Sustainability Science (2018) 13:1323–1335
https://doi.org/10.1007/s11625-018-0573-2

SPECIAL FEATURE: ORIGINAL ARTICLE

People, Technology and Governance for Sustainability: The Contribution of Systems and Cyber-systemic Thinking

Providing sound theoretical roots to sustainability science: systems science and (second-order) cybernetics

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Received: 30 October 2017 / Accepted: 24 April 2018 / Published online: 15 May 2018

Abstract

After its infant stage, a new science usually starts reflexing on its identity and theoretical roots. Sustainability science is not an exception, and the needs of self-reflection are even more pressing because of its inter- and trans-disciplinary characters, which involve a plenty of different approaches, theories and practices. In fact, such a variety does not provide a consistent ground for its future development. Without a solid grounding on a reliable base, the plethora of different theories that currently crowds its arena could in the near future produce a rejection from disciplinary specialized researchers, thus confining sustainability science to a scientific fad. Convincing theoretical roots can be found in systems science and cybernetics, and in particular second-order cybernetics, once amended from autopoiesis theory and radical constructivism, which raise serious doubts of validity and applicability. If sustainability science acknowledged its systemic and cybernetic nature and adopted second-order cybernetics in its amended version, it would gain a powerful reference paradigm and a theoretical common denominator and language to support its researchers and facilitate their knowledge exchange. From their part, systems science and cybernetics would be better understood and embraced as powerful sources of knowledge for understanding modern challenging problems, and second-order cybernetics, after decades of scarce relevance for other scientific disciplines, would be revitalized and would finally evolve adequately in a promising science and social practice.

Keywords Complexity · Cybernetics · First-person account · Recursivity · Second-order · Self-organization · Sustainability · Systems science

Introduction

Scrolling through the scientific literature on sustainability one would discover countless references to a plethora of theories or (more or less diffused or consolidated) approaches[1]. This is typical of the infant stage of anything, be it a technology or discipline or art: there is a proliferation of different views or practices, which later are selected out by an evolutionary process of competition for the (temporally or locally) best or fittest[2]. Sustainability science (SS) is not an exception and after an explosive growth it has started reflecting on its own scientific identity and on its theoretical roots, and it is looking for a common background that could be shared by its researchers and practitioners. So far, this is physiological of the evolution of a new science. What is instead quite singular is that, though its evident approach is based on the systemic view and on the circularity of interaction mechanisms, when focusing on its foundational contributions (Kastenhofer et al. 2011; Komiyama and Takeuchi 2006; Moran 2010), besides a generic use of the "system" concept, one would not find trace of any reference to cybernetics (Ashby 1956; von

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[1] This polisemic state of the art is confirmed by the scientometric analysis made by Kajikawa et al. (2008) on about 10,000 papers concerning sustainability published up to 2005.

[2] I am not arguing here that what survives is necessarily the absolute best, the optimum. On the contrary, each best is always local and temporarily, and tomorrow or elsewhere could reveal unfit or far less than the best.

Foerster 1982; Glushkov 1966; Heylighen and Joslyn 2001; Wiener 1948) or systems science (von Bertalanffy 1950, 1968; Klir 1969; Rapoport 1986). With very few exceptions (Griethuysen 2002; Osorio et al. 2009; Thorén and Persson 2013; Wiek et al. 2012) that outcome does not change if the search were relaxed including other important (albeit not foundational) contributions (Bennett 2013; Blackstock and Carter 2007; Brandt et al. 2013; Jernek et al. 2011; Kajikawa et al. 2007; Kates 2017; Kumazawa et al. 2009; Matthews and Boltz 2012; Nucic 2012; Smith-Sebasto and Shebitz 2013; Steinfeld and Takashi 2009; Waring and Tremblay 2016).

Besides journals specifically entitled and dedicated to SS, others dealing with near and as well large and inter-disciplinary fields, such as, for instance, Ecological Economics or Ecological Complexity journals,[3] record the same problems of searching for an enough sound and trans-disciplinary theoretical ground. They too face with sustainability issues and the complexity of a holistic perspective crossing broad domains, such as social–economic–natural complex ecosystems (Wang et al. 2011). As for SS, here too we find a sharp difference between theoretical and applicative papers: while the latter make wide use of feedback concepts and systems methods, the former do not discuss in detail what they can get from systems science (hereafter SYST) or cybernetics (hereafter CYB).

This situation is even stranger because, among the different approaches and theories crowding the SS landscape, not only there would be the place for these two sound, consolidated and valued disciplines, but indeed because they, and especially second-order cybernetics (hereafter SOC), are particularly consistent with SS major claims, at least as they are used in most papers, and in particular in the foundational papers. Indeed, such a consistency between SS on one side and SYST–CYB on the other side is so strong that, as soon as we move from purely theoretical to applied sustainability analysis, most of the concepts and methods drawn from SYST–CYB are almost always and widely employed in SS. Moreover, SS offspring from SYST–CYB is evident not only in applications that explicitly employ methods like System Dynamics (Forrester 1968; Sterman 2001) or Soft Systems Methodology (Checkland 1998; Wilson 2001), but also in most contributions that lack a formal or quantitative analytical apparatus.[4] In short, it seems that cybernetics and systems principles and methods are widely used in applied sustainability analysis and are also very consistent with SS, but are not yet clearly acknowledged and discussed, especially within SS purely theoretical approaches. Hence, the goal of this paper is to provide good reasons to acknowledge the consistency of SYST and CYB with the so far claimed principles of SS, and thus, to candidate these two disciplines playing as its reference paradigm. Further, being SOC an important evolution of SYST–CYB, a special attention will be dedicated to understand the specific contribution that this research area can give to SS and its future developments and applications.

