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► **To cite this version:**

Fabrizio Li Vigni. The promises of complexity sciences. A critique. Perspectives on Science, In press, 31 (4), pp.465-502. 10.1162/posc_a_00592 . halshs-03912726

HAL Id: halshs-03912726

<https://shs.hal.science/halshs-03912726>

Submitted on 25 Dec 2022

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The promises of complexity sciences. A critique

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Abstract

Complexity sciences have become famous worldwide thanks to several popular books that served as echo chambers of their promises. These consisted in departing from “classical science” defined as deterministic, reductionist, analytic and mono-disciplinary. Their founders and supporters declared that complexity sciences were going to give rise (or that they have given rise) to a post-Laplacian, antireductionist, holistic and interdisciplinary approach. By taking a closer look at their content and practices, I argue in this article that, because of their physicalist, computationalist and mathematical assumptions, complexity sciences have paradoxically produced knowledge at odds with these four tenets.

Keywords

Complex systems, Santa Fe Institute, Science & Technology Studies, determinism, reductionism, holism, interdisciplinarity

Complexity sciences are an interdisciplinary and transnational field of study gathering several specialties from natural, engineering and social sciences. They employ different kinds of physics, mathematics and computer science tools in order to model and simulate natural, artificial and social complex systems (Waldrop 1992; Mitchell 2009). This domain of research emerged in the 1970s in Europe and the United States through the work of several researchers, but were strongly brought to the front of the stage in the 1980s by the Santa Fe Institute (SFI). This is a private research center based in New Mexico that was founded by a group of senior physicists from the Los Alamos National Laboratory and from other prestigious American institutions. The SFI is acknowledged for having disseminated “complexity science” (in the singular¹) and a series of now famous keywords (“complex systems,” “self-organization,” “emergence,” “networks,” “transition

¹ The founders of the SFI had in mind to launch a new discipline based on a general theory of all “complex adaptive systems” (Cowan et al. 1994). As I argued elsewhere, this project has failed (Li Vigni 2021a) and has given rise to what I proposed to call a *scientific platform*, that is a meeting point between different specialties that, thanks to a flexible common ground, pursue together shared or parallel socio-epistemic objectives (Li Vigni 2021b).

phases,” etc.), through general audience books (Lewin 1992; Gell-Mann 1994; Kauffman 1993; Holland 1996; Axelrod and Cohen 1999; Levin 1999; Holland 2014), to many fields of knowledge (Urry 2005; Grauwin et al. 2012) and to popular culture (Thrift 1999; Taylor 2003). Along with chaos and some other physical theories, complexity has become one of the most mediatized scientific fields of the last forty years and has attracted the attention of many philosophers (Wimsatt 1994; Rescher 1998; Cilliers and Spurrett 1999; Knyazeva 2005; Aziz-Alaoui and Bertelle 2009; Hooker 2011; Fraiso 2012; Taborsky 2014; Zuchowski 2018) and some social scientists (Helmreich 1998; Williams 2012; Li Vigni 2018a). In their written and oral manifestos, complexity representatives have often criticized what they name the paradigm of “classical science,” defined as deterministic, reductionist, analytic and mono-disciplinary. Complexity founders and supporters declared that this field was going to give rise (or that it has given rise) to a post-Laplacian, antireductionist, holistic and interdisciplinary science. Let me illustrate these promises as a preamble of the present article.

Against Laplace. Firstly, complexity founders and supporters propose to go beyond classical determinism. This is described as a linear conception of causality that is unable to give account of the openness and indeterminacy of

the future evolution of nonlinear systems. In this sense, complexity should focus on entangled, circular and other counterintuitive causalities, in the line of the first and second cybernetics (Rosenblueth et al. 1943; von Foerster 2003). Also, by integrating chaos theory in their frame, complexity scientists have often emphasized systems sensitivity to initial conditions: “[I]n a non-linear system small changes can have big effects, while sometimes big changes in the system don’t have much effect at all” (Homer-Dixon 2011, p. 3; see also Holland 2014, p. 41). In one of the best sellers dedicated to complexity, a leading figure of the SFI has written that “the presence of chaos in a system implies that perfect prediction *à la* Laplace is impossible not only in practice but also *in principle*” (Mitchell 2009, p. 33). Which means that complexity’s position about determinism is both epistemological and ontological. According to such a view, there are no simple causalities in nature: Positive and negative feedbacks are everywhere, so are threshold effects and phase transitions; moreover, the microscopic interactions producing the macroscopic order remain elusive. As a consequence, models and theories have to be stochastic and dynamical if they are to grasp the global emergent functioning of complex systems.

Against reductionism. The second famous promise of complexity scientists was to “move beyond the traditional paradigm of reductionism toward a new understanding of seemingly irreducibly complex systems” (Mitchell 2009, p. XI). Historically, most of SFI’s internal and outreach rhetoric focused on the “rebellion against the excesses of reductionism” (Gell-Mann 1994, p. 119). The very term of complexity has been chosen to signify such an epistemic project. The Latin adjective “*complexus*,” made up with the junction of “*cum*” and “*plectere*,” means encompassing, embracing or comprising. The metaphor applies to something interwoven, difficult to disentangle and thus irreducible. Such a discourse is not only one of the leitmotifs of the promotional and general audience literature about the SFI, but had a certain repercussion in academia, as shown for instance by a special issue of *Science* published in 1999 and entitled “Beyond reductionism” (Gallagher and Appenzeller 1999), or as illustrated by what physicist Albert-László Barabási has called the “network takeover” (Barabási 2011).

Against Descartes. In the third place, according to the SFI’s discourse, the multiscale “architecture” of complex systems calls for a science that is more holistic than analytic (George Cowan in SFI 1988b, p. 5; Simon 1962). The micro-interactions are too difficult to capture, whatever the level of the

system taken into account; but for the complexity expert, the micro-interactions give rise to macroscopic regularities that can be apprehended as such. Holism is thus meant to address the ensemble of elements of a system taken as a whole through numerical modeling. In a way, complexity sciences can be seen as a renewal of Ludwig von Bertalanffy's "general system theory" or "systemics" (von Bertalanffy 1968; Pouvreau 2013). Historically speaking, this claim is false, because the intellectual filiation between the two is not direct (Li Vigni 2018b)². Yet theoretically their approaches are similar: Complexity – like systemics – aims indeed at focusing on the whole, for this is the level that can be more easily seized by mathematical or computational formula when scientists deal with large, diverse and integrated systems.

Against disciplinary barriers. In the fourth place, complexity supporters made of interdisciplinarity their constitutive *modus operandi*. Citing Charles Snow's famous book about the "two cultures" (humanist and scientific), physical chemist George Cowan – kingpin and first president of the SFI – wrote in his memoirs that his wish was to bridge the gap between them by

² Isolated exceptions exist though, because some people from complexity sciences know and mention von Bertalanffy (e.g. Cowan 1994, p. 2), while some systems experts know and mention the SFI strain (e.g. Rosen 2000, p. 1).

employing the computer (Cowan 2010, p. 131). The New Mexican institute was founded with the very intention of pushing interdisciplinary endeavors further than what was done by the Los Alamos National Laboratory (which most of SFI's founders came from); even the idea of complexity came after, as declared by physicist Edward Knapp, one of SFI's initiators: "We became enthusiastic about the possibility of establishing an interdisciplinary institute in Santa Fe. At that point we hadn't homed in on the sciences of complexity and nonlinear systems" (SFI 1990a, p. 8). So, to foster interdisciplinarity, SFI's founders conceived the institute as a visiting research center "free from the artificial barriers defined by the traditional disciplinary and programmatic limitations" (Mike Simmons in SFI 1988b, p. 3).

