Complexity sciences: A scientific platform

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Abstract

Social scientists have proposed several concepts to give account of the way scientific life organizes. By studying 'complexity sciences' – established in the mid-1980s by the Santa Fe Institute in New Mexico (USA) –, the present article wishes to contribute to interdisciplinary studies and emergent domains literature by proposing a new concept to describe this domain. Drawing from Bourdieusian sociology of science and STS, a 'scientific platform' is defined as a meeting point between different specialties, which, on the basis of a flexible common ground, pursue together shared or parallel socio-epistemic objectives. Most of the specialties inscribed in complexity suffer from a relative marginality in their disciplinary field. The term 'platform' metaphorically refers to what the heterogeneous members of the collective mutualize, both in cognitive and social terms, in order to exist and expand.

Keywords: Complexity, Santa Fe Institute, interdisciplinarity, disciplines, emergent domains

Introduction

Several notions of 'complexity' circulate in science and technology. The communities that coalesce around some of them share a common definition, a set of operational tools and references, an ensemble of meeting spaces, and an institutional project (Li Vigni, 2018a). One of these communities christened herself as 'complexity science(s)', a field that can be defined as an interdisciplinary and transnational association of specialties, whose aim is to computationally model and simulate natural and social 'complex systems' (Waldrop, 1992; Helmreich, 1998; Williams, 2012; Li Vigni, 2018b). These are defined as big ensembles of heterogeneous elements whose interactions produce emergent properties that are not deductible from their microscopic level: because of the vagueness of this notion, basically everything from ecosystems to cities, from epidemics to financial mar-

kets can fall within it (Mitchell, 2009). The field 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. After two years of meetings and discussions, in 1984 the group established a small private research center called the Santa Fe Institute (SFI) in the New Mexican city of Santa Fe. Even if historically this group is not the first reclaiming the study of complex systems, the SFI made organizing "a general science of complexity" its core mission (SFI Arch. #1: 3). The institute succeeded in establishing a standard of complexity sciences through publications and educational devices. Moreover, thanks to the symbolic capital of the founders and to a series of general audience bestsellers (Waldrop, 1992; for

a longer list, see Williams, 2012: 194), the SFI has since then generated many vocations around the world and inspired the foundation of several dozens epigone institutes.

Nevertheless, the unity of complexity science is highly questionable, both under an epistemological and a sociological viewpoint (Li Vigni, 2020a; Li Vigni, 2020b). In a precedent work, I have retraced the history of the SFI and argued its failure in establishing complexity as a new discipline (Li Vigni, 2020c). While its cultural influence is undeniable (Thrift, 1999; Taylor, 2003; Urry, 2005), the generalization of an idiom or a set of metaphors such as 'complex adaptive systems', 'networks', 'edge of chaos', 'tipping point', 'emergence', etc. does not imply we face a scientific field in the Bourdieusian sense (Gingras, 1991). If "[t]he central function of the institutionalization of the disciplinary community consists in preserving the permanence of the disciplinary activity through *reproduction* of its potential" (Guntau and Latkau, 1991: 21, emphasis in the original), then complexity cannot be considered as a discipline. Complex systems groups are very common in physics and mathematics faculties – a little less among life and cognitive sciences. But the institutes and degree courses, summer schools, masters, and PhDs that explicitly and primarily inscribe in this label are a few. That is because the academic identity of complexity specialists remains anchored to their disciplines.

At the same time, complexity specialists have theoretical affinities, show reciprocal acknowledgements, meet in thematic conferences, pursue collective funding, and weave research collaborations for example through what the SFI called the "integrative workshops", sort of brainstorming conferences where participants pursue transversal and interdisciplinary theories and models. From an object-driven viewpoint, we face a paradox: if the boundaries of complexity seem soft, undefined and open, its label has nevertheless a consolidated, acknowledged and clear identity. When looking at complexity sciences, it is indeed possible to feel a palpable tension between the solidity of this interdisciplinary field and the openness of its epistemic, social, and institutional boundaries and features. At the beginning of SFI's history, its founders wanted to establish a new