To discuss these ideas, in the next section, I will highlight SS main distinctive points, right followed by those of SYST–CYB and SOC. Then, in "A consistent matching", the strong consistency between the SS and SYST–CYB will be evidenced. Later, I will suggest not following the (perhaps currently major) research stream of SOC, namely the one based on autopoiesis theory and radical constructivism, because it raises serious doubts of validity and applicability. Instead, I will propose to adopt SOC in an "amended version", but at the same time to integrate it with recent developments of cognitive and complexity sciences. In the same vein, but looking at future developments and applications of SYST–CYB to SS, in that section some methodological issues will be touched, with a special reference to agent-based simulation methods. Finally, in the last and conclusive section, I will underline the relevance for SS to acknowledge SYST–CYB as its theoretical roots and the reciprocal advantages to adopt SOC in its amended version.

Main distinctive points of sustainability science

Some of the main SS distinctive points can be drawn from the editorial of the first issue of this journal, signed by Komiyama and Takeuchi (2006). Above all, there is a strong claim for a holistic view of reality, comprehending the natural, the social and the human spheres, with its many interactions and in a global perspective. Global warming, waste production and the spread of infectious diseases are addresses as paradigmatic examples of such interactions. Thus, there is a strong emphasis on interdisciplinarity because each of these spheres is constituted by a multitude of specialized research areas, which should be combined in some kind of synthesis. A further claim is that the "emerging discipline needs to be a dynamic and evolving field of inquiry that provides visions and scenario analysis pointing the way to global sustainability". Next, the authors underline the complexity characterizing all these phenomena and the need to structuring

[3] Indeed, nowadays at list these journals are focusing on and systematically contributing to some common issues. Just to name one of them, let see at the question of creating appropriate indexes for a sustainable society. The list would considerably lengthen when enlarging the spectrum also to methodological aspects, in which case we should add journals like Environmental Modelling & Software, Ecological Modelling, etc.

[4] Among the exterminate and fast growing literature on applied sustainability using cybernetics or systems principles, see Blay-Palmer (2010), Kopainsky et al. (2012), Lang and Barling (2012), Smith and Stirling (2010), just to name a few recent ones.

SS knowledge in a way to facilitate a trans-disciplinary approach[5] and knowledge exchange.[6]

Very importantly, in that paper there is a first, albeit weak, hint to the difficulty that should be overcame if a "highly restricted perspective" were assumed, especially as concerning "phenomena identification and problem solving". Still in the vein of these epistemological–methodological considerations, Komiyama and Takeuchi warmly support the creation and development of appropriate sets of criteria and indicators conforming to scientific standards, and—very wisely—they do not suggest to strictly deriving concrete solutions from them. Instead, they recommend that criteria and indicators "should be sought in accordance with the particular environmental and cultural conditions of each nation or region". Solutions—it seems to understand from their paper—should be shared as most as possible and not imposed, and be leveraged by bottom-up processes. The focus on the identification and role of knowledge brokers and facilitators (Hering 2016) that characterizes some part of the recent literature on ecological issues and SS is consistent with and addressed to concretize that perspective. Put differently (and likely in a fashion close to evolutionary economics and organization sciences), rationality and its products are necessarily local and bounded, and (more importantly) choices should be oriented by cultural values. I will come back on this topic in "Useful amendments and integrations to second-order cybernetics".

Finally, it is also very important to underline what is *not* claimed by all SS founders: no any suggestion—no illusion, it could be remarked—of optimal states or choices. This missing claim is more important than other present claims, because it marks the sharp distance from standard economics and most branches of engineering and operational research (Biggiero 2016a). These disciplines constantly suggest the view that it is possible to find optimal solutions, whose discovery is obtained at the price of oversimplify the complexity of real phenomena.

Among the other foundational contributors, Moran (2010) highlights the complex nature of the interactions between the ecological and the socio-economic systems and more generally of the human–environment dynamics. He adds an emphasis on the self-organizing properties of these systems, and as already did by Komiyama and Takeuchi, stresses the crucial role played by the cultural environment and the education system. Kastenhofer et al. (2011) argue that three established inter-disciplines, namely ecological economics, technology assessment and science and technology studies, can effectively help constituting SS in its inter-disciplinary aim. Recalling the previous literature describing SS main traits, they drew up a list within which some points are particularly fitting our discussion: addressing complexity, uncertainty, cross scale (micro/macro) and multilevel interactions (local, regional, national and global), acknowledging change, evolution and dynamics (long term perspectives), (re-)contextualizing research and results, addressing normativity (acknowledging and explicating values), engaging in a dialog with practitioners, implementing participation (participatory methods, extended peer review), consciously defining and enacting its societal role by staying independent, communicating results to society and formulating policy advise.