These four promises constitute what hereafter will be named the *complexity discourse*. This was initially formulated among the SFI's architects at the founding meetings recorded by the institute's archives (in the 1980s), it was then popularized through mass media and divulgation books (in the 1990s), and it was finally reiterated by some social scientists' works (in the 2000s). For example, British sociologist John Urry has talked about a "complexity turn" in knowledge (Urry 2005) and has claimed that "complexity sciences seem to provide the means to overcome [the] divisions between nature and

society and between the natural/physical sciences and the social sciences” (Urry 2006, p. 115). In a similar vein, British sociologists Brian Castellani and Frederic Hafferty have stated that “the major challenge of 21st century science is to think about the world in terms of systems and their complexity” and that “this challenge is so profound that many scholars believe it is creating a Kuhnian paradigm shift in the natural sciences, resulting in a new way of doing science called, appropriately enough, complexity science” (Castellani and Hafferty 2009, p. 119; see also Schweber and Wächter 2000). To sum it up, complexity sciences provide a revolutionary approach because they unite natural and social sciences for the better good of both.

Nevertheless, if we adopt a Science & Technology Studies approach – attentive to scientists’ practices – and a critical-pragmatist frame – based on the empirical analysis and on the philosophical critique of scientists’ activities – we are soon brought to question such an account of complexity. In the following pages I will argue that, contrary to the *complexity discourse*, the field popularized by the SFI does not depart from a deterministic, reductionist, analytic and mono-disciplinary approach. By comparing its discourse to the *complexity practice* – i.e. what complex systems scientists actually do – I will show that this field of research rather renovates and even

radicalizes the “classical science” approach by extending it to new study objects. But the aim of this paper is not only to show how complexity produces knowledge at odds with its promises. The question is philosophically and sociologically intriguing also because it poses an interesting paradox: How to explain that “complexity science” produces reductionist knowledge? How come that this new approach, supposed to revolutionize all fields of knowledge, ends up pushing further the “classical” approach it openly challenges?

After a section dedicated to materials and methods, four parts follow that offer a deconstruction of the promises of complexity: Examples from different sorts of texts and first-hand sociological interviews are given to show how the *complexity practice* contradicts the *complexity discourse*. The last section of the paper proposes an explanation of the paradox just mentioned. Therein I defend the idea that, from the outset, the epistemic project of complexity sciences was to address living, artificial and social systems through physicalist, computationalist and mathematical lenses (Li Vigni 2020a). As a consequence, complexity *à la* SFI has always had an *imperialistic* attitude toward the other fields it aimed to englobe. By imposing formalistic tools and frames to “soft” sciences, it ended up mutilating,

informatizing and naturalizing living, artificial and social systems. The conclusion of the article defends the idea that, while complexity tools may reveal useful to simulate complex systems, interdisciplinary collaborations are the most fruitful when conducted in the reciprocal respect of all the disciplines involved.

Materials and methods

The researchers who inscribe within complexity sciences are far from being a unified and homogeneous social group, either on the epistemological (Li Vigni 2021c), the institutional (Li Vigni 2021b) or the normative level (Li Vigni 2020b). Yet, this article focuses on what complexity scientists tend to share. It thus addresses some common assumptions epitomized by the SFI, which is indeed taken as the main study object³. Based on an empirical research inscribed in history and sociology of sciences (Li Vigni 2018a), this paper offers a philosophical critique of complexity sciences. Its material is

³ While American complexity specialists tend to be more homogeneous from a socio-epistemic viewpoint, the European ones show more internal variability. If some are faithful to SFI's discourse (Solé 2009), most of them show a larger spectrum of postures – from minor differences (Chavalarias et al. 2009) to major dissent (Jensen 2021).

composed by scientific literature, popular books, institutional archives and interviews. Let me present the two last categories of materials, before concluding with a brief presentation of my theoretical approach.

As for the archives, a support is particularly of help here: the SFI's main outreach document. From 1986 to 2014, the American Institute published 40 issues of its Bulletin. The articles it contained were written by SFI's staff members, resident scientists, and freelance journalists. It was addressed to the members of the Board of Trustees, the research officers, the SFI's advisors, the scientists, the donors (past and potential), as well as to university, industrial, and governmental directors. Its aim was to inform such a public about the scientific and administrative programs of the institute. The Bulletin was published once or twice per year. Printed in 5000 copies, it was available for free upon request. Later, it became electronic and old issues were digitalized. In the mid-2010s, the Bulletin was curbed because it was considered less efficient than other supports. From a historical point of view, it provides excellent materials to explore some of the main programmatic discourses, research projects, tools, frameworks, and protagonists of the American (and in some part international) complexity community.

As for the interviews, they are in number of 115 and have been conducted with complexity scientists from the US and Europe. They were semi-structured – partly open and individualized, and partly following a general framework. Interviewees were mostly confirmed researchers, but roughly a third were either Ph.D or postdoctoral. Among the scientists, about two-thirds were men. The recorded interviews lasted two and a half hours on average with a few being less than one hour long and others lasting more than four hours. The majority were conducted in face to face settings within the researchers' lab. Others were conducted in person elsewhere (classrooms, cafes, or private houses), by telephone or by video conference. The bulk of the interviews were determined by the choice of the pivotal institutions taken as study objects – the SFI and the Parisian Complex Systems Institute, a research collaboration driven by the French Centre National pour la Recherche Scientifique (CNRS). These institutions were chosen in order to explore the hub of the American and international community on one side, and the hub of the French community (one of the largest in the world) on the other side. The rest of the participants come from other laboratories inscribed in complexity sciences in the US and in Europe. Interviewees were contacted at conferences, seminars, and through the snowball effect in order to have the

widest diversity of disciplines, countries, career degrees, and institutions. Each quote contained in the present article relates to scientists' declarations of intent and research practices, or to their epistemic and ontological views and assumptions. Citations have been chosen in order to show the way complexity specialists intend post-determinism, anti-reductionism, holism and interdisciplinarity. The interview framework contained a dozen questions about many subjects, such as personal pathway, view of complexity sciences, main epistemic practices, personal and disciplinary ontological positions, as well as definitions of computer modeling and simulation. In order to bring the interviewees to make their epistemic practices explicit, the questions focused essentially on the way they validate models and conceive error. In order to dig up their metaphysical assumptions and to describe their ontological views, the questions invoked Aristotle's distinction between formal and material causes. If very few interviewees were familiar with the Stagirite's terms, all of them had a clear idea of what characterizes the ontological structure of their study objects, of their modeling tools, and of the relation between the two. The interpretations proposed here were built in the manner of fieldwork research, since the meetings with the interviewees were dialogic experiences in which I

formulated and tested hypotheses with them; the writing and the outreach phases have refined such interpretations.

