the world) are such that a plurality of accounts or approaches will be necessary for answering all the questions we have about those parts or situations" (Kellert *et al.*, 2006, p. xxii).

Such a plurality could be needed, for instance, to address the limitations and "perspectiveness" of the means employed. We can resume here the argument concerning scientific modelling. Owing to the abstractions and idealizations that they take in, models are forced to simplify the system under investigation and can only partially represent it. Using a pluralist scheme can be a suitable way to address these limitations, as occurs in investigating the climate (i.e. a highly complex system) through multi-model ensembles (e.g. Tebaldi and Knutti, 2007). Although the models considered in an ensemble share the fact of being all grounded in recognized physical principles, they make use of different simplifying assumptions and approximations (e.g. parameterizations of given climatic processes). Since no model has, however, demonstrated a marked superior performance over the others, they are used together as complementary devices, especially for probing how climate may change in the future under diverse emission scenarios (Parker, 2006). Besides, the degree of agreement of their results is evaluated too, making reference to the notion of robustness, i.e. implying that a scientific result is more reliable if derived from different (and independently developed) models (e.g. Weisberg, 2006; Wimsatt, 2007).

Another reason for employing pluralist research strategies could be connected to the fact that, due to their complex organization, various systems and phenomena need to be inspected from different levels and standpoints. Take the case of systems biology (e.g. Mazzocchi, 2012). Multiscale modelling strategies are employed for studying living systems, and this is often coupled with combining, on the methodological ground, reductionist and holistic schemes. These two procedures can be implemented simultaneously at different levels, going back and forth between them in a continuous exchange of viewpoints whereby a system can be studied (e.g. De Backer *et al.*, 2010).

Here there is a more general lesson: reductionist and holistic approaches, which look at the world from diverse angles, can be pragmatically integrated one to another, recognizing both their value and limitations, and establishing the range of applicability of their methods. For example, not only reductive methods can be used for studying closed and decomposable systems, but also when, apart from the type of investigated system, our explanatory purpose is to understand things analytically. On the other hand, in many other circumstances, e.g. in dealing with highly non-decomposable systems and in understanding complex relational patterns, reductionist approaches should be supplemented with (or replaced by) more holistically oriented ones, e.g. network modelling (Rathkopf, 2015).

Note that this pluralist reading of scientific research represents an outstanding novelty with respect to Newtonian science. The latter has been developed with the ideal that its ultimate goal was to establish a single and comprehensive portrayal of the natural world and facts, following a single set of basic principles. Pluralism would be then a marking feature of a new, "post-classical" way of conceiving science.

The fact that pluralism is embraced does not mean, of course, to succumb to relativism. Science is produced by scientific investigators in interaction with nature. What is here suggested is that there could be multiple legitimate ways to scientifically investigate and account a single underlying reality. Besides, admitting this plurality does not necessarily imply to believe that all the theoretical or conceptual systems are equally "successful" or valid. The "resistance" offered by the world to these systems should be also taken into consideration, and such a resistance can lead to distinguish among them (also see Feyerabend, 1999, and the idea of "constructive realism" in Mazzocchi, 2013, p. 372).

On the other hand, conversely to what thought by other pluralist thinkers (e.g. Giere, 2006), reality should not necessarily be seen as having a "unique structure". Remind Baker's (2013, p. 803) concern against this presumption in talking about networks, as also expressed in the following words: "even for systems with […] concrete connections […], there is [not] necessarily such a thing as *the* structure of the system, or *the* network that underlies the system". In order to move beyond the ideal of "uniqueness", we have to come to see the world as intrinsically nested and entangled: things are interconnected and interrelated to one another in multiple fashions, and many cross-cutting joints can be found. As a result, depending also on the purposes of investigation, there could be many different ways to divide the world into discrete parts.

Such a view also reinforces the idea that pluralism is not a temporary state of affairs (i.e. something that might be solvable in future or be solvable in principle). Rather it is a research strategy having an intrinsic value precisely because reality, owing to its multidimensional complexity and the perspectival nature of human knowledge, cannot be compressed into the boundaries of a single comprehensive classification or theory.

7. Conclusion

This paper takes on a premise which many scholars, such as Barabási, have put forward: "complexity has not yet fully delivered on its potential". However, differently from them, it points out that whereas working on the development of new scientific approaches and theories, such as network theory, is highly valuable, it is at the same not sufficient to guarantee that the searched advancement takes place. What is also needed is a refinement of the overall theoretical and conceptual scheme of complexity.

Three issues, which might contribute to such a refinement, have been indicated but they have not received much attention in the mainstream research yet.

First: understanding complexity requires a focus on the "right" level of analysis. In fact, it cannot be fully accounted by focusing on a single idea or theory. Rather it entails to consider how these items contribute all together to forming an overall framework. Speaking of "complexity" means referring to this framework.

Second: complexity should not be viewed only as a manner for describing the world. Rather it concerns also our ways of producing these descriptions. Both ontological and epistemological issues should be considered, as suggested by pioneer researches in second-order cybernetics and other complexity scholars, which emphasized the role of the observer in the process of knowledge gathering.

This observer-dependent depiction of scientific knowledge leads also to the third point, i.e. complexity entails recognizing the importance of pluralism at different levels. Different views, descriptive levels or approaches (e.g. reductionism vs holism) may be needed for studying the same system or phenomenon without implying the possibility to reduce one to another.

Especially the last two points are noteworthy because they can contribute to the development of a new, "post-classical" view of science that, in time, could be adopted as the result of a process of "self-transformation" of science itself.

Notes

1. The component parts of a network can be simple and their behaviour easy to be understood and calculated, and yet by combining these parts something complex which requires complex calculations is generated. Besides, in order for this complexity to increase, the connection of few more links can be enough.
2. Fox Keller (2005, p. 1066) summarized her criticism as follows: "First, power law distributions are neither new nor rare; second, fitting available data to such distributions is suspiciously easy; third, even when the fit is robust, it adds little if anything to our knowledge either of the actual architecture of the network, or of the processes giving rise to a given architecture (many different architectures can give rise to the same power laws, and many different processes can give rise to the same architecture). Finally, even though power laws do show up in the physics of phase transitions, the hope that the resemblance would lead to a 'new and unsuspected order' in complex systems of the kind that physicists had found in their analysis of critical phenomena appears, upon closer examination, to lack basis".
3. The question of whether boundaries (that are necessary to identify systems and their parts) exist or not prior to investigation has been especially debated in the biological field (e.g. Wimsatt, 2007; Winther, 2011).

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