Systems science and second-order cybernetics

Skipping the history of very early precursors, while most researchers[7] came from Europe, SYST and CYB started as systematic and acknowledged scientific disciplines in USA right after WW2, in which most founders and followers took motivations, ideas and resources: all US military forces had been generous providers of funds, institutional contexts and laboratories. SYST and CYB have a large area of overlapping and can be distinguished only respect to different emphases on specific aspects (Umpleby and Dent 1999): SYST is more interested in identifying, classifying and studying any kind of systems, CYB is focused only on feedback-type systems and on its control and regulation mechanisms. Both disciplines followed a similar evolution and they are currently taken as the same thing or anyway hosted often in the same university departments (or journals) under the label of cybernetics and systems science. They have in common also the development and then a shift of emphasis from more engineering-based (or "hard") to more social-based (or "soft") approaches. In fact, besides the two founders—Bertalanffy (1950, 1968) for SYST and Wiener (1950) for CYB—who were very much concerned of both biological and social issues, early developments were focused mostly on physical and artificial (mechanical[8]) systems applications,

[5] The claim for trans-disciplinarity is frequently made also by other authors within the field of SS: see for instance, Lang et al. (2012).

[6] Jernek et al. (2011) and Kumazawa et al. (2009) deepen the issue of knowledge structuring, but do not touch SS theoretical grounds or roots.

[7] As in many other fields of science, art and literature, most scientists were Europeans escaped from Nazis' persecution or war life. To have an idea of the key-scientists in the cybernetics group see Heims (1982, 1991) and Scott (2004). More recently, Kline (2015) revisits that history, and provides arguments to explain the relevance of cybernetics for current and future society.

[8] It is worth specifying the adjective "mechanical", because scientists often forget that, though its properties are very different from those of the mechanical systems, even social systems—at least those that are intentionally built up—are "artificial" in the sense of men-made, that is, produced by the society and not by the nature alone.

which have been progressively accompanied by interests towards economic, biological and then social and psychological systems. Such a "drift" required and enhanced a progressive complexification of appropriate methodologies and a separation from the very hard core of operational research, which indeed born just with these two disciplines. "Soft" methods and applications to socio-psychological or socio-cognitive systems cohabited for some times within the same operational research departments, to be often marginalized and evicted over time, so that nowadays usually only "hard" methods have citizenship there.

The primer goals of SYST were to underline that the physical world is discontinuous, because phenomena are characterized by systems, which mean sets of interconnected elements that behave as a whole, using and responding to inputs to produce its outputs. It followed soon the issue of how to identify systems boundaries, that is, to mark such discontinuities. The other fundamental goal has been that of stressing the existence of a holistic property, that is, the fact that, once elements are considered into a system and not in isolation, its features can significantly change and be very hardly—if not impossibly—predicted. Moreover, elements interactions can give rise to nonlinear effects, so that a system dynamics can follow complex behaviors (trajectories). Therefore, many systems show the so-called emergent properties, that is, hardly predictable behaviors—which become unpredictable in the long run. Nevertheless, though the mathematical theory of systems dynamics deals exactly with these issues (Bertuglia and Vaio 2005) and dates back to almost a century, for long time—and still now in some scientific milieu—the holistic perspective is seen with hostility and suspect, as a sort of mysticism, because it opposes to reductionism and the never-ending illusion of large predictability power.

Born with the military needs of developing servomechanisms and weapons targeting mechanisms, CYB focused immediately only on that particular class of systems that are characterized by feedback mechanisms and on the ways to regulate and control them[9] (Heylighen and Joslyn 2001). A feedback mechanism implies a form of circularity, because the effect of a cause produces consequences on the system's cause—or even becomes a cause itself. This is exactly the matter of recursive functions in mathematics, and it is paradigmatically represented by the logistic map (Bertuglia and Vaio 2005; Hall 1991). When the feedback is positive, nonlinear dynamics is produced, and consequently most of the main and (now) well-known forms of complexity too (Biggiero 2001a; Casti 1994). It could be said that positive feedback is the true source of nonlinearity, and then of complexity.

Early cyberneticists (McCulloch, Rosenblueth, and Wiener) showed also another implication of that circularity, namely that a systems behavior can be led by its own goals, that is, by its expected events rather than by its causes. Put differently, for teleological systems, the expected (or pursued) effects are the causes of its behavior. This fundamental epistemological remark has very important implications on the juxtaposition between determinism and intentionality in human systems (Biggiero and Laise 1998), and on causality in science tout-court. Therefore, nevertheless the legitimation and formalization coming from the mathematics of recursive functions[10] and nonlinear dynamics, and nevertheless the several practical results obtained with successful applications, the attack to the traditional view of causality and the claim for circular explanations and thinking[11] casted on CYB a light of suspect and hostility by traditional and positivist scientists, not differently from what happened to SYST for its claims of holism and emergent properties.

Indeed, from that time on, the issue of self-… something, namely self-organization, self-reference, self-production, self-reproduction, and self-maintenance became a central topic in SOC (Scott 2004; Ulrich and Probst 1984) and beyond it.[12] The revolutionary content of self-organization is that self-organizing systems are capable of a certain degree of autonomy, which means that external inputs can

[9] As Wiener says in the introduction to the original edition of his foundational book (1948), the term "cybernetics" was chosen by him and the Mexican neurophysiologist Arturo Rosenblueth to recall the concept of feedback and its regulation mechanisms that Clerk Maxwell called "governors" in a paper published in 1868. Wiener writes also that his ideas and those of Shannon regarding the mathematical theory of communication were consistent and supporting each other. In fact, the debate developed during the 60s and 70s on the nature of self-organizing systems referred always to Wiener's and Shannon's works on feedback mechanisms and information entropy, respectively. See Ashby (1956, 1960) and von Foerster (1982).