Lastly, my approach draws from pragmatism and Science & Technology Studies, two fields that are historically intertwined and that refer to “following the actors,” to “taking the actors seriously” and to “take the scientists as informers about whom to doubt” (Latour 1987, 1996; Boltanski 1990). In France, American pragmatist philosophers (William James, John Dewey, Charles Peirce, and George Mead) have inspired an entire sociological stream of research – alternative to the hegemonic one of Pierre Bourdieu – which, according to two of its representatives, follows a series of maxims such as: the “primacy of experience;” the “primacy of reasoning through consequences;” a preference for addressing actors’ actions more than conceptual essentializations; and theoretical and political “pluralism” (Chateauraynaud and Debaz 2017, p. 604–6). The objective of pragmatism is to bring the social scientist to privilege – at least in the first place – a comprehensive more than a normative approach to the study object. For this reason, the representatives of this approach have been complained by “critical” sociologists for depoliticizing society. According to Bourdieusian and Foucauldian scholars, pragmatists’ attention toward societal dynamism

and the “principle of symmetry” – which considers all actors on the same plane – have indeed tended to occult social reproduction and to neglect power struggle and domination phenomena (Pestre 2012). On their side, pragmatists have defended the critical and emancipatory power of their sociology. Among other things, they have argued that it is precisely by providing an equal attention to all actors – big and small – that small actors can become as visible as big ones (Barthe et al. 2013). They have also defended the distinction, within sociology, between the “technically primary tasks” – understand and describe – and the “technically secondary tasks” – anticipate, explain and criticize (Lemieux 2011). This article leans on both kinds of tasks and on the pragmatist concept of *ascendancy* (“*emprise*” in French), which Chateauraynaud (2015) defines as the taking of power, visible or invisible, of an actor in a given situation to the detriment of another actor. Such taking of power establishes an asymmetry that can be short or durable and that can be criticized for its social consequences. This concept is mobilized in the fourth and in the last sections of the paper.

An old determinism extended to new fields

During the 20th century, many fields of knowledge have challenged and complexified the modern view of causality – mostly linear and deterministic. In particular, quantum mechanics has revealed the non-deterministic behavior of the subatomic level, while first and second cybernetics have pointed at positive and negative feedbacks in complex phenomena. Yet, despite the promise of departing from Laplacian determinism, complexity sciences *à la* Santa Fe have mainly drawn from the chaos theory view of systems sensitivity to initial conditions and have extended it to new fields. It is important to say from the outset that the two levels of determinism that philosophers of science generally distinguish – epistemological and ontological (Bishop 2017) – tend to be conflated by complexity in a closed circularity where the one legitimates the other.

For the epistemological side, consider the following extract from an SFI's working paper dedicated to a time series forecasting algorithm:

Chaos is about the irregular behaviour of solutions to deterministic equations of motion [...] The equations must be nonlinear to generate chaotic solutions, but apart from that can be *remarkably simple*. [...] in

many cases chaotic solutions relax onto a *strange attractor* which has a fractal structure [...]. (Casdagli 1991, p. 2; first emphasis added)

As for the ontological side, consider a sentence by Nobel physicist Murray Gell-Mann, contained in the proceedings of one of SFI's founding conferences, which was a way to set the pace of the *complexity practice* for the institute's members: "Surface complexity arising out of deep simplicity" (Pines 1988, p. 3). This abstract – almost mystical – formula (and its derivatives) became one of the institute's best-known leitmotifs, thanks to Mitchell Waldrop's *Complexity* and to other journalists' popular books, as well as through the works of prominent figures of complexity such as Artificial Life founder Christopher Langton, cellular automata specialist Stephen Wolfram and network modeler Albert-László Barabási (SFI 1988a, p. 15; Wolfram 2002; Barabási 2003). In such an ontological view, complexity is only apparent for it conceals, in fact, an underlying simplicity that one just needs to unveil. In the same way as chaos theoreticians had shown that what seems random in weather or in fluids is (or at least can be seen as) the effect of regular deterministic phenomena, complexity scientists have claimed that nonlinear systems function accordingly to a handful of

principles and laws (Holland 1996). Book titles like *Simply Complexity* (Johnson 2007) or *Simplexity* (Kluger 2008) capture well this idea. In different degrees, all complexity inquiry tools – from agent-based simulations to network modeling, passing through cellular automata, genetic algorithms and statistical physics – indeed apply a small number of rules to a given set of elements assembled in a system. The interaction of these elements is what gives rise to macroscopic emergent behaviors. Now, the problem is that neglecting real-world complexity has epistemological repercussions. If complexity is just an illusion because reality is actually simple, there is thus no need for particular strategies to explore complex systems. For example, Aristotle’s concept of *phronesis* – the human faculty that permits to navigate through multifactorial phenomena via practical intuition – is not brought into play by SFI’s fellows and followers, despite its pertinence for any scientific activity (Ratti 2020); also, symmetrical interdisciplinarity is in most cases neither invoked nor practiced, (as we will see below) while the analysis of any complex phenomenon needs by definition several points of view; instead, “remarkably simple” equations – coming from dynamical systems theory in Casdagli’s working paper – can suffice to study a system if they are able to unveil its “attractor.”

Consider now another example: agent-based modeling. As a French handbook dedicated to this broad family of simulation tools posits, “Every agent-based model is a system composed by multiple entities or *agents*, which evolve in an *environment*, conceived as a particular entity, where they are localized” (Treuil et al. 2008, p. 13; emphasis in the original; translation from French mine). While agents have a relative autonomy thanks to the fact that they possess attributes, goals and the capacity to communicate with other agents and their environment, they remain strongly constrained by the environmental features and by the rules of interaction imposed to them. Complexity scientists have often highlighted the capacity of such simulations to produce unpredictable results, “surprising even the programmers” (SFI 1988a, p. 15). But where does this surprise actually come from? First, from the impossibility for the scientist to calculate what the simulation can easily calculate in his or her place. Second, from the introduction into the model of randomness through Monte Carlo simulations or through stochastic differential equations. Now, a stochastic process is defined by a probability law – for example, in Monte Carlo simulations, the random variable can be approximated by taking the empirical mean of a sample. Consequently, the simulated system is deterministic except for a probability variable which

determines a range of “artificial” randomness. In other words, complexity tools are different from static deterministic mathematical models because they introduce stochasticity into a simulation so to make it dynamic, that is capable of evolving during time in “unpredictable” ways for the programmer. But this does not depart from Laplace since, if the scientist was an informatic Laplacian-like “demon” capable of computing as quickly as the machine, he or she would have no reason to be “surprised” by the simulation.

Thus, Laplacian determinism is not only present into complexity models, but it is also attributed by scientists to the systems under study – be they natural, artificial or social. Let us see now how this physicalist view is extended to new study objects. Consider an example from quantitative geography, an important specialty at the SFI. Two former physicists from the institute have vigorously invested this field since the beginning of 2000s (Bettencourt and West 2010). In order to analyze urban data, they often apply the power law – a mathematical formula describing scale-free phenomena – to address macroscopic regularities among cities. In order to analyze the huge databases that they obtain from public and private organizations, these researchers apply a relatively simple mathematical tool to show what makes two megacities like New York and Delhi more similar to each other than to the

mid-sized American and Indian urban centers respectively. According to them, while basic needs remain the same regardless of the city under consideration, social phenomena increase at the same rate everywhere, mainly as a demographic function. Put differently, while the population increases, the GDP, the wages and the patents grow just as fast as the number of crimes and car traffic (Bettencourt et al. 2010). On the other hand, one observes economies of scale with regard to the infrastructure: If a city's population doubles, infrastructure only increases by 85%. Conversely, social phenomena only increase by 15% compared to the expected linear variation. What these SFI fellows share with other quantitative geographers and complexity scientists is the use of numerical formalization to capture "universal" trends in complex systems. In their view, the size of cities has more determining a role than their political and social history or design – elements that are explicitly seen as having secondary roles. These researchers also reject cultural geography's emphasis on the relativity of customs and traditions, arguing that human beings are fundamentally predictable even when they feel free. In this view, policy "cannot break those rules or build them anew but [it] can drive them in the right or wrong direction" (interview with Luis Bettencourt, 28.09.16). Indeed, the room for political initiative is,

according to them, limited: “[T]he general trend and the coarse-grained scale of it is probably determined for you” (Geoffrey West in SFI 2008, p. 8). These researchers not only postulate that physical rules strongly constrain human agents, but they also apprehend the latter as statistical profiles, classes of individuals or demographic flows. As their British colleague Michael Batty has written, the laws identified by quantitative geographers “may not be laws in the sense of the physical sciences, but they reveal strong regularities that seem to persist over time and space” (Batty 2013, p. 38). Besides Bettencourt, West and Batty, the other interviewees inscribing in quantitative geography draw, they too, inspiration from physics to make geography more of a “science,” and see sociotechnical and ecological systems as networks that can be analyzed through digital or mathematical tools (Pumain 2020a, 2020b).