[10] Not to say of the special recursive logics elaborate to his aim by Günther (1962, 1967) and Spencer-Brown (1968), then applied by Varela (1979) to biological systems and particularly to the immune system.

[11] Since the logical and semantic paradoxes discovered by Russell's and Withehead's "Principia Mathematica", circular thinking has been almost always rejected as source of paradoxes or avoidable difficulties.

[12] In physics, Haken (1983), Nicolis and Prigogine (1977) and Eigen and Winkler (1993) deserve self-organization a primary place; in mathematics, I have already mentioned the theory of recursive functions, and more precisely into the field of logical self-reference, Günther's (1962, 1967) works; in computer science, von Neumann (1958) made the seminal work on self-reproducing automata, soon followed by cellular automata (Wolfram 1994) and Boolean network studies (Kauffman 1993, 1995), then evolved into artificial life (Waldrop 1992) and later into artificial societies; in biology, Kauffman L (1986) and Kauffman SA (1993, 1995); in various other fields, Foerster and Zopf (1962), Roth and Schwegler (1981), Yates (1987), Yovits and Cameron (1960), Zeleny (1980, 1981). The axiomatization of self-reproducing automata was provided by Löfgren (1968).

be absorbed and elaborated in various ways depending on a system's inner structure, so that its outputs become largely unpredictable. Perturbations can induce either a simplification—and hence increasing redundancy—or a complexification—and hence increasing entropy. But relatively simple systems, as engineering servomechanisms and targeting systems studied at the beginning of CYB, were rarely producing such complex behaviors. Conversely, biological or social systems showed such a complex inner structure to generate self-organizing properties. Memory and learning are nothing else than manifestations of these properties.

A second central theme was that of including the observer into his observations, that is, moving from observed to observing systems. Such a shift intends to achieve a reasonable and eventually also a much more ambitious goal.[13] The reasonable goal is to stress the fact that, besides simple systems, whose identification and boundaries are usually rather clear, stable and shared, many natural systems and most social systems can be identified in a variety of different ways, and even more importantly, its goals, functioning and properties are very disputable, unclear and unstable. In short, system identification is observer-dependent. The more ambitious goal is to frontally attack all kinds of realist or representationalist epistemology by arguing that, being humans necessarily subjects, their observations and (scientific) theories are necessarily subjective too. Therefore, reality cannot be understood objectively, but rather only subjectively constructed. Any supposed objective knowledge would necessarily be an illusion. Von Foerster (1982, 2003) and von Glasersfeld (1995), jointly with Maturana and Varela (1980, 1987), propose to replace any kind of realist or pragmatist epistemology with their radical constructivism.[14]

The third central theme of SOC is the emphasis on the complexity of natural and especially social systems, and consequently on the substantial impossibility of its control. Recalling the basic cybernetic concept of a system—or machine, in the language of engineers and automata studies—as a black-box, von Foerster (1984) proposed the distinction between trivial and non-trivial machines, the latter being systems that have internal states. Now, while the complexity of a trivial machine is done by (2^{output})^(2^{input}), which is already an extremely high number for even small number of outputs and inputs, the complexity of non-trivial machines is much higher, because its dimension raises to $(2^{k\text{output}})$^$(2^{k\text{input}})$, where k is the number of internal states. It is easy to show that almost all natural and social systems are non-trivial machines, whose future behavior is therefore almost completely unpredictable, at least in the long run. Therefore, they cannot be controlled, but rather, in the best case, they can only be steered by designing (if possible) self-regulation mechanisms and by enhancing conversation.

The fourth (and last) central theme is, in fact, that of underlying the crucial role of conversation (Pask 1975) and the maintenance of social variety, then hindering any form of imposition and uniformity. As a sort of exhortation, von Foerster advanced the following principle: if you want to improve society, act always to increase variety. Pask remarks that communication takes always the form of reciprocity, and thus, of self-reference between the communicating parties. In a dialog, communication proceeds by referring to the other's words and hopefully, if some form of mutual understanding emerges, this self-referential process converges to some common action or decision. It could be called an "eigen-behavior", that is, a behavior resulting from recursive operations on the reciprocal words. Shared values and beliefs are made of the same matter and generated in the same way: communities can form them only through conversation.[15]

In short, while early CYB was dealing with relatively simple systems, which can be well identified and sufficiently controlled, and which usually have poor (if any) self-organizing or self-referential mechanisms, as soon as the interest of cyberneticists moved to natural and then social systems they had to weakening all their ambitions: such systems can be variously identified in its boundaries as well in its inputs, outputs and goals, they are characterized by high complexity and a number of self-organizing mechanisms, and thus, they cannot be controlled, at least in the full sense of operations research. Early CYB, with its emphasis on control and optimization, remained confined

[13] There is indeed a third sense of including the observer into his observations: the idea is that when an observer interacts with an observed system (at least some kinds of observed systems), he modifies it, so that object is no more the previous one: it becomes a new object derived from the interaction between the observer and the observed. Thus, it is a source of true (insurmountable) complexity (Biggiero 2001a). It can be read as a manifestation of Heisenberg's indeterminacy principle, which in fact is very well-known also into the realm of organization science under the label of the Hawthorn effect. More generally, all expectation- or observation-based phenomena, such as self-fulfilling prophecies, produce forms of Heisenberg's indeterminacy principle when they concern social systems (Biggiero 1997).