Despite the existence of individual exceptions, epistemological and ontological determinisms prevail within the complexity community in general, well beyond chaos physics and quantitative geography. For instance, after having established that “amazingly simple and far-reaching *natural laws* govern the structure and evolution of all the complex networks that surround us” (Barabási 2003, p. 6; emphasis added), network specialist

Albert-László Barabási has come to conclude that “no matter what we [do], we unconsciously [follow] the same law – a power law” (Barabási 2010, p. 105). By taking the example of sending e-mails, he shows that we do not behave randomly (following a Poisson distribution) but through “bursts” (which indeed follow a power law). In point of fact, complexity scientists share – of course with different nuances – the idea according to which free will is just an illusion. SFI associate and MIT professor Seth Lloyd clearly claims this idea in one of his books:

For years my wife and I would go for lunch to Josie’s in Santa Fe. I, after spending a long time scrutinizing the menu, would always order the half plate of chiles rellenos, with red and green chile, and posole instead of rice. I felt strongly that I was exercising free will: until I chose the rellenos half plate, I felt anything was possible. My wife, however, knew exactly what I was going to order all the time. (Lloyd 2006, p. 36)

This quote emblematically shows the way in which the SFI’s approach leans on deterministic chaos. Seth Lloyd’s restaurant choice pattern is apparently

unpredictable like the weather, but his wife – just like a meteorologist – can detect a deep regularity in his behavior. Leaving aside the debate about free will, it is possible to comment here that the problem with complexity sciences is not only their radical interpretation of determinism, but also the fact that their representatives extend it to other ontological realms such as society. Admittedly, social scientists acknowledge that humans are influenced (but not always literally determined) by a certain number of factors – by biology and in a larger measure by culture, power, etc. But complexity scientists even go to assess the degree of predictability of human beings – established at 93% by some of them (Song et al. 2010). Also, when social scientists talk about social phenomena they try to explain them through other social phenomena (according to Emil Durkheim’s methodological rule). On the contrary, when claiming that humans are predictable, complexity specialists talk less about *social* factors and more about *natural* ones – be they physical, topological or biological. So that it is possible to conclude that, far from being overpassed by the consideration of complex causalities and by the deployment of *phronesis*, old physical determinism remains alive in the *complexity practice* and is even generalized outside the physical realm.

Complexity as a *computatio universalis*

Most publications about complexity start with some criticism of reductionism. Yet, SFI's fellows and followers often end up producing reductionist positions. But how to characterize such reductionism? As philosophers and scientists know well, reductionism is a matter of taste and degree (e.g. Jessor 1985; Peacocke 1976; Andersen 2001; Ney 2008; Chibbaro et al. 2014). Where to put the line depends on different philosophical and historical reasons that have to be made explicit. What this section shows is how the complexity practice operationalizes (and contributes to spread) a form of ontological and epistemological reductionism based on a computational view of nature and of society.

As said above, within complexity sciences the properties of each system – be it natural, artificial or social – are generally conceptualized and modeled by the same types of tools, construction rules and interpretation practices. Agents, cells or nodes are indeed categorized by statistical classes, whose interactions are governed by a finite set of simple rules, relatively perturbed by a stochastic function introduced here and there. In this context, the elements of a system are – independently of the discipline – seen and treated as particles or as electrons of a network capable of moving fluidly. Here again

epistemological and ontological reductionism – normally distinguished by philosophers (Sartenaer 2016) – are conflated by the *complexity practice*. So much that the frictions of matter, the resistances of borders and the unforeseen events of culture are neglected, the vision of complex systems being flattened on the informational, deterministic dimension. Complexity specialists make no secret of this fact: For some of them the universe is a computer; for most of them it functions on the basis of the exchange of information between its components. In other words, complexity generally presupposes a *mathesis universalis* or, to update Leibniz' formula, a *computatio universalis*. As a result, the members of this field end up being even more reductionist than some physicists or biologists are in their own fields. While classical reductionism reduces one physical or biological level to another physical or biological level, the leap made by complexity sciences is greater since it tends to interpret every system, whatever its specific ontology, through numerical abstraction. By analyzing complexity scientific production, discourses and commitments, a *leitmotiv* indeed occurs the most often:

It is [...] clear that essentially all complex, adaptive systems are designed to *process information*. They are equipped to gather information from their external environments and to react to it or store it internally in a compressed form and to retrieve it when necessary. (George Cowan in SFI 1989, p. 2; emphasis added)

Ten to fifteen years after the foundation of the SFI, network science boosted and spread even more such a view thanks to its practical results and cultural influence (Watts 2003; Taylor 2003; Newman 2018). One of the metaphysical assumptions that allow complexity specialists to employ their tools to all fields of knowledge is the alleged homology between the various systems they analyze: “Networks are present everywhere. All we need is an eye for them” (Barabási 2003, p. 7). Wherever it is, from the moment in which a system can be thought of as a network, it *is* a network: “As soon as we reduce networks to their minimum description, relieved of the terminology specific to each discipline [...] what we discover about biological networks *must be* partly applicable to sociology or computer science” (Bersini 2005, p. XVIII-XIX; emphasis added). Albeit there is a minority of complexity practitioners who reject the informational

metaphysics of nature and who believe that simulations run on a different material and formal sphere compared to the “real” world (a regime I called “dualist”⁴), the vast majority of complexity scientists belong to three ontological regimes I proposed to call the “homomorphic,” the “vitalist” and the “monist” (Li Vigni 2021c). *Nota bene*: Such terminology has nothing to do with the usual philosophical distinction between metaphysical dualism and monism, which states that there is just one material world. One can indeed be a metaphysical monist and still belong to the “dualist” regime, if he or she believes that both computer material and formal causes diverge from living and social systems ones; at the same time, the complexity scientists I ascribe to “monism” do believe in just one world, but subdue the matter to the form. More common than any other regime, the “homomorphic” refers to scientists (e.g. Barabási 2003; Bar-Yam 2004; Bersini 2005; Solé 2009; Ajelli et al. 2010; West 2017), as well as to philosophers (e.g. Galison 1997; Sismondo 1999; Winsberg 2003; Elsenbroich 2011; Peschard 2013; Rathkopf 2014), who believe that the world of simulation and the world of

⁴ According to it, computer simulations are just a heuristic aid for research and cannot prove a theory. For philosophers holding this position, see for example Oreskes et al. (1994), Longo (2009) or Morgan (2012).

real systems do not share the same material cause, but do share the same formal one. In their view, the ontological homology between the structural arrangement of the target system and that of the simulated one allows researchers to claim that computers can provide sound proofs and credible predictions for the world. An Italian physicist based at the French National Institute of Health and Medical Research, who has become a computational epidemiologist after an interdisciplinary parenthesis at a complexity institute, has a perfect sentence to illustrate the homomorphic position: “If a real form exists, the form of the simulation is an abstraction of the real form” (interview with Vittoria Colizza, 09.05.17). The vast majority of complexity scientists belong to this regime (i.e. 83% of my corpus of interviewees⁵). While most dualists come from and contribute to life and social sciences, most homomorphic researchers come from physics, mathematics, computer science and contribute to many different disciplines. Then, the category of “vitalists” coincides with the Artificial Life community (Boden 1996; Langton 1997; Helmreich 1998). Inspired from Artificial Intelligence, “vitalists” push to the extreme the ontological symmetry between the world and the model, by considering that their simulations “live” in the literal

⁵ See the conclusion of Li Vigni (2021c) for the statistical limits of this percentage.

meaning of the word. For Artificial Lifers, evolving computer programs are instantiations of Darwinian evolution and, hence, can be studied in terms of actual biological systems. Finally, the “monist” regime differs from the former ones insofar as, for its few representatives, the entire universe is a computational process (Wolfram 2002). According to this view, the parallel rails of the “real” world and the simulation make one and the same thing: “[T]here is a computational process which is equivalent to the Universe, which reproduces the Universe” (interview with Stephen Wolfram, 13.09.16); or said otherwise: “The universe is a quantum computer” (Lloyd 2006, p. 3).

Nuances apart, homomorphic, vitalists and monists share a similar informational view of the universe. What underlies their regimes finds its origins in the Artificial Intelligence and cognitivist idea according to which 1) hardware and software are separable and separated; 2) the features of the hardware have little or no importance; and 3) the software is portable. For this metaphysical position (which partially stems from a misinterpretation of Turing [Longo 2018]), what actually carries causality and determines the identity of a system is the way it is organized – its form or code – not its matter. Importantly, according to this frame, the organization of a system is

mathematically graspable and transformable into mathematical theory (Rathkopf 2018). It is no coincidence if one of the mantras of complexity specialists is that general or local formal models of life and social systems are possible and must be sought for, if we wish to have a deep understanding of nature (Holland 1996; Axtell 2000; Marquet et al. 2014).

All this has a long history behind. One of the starts was the work of Shannon and Weaver who, along with the cyberneticians, developed and extended the theory of information to machines, animals and human psychology (Bateson 2000; Dupuy 2000). Another start is represented by the inventors of the digital computer and the initiators of cognitivism and Artificial Intelligence, who introduced the sharp and hierarchical division between hardware and software, and compared the human mind to an algorithmic machine – a position known as “computationalism” (Dreyfus 1972; Russell and Norvig 1995; Steven 1996; Scheutz 2002; Piccinini 2012; Bermúdez 2014; Varela 2017). Biology was one of the first domains in which this informational metaphor – become an actual metaphysics – was thoroughly applied (Oyama 2000; Atlan 2011; Longo et al. 2012; Morange 2016). Quite soon, the idea conquered popular culture through the cyberpunk movement and numerous science-fiction authors (Asimov, K. Dick, Wells...) and movies (*Ghost in the*

Shell, Matrix, Transcendence...). Some complexity scientists have contributed to the establishment and dissemination of such a worldview well outside the scientific boundaries. General audience books about networks have contributed to spread the idea that we live in a “small world” where “everything is linked to everything else” (Barabási 2003; Watts 2003). In such an interconnected world, movement appears easy, fluid and immediate; interconnections allow planetary leaps as the case of epidemics modeling clearly shows (Opitz 2017). This may give the illusion that ontological heterogeneities do not really count, and that the master of nature and society is the physicist-informatician who can manage such ensembles of nodes, edges and hubs. The exteriority and superiority of form over matter make it necessary for scientists to only deal with what is measurable. Such pure exteriority is well expressed by a distinction that French mathematician René Thom used to do between “pregnancy” and “saliency,” respectively what can only be experienced from within (meaning and senses) and what can be perceived and measured from the outside (forms and size) (Wildgen 2010). Indeed, computationalism treats the world as a pure “saliency” whose truth regime leans more on an internal mathematical rationale than on empirical testing (Stiegler 2018). American literary critic Katherine Hayles calls this

position “virtuality:” “the impression is created that pattern is predominant over presence. [...] When this impression becomes part of your cultural mindset, you have entered the condition of virtuality” (Hayles 1999, p. 19). For her, the problem “comes when the move circles around to constitute the abstraction as the originary form from which the world’s multiplicity derives” (Ibid., p. 12). So that computational onto-epistemologies lay “the groundwork for a new variation on an ancient game, in which disembodied information becomes the ultimate Platonic Form” (Ibid., p. 13).

Let us thus draw some conclusions from this section by resuming and reformulating its main ideas. First of all, one of the risks of complexity epistemic reductionism is to produce knowledge which, if not fundamentally false, is heuristically not very insightful or even trivial. In one of the rare critical texts of complexity that can be found in the literature, this criticism is addressed to power laws in particular:

There are doubtless interesting ways to elucidate the power laws we can abstract from diverse phenomena. It’s just that the act of abstraction here has been so severe — so many aspects of the phenomena we were looking at have been left out — that our discoveries, while interesting in their own

right, will tell us almost nothing about these particular phenomena.
(Talbot 2002, p. 20)

Besides triviality or uselessness, another risk that complexity runs is to fall into what two French pragmatist sociologists have called the “autonomous axiomatic” – a way of thinking that “allows to generate actions and judgements which cease to be accountable vis-à-vis reality, because of its internal hyper-coherence that makes any effort of cross-checking pragmatically useless” (Chateauraynaud and Debaz 2017, p. 588; translation from French mine). Because of an autonomous axiomatic, scientists may end up taking their models as the reality. Hence, as French philosopher Edgar Morin (2007) has written: “In a way, [complexity scientists] acknowledge complexity, but at the condition of decomplexifying it. Thus, they open the breach, then they try to patch it up: the paradigm of classical science remains, just a bit fissured.” Which brings us to a paradoxical conclusion:

It is [...] arguable [...] that the tools complexity researchers bring to their work are even more severely constrained, more one-sidedly abstract and

quantitative, less tolerant of qualities, less relevant to the richness of the world given through observation, than was the case with much of the science they are trying to reform. (Talbot 2002, p. 23)

In other words, the revolutionaries of complexity reveal positions that are even more conservative than the classical science they want to overcome or update. Next section explores the same tendency in what concerns holism.

Holism is another kind of analytical approach

At the beginning of the 1970s, American physicist Philip Anderson (one of SFI's builders) wrote a now famous article entitled "More is different," which has retrospectively been seen as one of the founding texts of the field of complex systems (Anderson 1972). The fundamental idea of the paper was that "at each level of complexity entirely new properties appear, and the understanding of the new behaviors require research which I think is as fundamental in its nature as any other" (Anderson 1972, p. 393; see also Gell-Mann 1994; Miller and Page 2007). Put another way, Anderson and several complexity scholars have invoked the need to study each level of reality with

the relevance that its specific ontology requires. Such “multiscale” approach is designed to consider the properties of each dimension of nature, from the physical to the biological and the cultural, and to fully address each level of complex systems (Chavalarias et al. 2009). The controversial concept of emergence has been one of the most prominent ideas put forward by complexity representatives to precisely give account for the transition from the micro to the macro levels (Bedau and Humphreys 2008; Bersini 2007; Chérel 2013).