[14] In "Useful amendments and integrations to second-order cybernetics", while proposing amendments to the adoption of SOC, I will come back on this point. To place autopoiesis and radical constructivism within the development of SOC see Glanville (2004) and Scott (2004).

[15] Viewed from current eyes of modern cultural anthropology, sociology and social network analysis, this conceptualization could sound not so innovative. However, the judgment changes when considering not only that more than 40 years passed, but (more importantly) that through that conceptualization the concrete problems of social, political or economic conflicts that sustainability choices can raise within communities can be analyzed and understood at a deep level.

into engineering departments, which deal mostly with simple (trivial) artificial machines.[16]

Indeed, systems scientists experienced the same drift and reacted to systems complexity in the similar way of cyberneticists: Soft System Methodology (Checkland 1998; Wilson 2001) has been built just for the ill-structured problems typical of social systems. Noteworthy, large part of this methodology is devoted just to identify a system's boundaries, (dis)functioning, presumed actual and desired goals, and to match, through conversational and social–psychological methods, latent or manifest conflicts. Not by chance, Umpleby and Dent (1999) list also various organizational learning approaches under the label of social systems science. A noticeable exception of an old-fashioned approach that is progressively and successfully diffusing is that of System Dynamics, which comes directly from the servomechanism studies of its founder, the engineer Forrester (1968). He provided, in fact, the basic methodology to realize the first famous study that could be labeled as dealing with sustainability on the planet scale: the Meadows report on *The limits of growth* (1972). Its use seems growing within the community of researchers on sustainability science.

A consistent matching

As we have seen, SS claims inter- and trans-disciplinarity, because they aim at combining different disciplines and getting holistic views. It is stressed the need to analyze a problem and elaborate a solution by looking at the whole chains of interdependencies that it involves in its own field and even across other fields. Thus, SS takes a clear systemic perspective and attempts to build scenarios based on the explicit acknowledgment of positive and negative feedback mechanisms, either within a single sphere variables, for example, the ones concerning climate change, or between different spheres, for instance, when considering interactions and feedbacks between social and natural variables. Further, SS is well aware of the uncontrollable complexity of socio-natural systems, and hence especially in its applications, it does not claim to be able finding optimal solutions, but rather viable and reasonable solutions.

Moreover, as it emerges more explicitly in mid-theoretical papers, like that of Wiek et al. (2012) where empirical works are conceptualized, the value of conversation and dialogs—as the appropriate means to reconcile conflicts and different interpretations—is taken in the highest consideration. Not by chance, knowledge diffusion and brokering are seen as critical functions of ecological themes, explicitly acknowledged as ill-posed questions (Loehle 2011), thus involving the problem above mentioned of systems identification, goal direction, etc.

Finally, no trace of illusory optimal solutions is usually found in works concerning sustainability. It could not be else, because inter-disciplinary, complex, ill-posed and people-sensitive questions can really be hardly optimized. The French school of operational research has demonstrated since long that truly multicriteria problems cannot be optimized, at least in the general case. Only satisfying solutions can be obtained through algorithms such as the outranking methods. This is another dimension of bounded rationality, a dimension particularly important (albeit poorly acknowledged outside a small community of researchers) because it does not derive from cognitive biases or computational loads.[17]

These issues are not always manifested and discussed in the so far SS theorizing, because it is still at an embryonal stage, with few papers that intentionally approach foundational issues. However, all these traits can be easily retrieved by reading the huge mass of applied studies where sustainability is put as the main or distinctive purpose.

If taken jointly, the evolved versions of SYST and CYB, namely (and respectively) System Dynamics, Soft Systems Methodology and SOC, which developed from the end 60s by tackling the biological and then the socio-economic domains, perfectly match all SS main topics. Besides the acknowledgment of ill-posed questions and ill-structured systems, which is the peculiar theme of Soft System Methodology, SOC provides a formal theorization and practical application of the main features of complex systems: its non-linearity, adaptability, recursivity, (partial) autonomy, and creativity. SOC's strong orientation towards discovering abstract trans-disciplinary frameworks marked its development from the very beginning, and indeed roused the criticism of lacking any new operational methods. This caused its scarce appealing for normal science and practical applications, because the former privileges specialism and ignores or even disregards inter- or trans-disciplinarily, and the latter

[16] Unfortunately, through operational research methods and its consistency with mainstream economics, the trivialized, oversimplified and inappropriate view is taught to students and applied to society and economy. For some criticisms on this issue see Biggiero (2016a). Interestingly, when these departments began to deal with robotics, and especially advanced robotics, such as robots societies, then they started to come back (or go forth) to the typical issues of SOC. In other words, when machines become truly complex, then the fundamental issues of self-organization and communication are unavoidable. For a discussion of the implications of robotization for economy and society, and its relationships with cybernetics and hierarchy, see Biggiero (2018).

[17] For applications into the fields of economics, finance, technology policy, and management science, see Biggiero and Laise (2003, 2007) and Biggiero et al (2005).

requires simple rules or guidelines. In this perspective, the birth of SS and some other strong inter-disciplinary fields such as ecological economics, and the claims of Mode-2 scientific development (Gibbons et al. 1994; Nowotny et al. 2003) as a requisite to match the challenges of complex phenomena, create the best conditions to revitalize SOC. The ideal milieu is a cultural environment not more hostile, and perhaps explicitly favorable, to trans-disciplinary research, like the one that is nurturing SS.

Useful amendments and integrations to second-order cybernetics

Not all streams of SOC are recommended to be put at SS theoretical ground. There are two of them that seem less consistent with SS and raise a lot of doubts about its validity and applicability: they are autopoiesis theory (Maturana 1975, 1981; Maturana and Varela 1980, 1987; Varela 1979; Varela et al. 1974) and radical constructivism (von Foerster 1982; von Glasersfeld 1995). The latter is an epistemology very much related to the former, and both have a significant following in some branches of continental sociology (Luhmann 1986, 1990) and in management sciences (Magalhães and Sanchez 2009; von Krogh and Roos 1996; von Krogh et al. 1998; Zeleny 2005), especially in information systems theories (Magalhães 2004; Mingers 1995; Yolles 2006).

It is useful to briefly remind to the connection between autopoiesis and radical constructivism.[18] The key point of reasoning is the following: as an autopoietic system, a biological system has an operationally closed nervous system totally separated from the external reality.[19] Two implications follow: (i) the system (the observer) perceives (observes) the external environment only through the impacts (perturbations or signals) that it is able to receive (perceive) and elaborate, (ii) the images and properties of reality are then observer-dependent and relatively free constructions (inventions) of the observer and are constrained within its cognitive domain. This cognitive domain is an autonomous system that—as it was argued by Maturana and Varela—has an invariant organization. Its behavior changes depending on the perturbations (perceptions) received by the environment and its own dynamics in terms of recursive operations. In some essential sense, hallucinations and "real" perceptions are indistinguishable, excepted for the fact that the latter are "confirmed" in successive observations: "real" objects are stable respect to recursive observations. Therefore, according to von Foerster (2003), "real" objects are nothing else than the eigenvalues of recursive observations.[20]

This idea has been revalued and relaunched by Müller and Riegler (2017) and Kauffman (2017) as the ground on which building a new subject-based epistemology. After 50 years of stagnation, the very recent volume edited by Riegler et al. (2017) and the 12-year contributions of the Constructivist Foundations journal are attempting to give new impulse and new directions to the SOC research program The two main conceptual pillars identified for its revitalization are the pervasive presence of circular interaction mechanisms in almost all phenomena and the integration of the observer's view into the production of scientific knowledge. They argue to call this latter aspect "the view from within", juxtaposed to the view from outside, which they call "the view from without", represented by the need of an observer's neutrality—related to the supposed existence of an "Archimedean point"—characterizing the epistemology of standard science. Riegler and colleagues propose that these two issues should be the research streams of SOC future developments, and these are also the perspectives orienting the contributions collected into their volume. The emphasis on these two issues is so strong that Umpleby (2017) claims that SOC is bringing forth a scientific and epistemological revolution.

As we have seen, these two aspects are not peculiar of SOC, but rather they are common to all SYST–CYB research tradition and also to other disciplinary areas beyond it. Moreover, in some cases, they have been discovered before SOC and developed parallel and independent of it. For instance, circular causality, which in the SOC literature is preferably called as reflexivity or second-order approach, dates back to the mathematics of recursive functions and it is easy formalized with the generic and broad form as $x_{t+1} = f x_t$ (Bertuglia and Vaio 2005). All the mathematics of system dynamics is based on the concept of circular causality, and physics, chemistry and engineering have been based on positive and negative feedback mechanisms. Not to say about the logical paradoxes treated by Russell and Whitehead in their Principia Mathematica and widen in the

[18] Let us remind that there is also a sociological constructivism, born and developed totally independent of cybernetics, even though during the same decades. For an articulated answer to both sociological and cybernetic constructivism see Biggiero (2012), who places this issue within the debate on two alternative views of knowledge, seen as practice or possession, which he sees as a false juxtaposition suggested by the constructivist epistemology.

[19] The researches of Maturana and Varela at Foerster's Biological Computer Laboratory of the University of Illinois were focused exactly on the perceptions and view of frogs through its nervous system.

[20] Eigenvalues are the fixed points, the attractors of a recursive function. This idea has been revalued and relaunched by Müller and Riegler (2017) and Kauffman (2017) as the ground on which building a new subject-based epistemology. I will come back on this point later on.

following set theory and its further developments.[21] Self-reference is at the root of all the paradoxes and problems discussed in the long lasting debate on the foundations of mathematics, of which Gödel's famous theorems represent a crucial part (Casti1989, 1994).

Even though it is true that SOC insisted on this issue, it has neither the primacy nor the exclusivity on that. Nevertheless, Riegler and colleagues claim that, since (almost all) phenomena have a reflexive nature, an entire new research field can be baptized as second-order science (Müller 2016). Indeed, many social sciences, and in primis standard economics, have been systematically and persistently reluctant to consider circular mechanisms, because of the very good reason that its fundamental purpose of demonstrating the existence, uniqueness and stability of a fixed point would have put in serious danger by that acknowledgment.[22] Even because of this danger, the recalling and emphasis on von Foerster's idea of grounding a new kind of realist epistemology on objects as the eigenvalues (or fixed points) of individuals' and collectives' observations sounds rather suggestive, challenging and disputable at the same time. And also a little bit naïve, when considering the many decades of debates in economics and mathematical physics as concerning the many difficult and constraining conditions required by a system to reach a fixed point.