Now, once you have considered every dimension of the world through multiscale lenses, you still have to figure out how to tackle each one of these levels. Complexity’s holism prefers to zoom out from the particular elements (that it considers too difficult to study or even misleading to really understand a system) and to take a “crude look at the whole” (Miller 2016). One of the sources of this idea is statistical physics, which indeed became paradigmatic in complexity sciences (Pastor-Satorras and Vespignani 2007; Pietronero 2008; Tsallis 2016). The philosophy behind it is that the whole is not equal to the sum of its parts, but “more” than them – in the sense that their interactions produce properties that do not exist at the microscopic, individual level. It is the interactions between the elements of a system that,

according to the *complexity discourse*, create a unified, highly interdependent whole which produces new qualitative properties. In this framework, the concept of emergence keeps the ideas of multiscale and holism together. As Ladyman et al. (2010, p. 40) remark, “A strong, perhaps the strongest, notion of emergence is that emergent objects, properties or processes exhibit something called ‘downwards causation,’” also called “stigmergy” (Grassé 1959; Théraulaz and Bonabeau 1999) or “immergence” (Chavalarias et al. 2009). These terms refer to the idea that the whole has somehow a form of causality over the parts that compose it: The individuals make up the whole in a bottom-up relation and the whole in its turn influences and regulates its components.

Yet, the complexity practice reveals that holism can be considered as another kind of reductionism. To substantiate this claim, it is first of all important to remind that the computational reductionism described in the precedent section of the paper does not entail that biological and social levels are ignored as per se by complexity scholars. If it is not a question of reducing everything to the bottom sphere nor of denying the specificity of each level, then where lies the issue? I argue the problem of complexity is that it sees each ontological level in the same way theoretical physicists see and study

the physical realm, namely through calculation. Complex systems scientists do address the several levels of reality, but they interpret them as if these were made of bits and of pure logico-mathematical relations. In this perspective, ontological realities have a mathematical structure and, thus, mathematics allows the researcher to describe each level of reality as well as the relations between levels. Here holism is not a Durkheimian qualitative interpretation of the whole, seen as the sphere which precedes and determines individuals more than it is determined by them⁶. Instead, holism here entails a set of mathematical equations that permit scientists to wrap up the main mechanisms of a given system into an agile formula. This is why many complexity scholars tend to judge “soft” sciences as “messy” and in need of mathematical and conceptual unification. As SFI mathematician Daniel Rockmore once wrote on the SFI’s bulletin, such unification can now be done thanks to complexity sciences:

⁶ Actually and moreover, complexity scientists generally adopt methodological individualism in order to study society and thus tend to position far from Durkheimian holism (O’Sullivan and Hakley 2000).

Self-organization would be the lens through which all of life could be seen, quantified, and well, organized – putting the messy sciences that are biology, sociology, and economics (as well as some of the most complicated physical phenomena) into a universal framework where mathematics and computation would guide research and discovery. (SFI 2004b, p. 4)

It is here that holism becomes another form of reductionism. To make sense of it, Edgar Morin's critical insight of Ludwig von Bertalanffy's systemics perfectly applies to complexity sciences as well:

Systems theory reacted to reductionism with its idea of the whole, but believing it had surpassed reductionism, *its "holism" merely brought about a reduction to the whole*, from which arose not only its blindness to the parts as parts but its myopia with respect to organization as organization, and its ignorance of the complexity at the heart of any global unity. In either case, reductionistic or holist explanation seeks to simplify the problem of complex unity. The one reduces explanation of the whole

to the properties of the parts conceived in isolation. The other reduces the properties of the parts to the properties of the whole, also conceived in isolation. These two mutually repelling explanations each arose out of the same [analytic] paradigm. (Morin 2008, p. 101, emphasis added)

In other words, holism operates a “reduction to the whole” of the systems under study which inscribes in the continuity of the classical analytical approach.

As shown in the introduction to the present paper, some social scientists seem to have found in complexity the source for a paradigmatic renewal in social sciences. Here it is thus all the more important to warn against the danger that lies in the way complexity understands human societies. The practice of modeling them through mathematics or computer simulations derives from the idea that societies are law-like, mechanistic systems. In a machine as well as in physical and living systems, things are kept together and put into motion through stable (albeit evolving) mechanisms, which deeply and necessarily connect elements between them at a distance and subdue them to constant rules. The ontology of society seems to be very different though, for the connection between elements is looser. Communication, law enforcement or

trade, for example, do not follow constant rules and their elements are not as deeply connected as in mechanistic systems. Societies are certainly system-like, but *are not systems* like a machine and an organism are. Human groups can be rather described as *complex intertwining of transmission chains*, so that if a war destroys oil refineries in the Middle East, then the chain of production, transportation and even public services in other parts of the world are affected as a consequence. But the link between things is not materially the same, because mines, factories, transports, shops, etc. are not linked between them in the way the law of gravity links all the bodies of the universe between them, ruling over them instantaneously, necessarily and without intermittence.

It is for these reasons that, in conclusion, I agree with Australian philosopher Arran Gare, who affirms that “far from breaking with traditional science, the Santa Fe Institute, despite their claims, is at last providing reductionist explanations for all those phenomena that anti-reductionist scientists and philosophers had been calling attention to as requiring holistic forms of thinking to understand” (Gare 2000, p. 333). Interestingly, some exceptions exist: Complexity mathematical holism indeed does not go without opposition within the community, where some physicists (turned social

scientists and collaborating with trained social scientists) may adopt the opposite attitude to the one just described – they namely argue that “society cannot be put into equations” and that social theories and ontologies must be taken seriously when using numerical enquiry tools (Jensen 2021; Venturini et al. 2015). These remain isolated cases in which interdisciplinarity – contrary to the Santa Fe-like practice – is intended and practiced in more symmetrical a fashion, but as often exceptions confirm the rule.

An asymmetrical interdisciplinarity

In the promotional books dedicated to the SFI and to the kind of science it promised to foster, the American institute was described as the “Meccah” of interdisciplinary science. In the light of their population and of their scientific production, it is no doubt that the SFI and the other complexity institutes around the world can be said as hosting different disciplines and as contributing to several fields of knowledge. But what kind of interdisciplinarity is at stake there in fact? In an interview published on the SFI bulletin, mathematician Erica Jen does not hesitate to praise the approach of the Institute in terms of mutual intellectual enrichment for its members:

The best part of collaborating in a truly interdisciplinary fashion, when it works, is that it places a stress on researchers and how they think. By working together with researchers from different disciplines, you are literally forced, in the most constructive of ways, to think about different problems, to use tools and methods from other disciplines with which you are not familiar. (SFI 1996-1997, p. 7)

Admittedly, from a superficial reading of the socio-epistemic composition of several complexity institutes around the world, one would be tempted to think of collectives in which, in an *egalitarian* way, scientists from different epistemic cultures are in dialogue, holding their backgrounds and questionings in mind while enriching them with other specialties'. Physicists, computer scientists, biologists, ecologists, immunologists, epidemiologists, economists, geographers, archaeologists, sociologists and other specialists can all be found there. Moreover, since the foundation of the SFI, one of its main and distinctive activities has been the organization of a device called the "integrative workshop." Halfway between the conference and the summer school, this kind of event often lasts a week, even two, and brings

together two or three dozen scientists from several disciplines, in order to discuss a given scientific concept in a transversal way (e.g., resilience, robustness, contagion, etc.). Each participant intervenes by informing others of how the concept is being handled in his or her own field. After a brainstorming phase follows the attempt at synthesis (SFI 1992b).

At first sight, all this suggests symmetrical exchanges between scholars from different backgrounds. However, at a closer inspection, we discover inequality and domination in at least two respects: First, some disciplines are underrepresented in complexity institutional spaces while a few impose their epistemic and ontological frameworks to the others; second, as a result, complexity inquiry tools mostly belong to one or two types and take the form of computer modeling and equations. Let us start with the first empirical element of the two. The prosopography of complexity institutes' members confirms the physical and computational preponderance. SFI's founders are all physicists or chemists. The first active members were biologists, economists and computer scientists. Social scientists have been few all along its history, and some of them do not even have a training in social sciences. Consider also two random moments in order to give an idea of this tendency: In 1992 the new members of the institute's scientific council included an

economist, a computer scientist, an anthropologist, a molecular biologist, a bioinformatician, two mathematicians and five physicists (SFI 1992a). In 2001, most undergraduate students, as well as the majority of researchers, both temporary and permanent, came from physics (11), computer science and/or mathematics (8), life sciences (4), economics (2) and socio-informatics (1) (SFI 2001, p. 22-24). Whatever the epoch and the complexity institute taken into account, this sociology is confirmed (with a lot of internal variations, of course).