As for the other pillar proposed by Riegler and colleagues, that of the view from within, things are not smooth either. That view has been historically brought forth by anthropologists and ethnographers, some of whom indeed co-founded the field of cybernetics, such as Gregory Bateson and Margareth Mead. Since then, ethnographic approach is one of the many empirical methods of scientific researches in social sciences. Therefore, SOC can claim that it is a fundamental part of its research program, but it is not its prerogative. More disputable is the argument that such method requires and implies a different epistemology. On one side, it is no surprise that a methodological change might imply an epistemological change: it happened often in the history of science, and the structural view is just one more recent case (Biggiero 2016a, b). On the other side, there are doubts that this would be the case also for the view from within. More precisely, it is not yet clear whether the true point is on a perspective shift from the outside to the inside of a system or from a supposed (but illusory) neutral to a subjective observation. The former juxtaposition would be definitely more interesting than the latter, because the claim of the implications of the subjectivity of observations/perceptions is neither new nor effective in epistemology. As Ataria comments (2017), the SOC perspective on subjective perceptions (Gasparyan 2017) reminds once more the old argument of the subjectivity of knowledge due to the subjectivity of perceptions/observations. Moreover, that perspective overlooks Varela's support (1996) to the neurophenomenology research program, according to which there is no contradiction but rather complementarity between the first- and the third-person knowledge. Even more clearly, few years later Varela argues that "much wasted ink could have been saved by distinguishing the irreducibility of first-order descriptions from their epistemic status" (Varela and Shear 1999: 2). And few rows below, they reaffirm that "we are not concerned with yet another debate about the philosophical controversies surrounding the first-person/third-person split (a large body of literature notwithstanding). To make this possible, we seek methodologies that can provide an open link to *objective, empirically based description*" (italics mine). These two quotations highlight that Varela, one of von Foerster's most brilliant disciples and a SOC pioneer, disagree with one of the two pillars proposed by Riegler and Müller, namely the foundation of a new epistemology, based on the view from within. Further, Varela and Shear argue that the first-person observation can be studied objectively as typical of all empirical sciences. Finally, it should be noticed that he contends such arguments even in an issue like consciousness that could be considered the most paradigmatic for the authors of the recent horizons of SOC.

Indeed, this perspective is not new in the methodological landscape, because it is pursued since long by ethnographic, post-modern and neo-constructivist (in the sense of sociology research tradition and not of SOC) studies, and SS itself, which is just characterized by an extensive use of these types of methods and by the high value assigned to participation and practice.[23]

[21] Let us notice that a good reason to not use reflexivity or self-reference as the broad term to indicate the operation of an entity on itself is that in the realm of logics we can admit simultaneity while in the realm of natural or social or artificial phenomena there is time sequence. Therefore, it should be used the concept of recursivity: an entry operates on itself in a different time lapse. The lack of distinction of these radically different domains and the undistinguished use of the term "reflexivity" is a source of many suggestions made by von Foerster, but also a source of confusion when attributing the properties of reflexive logics and mathematics to the properties of recursive processes in the real world. The concept itself of circular causality would be more appropriate to indicate that A determines B at the moment t, while B determines A at $t + 1$.

[22] See Biggiero (2016a, b) for a short discussion of this point and the essential references to the broader debate.

[23] See various papers in this same journal, and in particular Wiek et al. (2012).

Future developments and applications of systems science and cybernetics to sustainability science

As discussed so far, SYST–CYB should be considered the soundest and most appropriate theoretical roots of SS. But this was the past and present. What can we say about SYST–CYB possible contribution to SS future development? And what could be the distinguished contribution of SOC?

As for the former question, the answer is short and clear: four are the main contributions that SYST–CYB can give to SS future development. One is insisting on claiming a holistic view of sustainability problems, opposed to the persisting reductionist attitude of scientific work. The second one is reminding the characteristic of recursivity—especially in the form of positive feedback mechanisms—characterizing all phenomena from the sustainability perspective. The third contribution is continuing to underline the need of trans-disciplinary approaches to sustainability science, because the various phenomenal domains and its corresponding scientific disciplines have many common properties and problems. The fourth one consists in emphasizing the role of conversation and participation in dealing with problems—and especially with policies and practices—of sustainability. In fact, the "view from within" always adds something more and different respect to standard scientific approaches built on the "observer's neutrality" assumption. Moreover, ethical issues can be hardly "measured" and accomplished in standard modeling and analyses, especially when they are limited to quantitative approaches. Therefore, voice and conversation should be maintained as crucial and indispensable methods of sustainability science.

As I briefly outlined in previous sections, all these four themes have already characterized SYST–CYB research tradition, and so one could contend that there is nothing new. It is true, but the hard task is insisting on them and updating its relevance, for example, by unmasking the new versions in which reductionist approaches return every day. Most papers and journals do still focus only on single small pieces of science, while holistic views waken usually scarce interests, if any. Most textbooks might even mention, in the early pages, the need for an integrated and systemic approach, but then, in the remaining chapters, that exhortation gets fatally lost. Consistently, the same forgetfulness occurs for the other three themes just reminded.

As for the second question, I propose to adopt SOC without its drift to autopoiesis and radical constructivism, because autopoiesis theory: (i) is not necessary to show that social systems are self-organizing networks, (ii) is misleading and backward[24] when it suggests that social systems are operationally closed and autonomous, and (iii) is superfluous to assert that social systems are cognitive systems. Further, I suggest integrating SOC with two fields: one refers actually to the fallacies of human rationality and comes from cognitive sciences; the other one refers to the modern developments of complexity science and the methodologies able to "grasp some more piece of reality". Of course, neither of the two can be discussed adequately here, but some clues could be useful. Instead of claiming a sharp and irreducible separation between our cognition and reality, since the pioneering works of Kahneman et al. (1982) cognitive sciences are studying more and more deeply the failures of human reasoning (Dawes 2001; Taleb 2007) and especially those of decision making (Gigerenzer 2008; Simon1983). About 50 cognitive biases have so far been well identified,[25] and many of them are under close scrutiny with experimental psychology and laboratory economics. Human behavior is strongly conditioned by these biases and failures, and consequently the behavior of policy makers, and more generally, decision makers too. Moreover, some of these biases are peculiar of collective decision making. Therefore, we guess that this literature should be part of SS theoretical background.

As concerning complexity, SOC has the great merit to have touched all sources of complexity in human systems (Biggiero 2001b), namely, computational complexity evidenced with the concept of non-trivial machines, relational complexity due to the disturbing effect of the observer–observed interaction, logical complexity related to self-reference, semiotic complexity due to language and subjectivity, and to a far less extent, chaotic complexity. However, its limit is that all them have been treated almost only at very abstract levels, and perhaps pushed by the influence of radical constructivism, as hopeless conditions that do not allow any advancement of empirical knowledge. On the contrary, though some part of modern research is aware that such sources represent unsurmountable limits to deep knowledge, many researchers nevertheless are convinced that weak forms of knowledge are possible even in the presence of one or more sources of complexity. Here "weak" means that knowledge is local or referred to the short-run or

24 Since the research on epigenetics in the nineties and post-genomics in the first decade of this century, we know that due to pseudo-Lamarkian learning processes or induced from the environment through food and chemicals, our deep inner structure do change over time. See Jablonka and Lamb (1995, 2000) and Choi and Friso (2009). It should be noticed that through bionics engineering the integration of a biological system with other biological or non-biological systems will be more and more strict.

25 To get a stimulating clue of them, check on wikipedia "List of cognitive biases".

approximate, like in the identification of most probable scenarios due to climate change or in the relationships between technology and energy resources.

While claiming to be open to a multi-methodological perspective (Biggiero 2016b; Mingers and Gill 1997), a method deserves a special attention of SS researchers: agent-based simulation modeling (Biggiero 2016b; Gallegati and Richiardi 2009; Gilbert 2008; Squazzoni 2012; Tesfatsion and Judd 2006). This family of models is a true methodological revolution for economics and management sciences (Biggiero 2016a) and generally for problems involving social or social–natural interactions, because they can dealt with most complex phenomena, take into account emergent and "immergent" (second-order) properties, and simulate different scenarios or policy interventions. Each model is a "virtual laboratory" in which a given problem can be "reproduced" and investigated under many respects. Within the area of formal methods—which are not the only useful ones, as remarked above—they are the best tools to face with high complex systems, as those usually implied by sustainability science. They have a strong link with SYST–CYB, because they derive from them through cellular automata and artificial life. As an expansion and refinement of artificial life models, it is possible to create and study "artificial societies". Further, agent-based models are a natural and consistent application also of SOC, because they are well equipped to deal with recursive mechanisms and with operational closure. To understand the sustainability lack of most systems of our current world and to design alternative courses of action, SS had to adopt agent-based simulation modeling as a privileged method of research.

Conclusion: the advantages of adoption

Both SS and SYST–CYB would gain a lot from posing the latter at the theoretical ground of the former. SS would legitimate itself with such formal and consolidate sciences that nurtured cellular automata, systems engineering, artificial intelligence, robotics, artificial life, and artificial societies: doubtless an extraordinary pedigree. Moreover, that acknowledgment would stimulate researchers to deepen SYST–CYB main themes and methods, thus providing a substantial improvement of research quality and development. At the same time, it would reduce theoretical proliferation, or at least it would favor a useful classification and recording of the plethora of current theories, methods and empirical applications to some basic theoretical categories. Finally, the formation of such a common background would facilitate knowledge exchange among SS researchers, who would share a common set of concepts, and above all, a common language. It could be a levee to the current extreme heterogeneity of concepts, methods and languages in SS scientific literature, which produces a marked sense of loss and hinders knowledge growth.

On its own side, SYST–CYB would receive a tremendous speed up and visibility that could bring it out of the exile in the engineering departments or scientific niches. It would be diffused and acknowledged as a fundamental paradigm to approach the crucial challenges facing our world today: how to make our life sustainable and survive our blind destructive tendency. Which better and more ethical channel of amplification could be conceived? Wiener, Bateson, and other founding fathers of cybernetics would be proud and glad that their theories and concepts, initially created in reference with simple mechanical machines but ideally yet extended also to human beings and societies, would be used and applied to avoid mankind and planet self-destruction.

Acknowledgements The author thanks the two reviewers and Bernard Scott for their useful comments.

Compliance with ethical standards

Conflict of interest The author declares there is no conflict of interest regarding the Journal *Sustainability Science* or the content of this specific contribution.

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