A second empirical element contradicts the alleged multidisciplinary and inclusiveness of complexity sciences. By analyzing the institutes archives, books, web pages, summer school flyers, as well as the titles of the conferences dedicated to complex systems – whether in the United States or in Europe – it is possible to identify a dozen models of investigation. The list is not exhaustive and some of these items were in vogue more at the beginning of complexity history than today, but it clearly shows that all the tools belong to the numerical sphere:

1. Dynamical, fractal and chaos systems (physics);
2. Cellular automata (computer science);

3. Statistical physics (physics);
4. Spin glasses (physics);
5. Neural networks (computational cognitive sciences);
6. Genetic networks (bioinformatics);
7. Network theory (physics, mathematics and computer science);
8. Agent-based models (computer science);
9. Self-organized criticality (physics);
10. Genetic algorithms (computer science);
11. Game theory (economics);
12. Machine learning (computer science);
13. Big data analytics (statistics, AI and mathematics).

As this list shows, no tool comes from, say, biology or sociology. In other words, complexity research equipment has just a few colors, even if it applies to all fields of knowledge. When an anthropologist self-defines also as a complexity scientist, he or she applies one or another of these tools.

We can now analyze the interdisciplinary exchanges that Erica Jen's quote referred to as a "constructive" process in which researchers from different

disciplines are forced to use tools and methods from other disciplines. Whom is “forced” by who to do what exactly? To answer this question, let us take an example from the SFI. The collaboration takes place between biochemist Walter Fontana and political scientist John Padgett. The first is a specialist of autocatalytic chemical reactions, the second of the golden period of Florence Renaissance. In their scientific exchange, Fontana gives a physical-chemical reading of the Florentine society studied by Padgett, but there is no actual reciprocity between the two researchers:

Through reading a paper Padgett wrote on the flowering of Florentine society, Fontana saw connections with abrupt physical transitions of many chemical reactions. “There was a natural resonance in Padgett’s analysis of Florentine society leading up to the Renaissance with the emergence of the first self-maintaining, self-reproducing cell, or how a new paradigm of organization comes into existence,” says Fontana. (SFI 2004b, p. 20-21)

Although in the rest of this excerpt the bulletin states that the two researchers “have both been able to see their own fields of research through different

glasses,” the one who actually gets inspiration from the other is Padgett, the political scientist, who declares:

Walter [Fontana] is interested in the folding in of chemical networks to get a self-sustaining system called a metabolism. If you look at my networks on marriage and economics in medieval Florence, pictorially there’s a great similarity between his pictures and mine, though his are chemical and mine social. Mine fold in to produce political parties [...] So, because I’m looking for self-sustaining mechanisms, *I’ve taken his models and used them for medieval Florence*. (SFI 1999, p. 6-7; emphasis added)

In this representative example, the change of perspective is not bidirectional: It goes into one sense only, from the natural sciences toward the social ones – this tendency of complexity resonates with other cases concerning the juncture of humanities and life, computer and cognitive sciences (Callard and Fitzgerald 2015; Lemerle and Reynaud-Paligot 2017; Larregue 2018; Broca 2016). In these cases, the dialogue between two epistemic cultures is

undeniably present, but one of the two brings its frames to the other, which has to (more or less passively) adopt them. In other words, in the complexity field, life and social science worldviews are marginalized in favor of numerical ones. In *complexity practice*, there is only one good way to study phenomena, and non-formal sciences must integrate it if they want to reach the status of “sound science.”

Ideally though, interdisciplinarity presupposes a multiplicity of voices and the equal collaboration of them. But most complexity institutes lack of physical, chemical, biological or behavioral science facilities. In fact, the study of complex systems is mostly pursued with personal computers (like any research center today), and only by that. Many of them also employ computational grids by renting them from public or private actors, and a few of them possess in-house clusters of servers in order to accomplish their own simulations. Indeed, except those who use toy models (Ylikoski and Aydinonat 2014), researchers working on complex systems have to perform hundreds of thousands, sometimes even millions of simulation runs on such grids, in order to statistically analyze, test and challenge their models filled with data. The computational-based nature of complexity was, after all, clearly stated by complexity founders from the outset. SFI biologist Harold

Morowitz once wrote: “The new approach is made possible, indeed it is mandated by computers” (SFI 1992b, p. 24).

It would nevertheless be wrong to think that there has never been an internal opposition to this view. Once again, exceptions reveal and teach us something about the majoritarian view within a given group. For example, SFI archaeologist George Gumerman, an expert of the American Southwest and Oceania, addressed a letter in 1993, just after an “interdisciplinary” conference at the New Mexican institute, to physicist Murray Gell-Mann. The letter was published on the institute’s bulletin and contains a critique to the operation of conquest led by SFI’s scientists in direction of other disciplines’ study objects. The tone of the archeologist is nonviolent, but straightforward:

My problems concern what I think might be some misunderstandings between the SFI complexity folk (mainly Stu Kauffman, Chris Langton, and perhaps yourself) and the collected Southwest archaeologists; on a more pessimistic note, I’m worried about one of the assumptions of the conference: if Southwest archaeologists can only learn about “complexity” from the SFI experts, they will become better

archaeologists. I write this memo, then, presuming that you'll tell me where I'm off base on how the SFI investigates "complexity" and also whether *my own notions of complexity in archaeology are of any interest to the gurus at the SFI*. (SFI 1993, p. 21; emphasis added)

However, this kind of protest remains rare. In the complexity community, specialists from "soft" sciences generally seek the expertise of computer specialists and spontaneously adhere to their culture in a reasoned manner; some even learn computer language by themselves or with the help of a modeler, so to become autonomous in the use of one or another of complexity inquiry tools (Banos 2016). In conclusion of this section we shall ask: What are the reasons of complexity's *asymmetrical interdisciplinarity*? The materials and archives cited here show that the motivation for SFI's naturalization of life and social sciences rests on a positivist conviction that George Cowan has illustrated more than once in these terms: "One of my friends says he judges papers by the ratio of narrative to equations. If he doesn't find a single equation, he doesn't read the paper" (SFI 2000, p. 3). In recounting this anecdote, the first SFI's president expresses his own hierarchy of knowledge, which is reminiscent of the famous phrase by Ernst

Rutherford on the importance of physics, a sentence that Cowan mentions too: “All science is either physics or stamp collecting” (Birks 1963). Such devaluation for non-mathematical knowledge is also reflected in the evaluation of the social impact of physics compared to psychology and the humanities: “The physical sciences have made immense contributions to human betterment. By contrast, the contribution of the behavioral sciences appears modest, and inadequate to the contemporary challenges” (George Cowan in SFI 2004a, p. 30). As a consequence of this conception, more than a fruitful dialogue between the “two cultures,” complexity sciences tend to deploy an *imperialist* project aimed at colonizing other fields of knowledge with their instruments and views of nature. To give an image of this process, it may be useful to draw a heuristic comparison: When paleontologists or archaeologists solicit radiologists for carbon-14 dating, the epistemic and ontological views remain under their control: They decide the questions to ask; they interpret the data; they establish their theories. In the complexity field instead, life and social sciences seem – at least for the time being – to abdicate to their culture vis-à-vis the physical-computational view. The next and last section of the article addresses more directly the origins of the gap between the promises of complexity sciences and their actual production.

The *ascendancy* of physics, computer science and mathematics

In this section, it is time to provide some elements of answer to the following paradox: How to explain the gap between the *complexity discourse* and the *complexity practice*? How come that the new science of complex systems, supposed to revolutionize all fields of knowledge, ends up pushing further the “classical science” approach it openly challenges? In order to answer, it is necessary to gather and make even more explicit some of the elements that have been presented in the former pages around two axes: the search for general theories and the mission of formalizing the “soft” sciences.

Recall that the SFI has been launched in the mid-1980s by a group of senior physicists from the Los Alamos National Laboratory and other American universities, with the aim of applying computer and interdisciplinarity to life and social sciences. By claiming a post-determinist, antireductionist, holistic and interdisciplinary approach, their aim was to export the physicalist approach to other fields, where abstract quantification was little or not present at all, in order to “define the principles of a general science of complexity” (SFI 1990b, p. 3). The main reason for this was and still is the belief that the complexity of higher phenomena stems from the *simplicity of*

the bottom levels. As Italian philosopher Giorgio Israel noticed, “The success of physics is due to the fact of having chosen as its guiding principle the Galilean approach of ‘pruning the impediments’ [...] that is the belief in the fact that there is a mathematical order underlying nature which is simpler than it appears, and that represents the essence of phenomena” (Israel 2005, p. 504). Collaterally, to the intrinsic simplicity of complex phenomena also corresponds a certain esthetics of theoretical work production, as Danish SFI physicist Per Bak once wrote: “The beauty of the model can be measured as the range between its own simplicity and the complexity of the phenomena that it describes, that is, by the degree to which it has allowed us to condense our descriptions of the real world” (Bak 1996, p. 44). If things at the bottom are simple, then the macroscopic messiness of the world can be ignored so to find the underlying and elegant commonality between systems. This gives what can be called the *unifying tendency* of physicists in general and of complexity scholars in particular: Just as in several fields of theoretical physics scientists aspire to general, overarching theories, in the same way the goal of SFI and of other complexity institutes was, at least until the mid-1990s, to achieve a unified general theory of complex systems. Several “integrative workshops” were organized to achieve such a goal (Cowan et al.

1994), but in the second half of the 1990s the project was abandoned, namely following the publication of a critical article published on the *Scientific American* by journalist John Horgan. In that paper, the writer bitterly criticized the research being conducted at the SFI for being “flaky” and “fact-free” (Horgan 1995). However, the search for unification in science remained intact among complexity scholars till today; it has simply been reinvested into the research of local theories and the production of partial generalizations. To give a quite notorious example, the work of ecologists Jim Brown and Brian Enquist with physicist Geoffrey West on power laws applied to living beings, which shows their similar metabolic ratios no matter the species and the realm taken into account, goes precisely into this direction: “They propose that the origin of this distinctive biological scaling arises from the fact that cardiovascular systems, respiratory systems, plant vascular systems, and insect tracheal tubes all exhibit the same fractal-like branching structure” (SFI 1997, p. 7; West et al. 1997). Their work, which has been criticized since (Kozłowski and Konarzewski 2004; Etienne et al. 2006), was marketized by the SFI as “perhaps the single most pervasive theme underlying all biological diversity” (SFI 1997, p. 10).

A second axis of the complexity epistemic project expresses the will to make “soft” disciplines “more scientific” through *numerical formalization*. In the 1994 SFI bulletin, the point is made unambiguously by citing the intentions of the first president of the institute: “Essentially, Cowan’s vision has been to apply the quantitative tools of the physical sciences, such as mathematics, to the social sciences” (SFI 1994, p. 3). The same destiny was reserved to life sciences, as illustrated by some workshops organized in order to provide experimental biologists – who have often “forgotten the mathematics learned during their college and graduate school days” – with “an in-depth understanding of the importance of mathematics, statistics, and computer science for analyzing experimental data” (SFI 2001, p. 27). While it is question of “[e]ducat[ing] experimentalists in the use of modeling and simulation tools,” it is a matter of only “[i]ntroduc[ing] mathematicians and other theorists to the language and concepts of biological systems” (Ibid.; emphasis added). As a result, the *ascendancy* of physics, computer science and mathematics over the other disciplines extends determinism to other fields of reality, amputates living and human complex systems of some of their dimensions by viewing them as computational networks, and brings holism back under the wing of the analytical approach. All this is the very

definition of reductionism, that is “the attempt to subordinate every aspect of reality to the same interpretative key” (Israel 2005, p. 505). In this sense,

The claim by some complexity researchers to have moved “beyond reductionism” is not justified by the facts. The decisive and damaging act of reduction within conventional science has always been the reduction, in thought, of the qualitative world of phenomena to abstract, machine-like models devoid of qualities. Complexity theorists seem at least as committed to this reduction as any other scientists. (Talbot 2002, p. 22)

In other words and to solve the paradox of complexity sciences, we can now claim that their founders’ project has never meant to foster a bidirectional exchange between disciplines, but rather consisted of an infantilizing operation of conquest of new territories of knowledge considered as non-scientific. Led by theoretical physicists persuaded of the intrinsic simplicity of nature and fascinated by mathematical and computational tools, such a project could thus hardly result in a post-Laplacian, antireductionist, holistic and symmetrically interdisciplinary science. If this aim is to be reached, other

approaches must be mobilized within a different socio-epistemic context. Far from any positivist fantasy aiming at a unified science (Knorr-Cetina 1999), it is a matter of inviting to “respect the methodological pluralism” of the different disciplines and schools involved (Ogien 2011), to make reflexivity the “epistemological basis of knowledge production” to make explicit any theoretical and normative premise with respect to others and to oneself (Camacho-Hübner 2007), to avoid subordinating the social sciences to the natural and engineering sciences by assigning them an auxiliary position (Callard and Fitzgerald 2015), and to build shared research agendas in a truly collaborative framework (Dubois, Guaspere, and Louvel 2018).

Conclusion

Complexity scientists are not a unified and homogeneous block of people and theories. Internal nuances and oppositions to the *complexity practice* exist and some have been mentioned in these pages. But the four theses exposed above are justified in the light of the fact that such exceptions remain rare and that numerical methodologies and ontologies are hegemonic within the complexity community. Despite its promises, the SFI’s approach has inherited from the 20th century physics the project of methodological

unification and reductionism of knowledge (Cat 1998), often giving rise to simplistic theories – firstly by presupposing and seeking determinism in all natural, artificial and human systems, secondly by reducing them to the ontology of computational networks, thirdly by mathematizing the “whole” while “pruning the impediments,” and fourthly by pursuing an asymmetrical interdisciplinarity where the formal sciences dictate methods, theories and views to the more qualitative ones. In conclusion, besides warning about the *complexity practice* the social scientists who may have fallen under the charm of the *complexity discourse*, and besides offering an interpretation of the gap between the two, this article is also a plea, not so much to abandon the usage of complexity tools outside natural and engineering sciences, but to remind, first, that the computational metaphysics of complex networks should go back to what it was – a heuristic metaphor – and, second, that interdisciplinarity provides more solid and interesting results as long as it is pursued under the auspices of a symmetrical dialogue between the parts, rather than in the context of an imperialistic endeavor.

Funding

Not applicable.

Conflicts of interest/Competing interests

The author declares no conflict of interests.

Availability of data and material

Not applicable.

Code availability

Not applicable.

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