discipline. Up to the mid-1990s, they invested their efforts into the creation of a "general theory of complex adaptive systems" – in reference to the evolutive aspect of living and social systems (Cowan et al., 1994). The project was nevertheless abandoned in 1995 after the publication of an article authored by scientific journalist John Horgan and entitled "From complexity to perplexity" (Horgan, 1995). Therein, the journalist bitterly criticized complexity science for being "flaky" and the SFI for being "fact-free". Horgan's article had a huge impact on the New Mexican institute's image and internal organization. Its Board of Trustees and Scientific Advisory consequently operated several changes: some people were excluded and the pursuit for a general theory of complexity was officially abandoned. From then on, the institute's members redirected their efforts towards the construction of local but transversal theories about different phenomena (e.g. robustness, contagion, aging, animal metabolism, ecosystems formalization, city evolution, etc.) (SFI, 1997, 2000b, 2004; Marquet et al., 2014). Albeit this domain is often well recognized by insiders and outsiders, and often qualified as a "paradigm" from which to get inspiration to renovate other disciplines[1], young researchers having spent a period in a complexity institute may encounter problems in the suite of their career. Mavericks and marginal scientists with an unusual path may find there a temporary shelter, but, as it has been observed for other interdisciplinary fields (Prud'homme and Gingras, 2015; Lewis et al., 2016; Génard and Roca i Escoda, 2016), they run the risk of experiencing troubles in finding a permanent job once outside the complexity "free-trade zone", since they "have vast persuasive work to do, for instance in demonstrating that work done in 'sociophysics' has 'enough' physics" (Williams, 2012: 166-167). What kind of scientific organization is then one that confers an "ambiguous reputation", to cite a German biophysicist from the University of Cologne (interview, 18.11.15), but still continues to exist within an environment – academia – where reputation is central (Bourdieu, 2004)? Even if the initial disciplinary project of SFI founders was abandoned, many scientists inscribe in this domain or get inspiration from it. How to explain such a paradox? If complexity sciences are not a

discipline, then what are they or, at least, how can they be thought of?

In the present text I wish to address the question of how to characterize this field. From a theoretical viewpoint, social scientists struggle to find a term to describe interdisciplinary fields in general. One can think of the several 'studies' (STS, gender, postcolonial, area, futures, environmental, animal, digital, game, etc.), but also of fields like cognitive sciences, Earth system sciences, nanotechnologies and others. Some scholars prefer to adopt terms like 'epistemic cultures', 'styles of thought', 'invisible colleges' or 'research programs' for they consider that more classical terms like 'discipline' and specialty' are inadequate before such heterogeneity of practices and scales (Granjou and Peerbaye, 2011). Others – followed here – think the disciplinary level can still be pertinent, even if that means we need to go beyond it with new concepts, such as 'interdiscipline', 'transdiscipline' and the like. Drawing from Bourdieusian sociology of science and STS, this article proposes to contribute to the interdisciplinary studies and emergent domains literatures by introducing the term of *scientific platform* to make sense of complexity sciences and, I guess, other similar fields. If on the one hand it must be admitted that the concepts to define meso- or microscale research groups proliferate (see Tari, 2015 for a review), on the other one the terms that take into account the disciplinary level are not as numerous. Moreover, existing concepts fail to grasp the specific social configuration that complexity sciences manifest on an institutional and organizational level. The thesis of this article is that complexity has a specific socio-epistemic existence, partly determined by the conception of science that its members have and partly shaped by the specific historical context in which this domain appeared. Complexity sciences can be defined as an association of fledgling and/or marginalized specialties, which ally under the same label – sharing the same tools, views and spaces – in order to pursue common or similar epistemic and institutional projects.

This article is structured in four sections. The first one describes the materials and methods upon which it relies. The second one offers a general overview of complexity sciences from a historical and geographical viewpoint. The third reports the way complexity scientists self-perceive within the specific historical context in which their field has emerged. The fourth section describes the complexity domain under three axes (epistemic, ontological and social); it introduces and discusses the concepts that social scientists have produced to describe scientific communities by focusing on the disciplinary level; it finally presents the interest of the *scientific platform* concept. The aim of this proposal is not to essentialize nor legitimize complexity, but to offer social scientists a concept to seize a dynamical phenomenon both in its specificity and generality.

Materials and methods

The present work stems from a PhD research in sociology dedicated to the study of complexity sciences. The material of the thesis is composed by scientific literature, institutional archives, a dozen laboratory visits and 198 interviews – systematically transcribed – with 170 different people from Europe and the US. 115 of these were complexity scientists; the rest of interviewees were staff employees, other complexity theories specialists, as well as a few journalists, policy makers and NGO or think tank leaders. Such material contributed to form an overall view of the field under study here.

Interviews were semi-structured – partly open and individualized, and partly following a general framework. Such framework contained a dozen questions about personal pathway, view of complexity sciences, scientific practices and methods, as well as institutional attachments and objectives. The bulk of the interviews was determined by the choice of the pivotal institutions taken as study objects – the SFI[2] and the Parisian Complex Systems Institute[3] – 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 biggest and most active in the world – on the other. The rest of the researchers came from other laboratories inscribed in complexity sciences in Europe and the US.

As for the archives, a support is particularly of help here. From 1986 to 2014, the SFI published 40

issues of its Bulletin. The articles it contained were written by the staff members, resident scientists and freelance journalists. It was addressed to the members of the Board of Trustees, the research officers, the advisors, the scientists, the donors, 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 to twice per year. Printed in 5000 copies, it was available for free upon request. Later, its publication became electronical and old issues were digitalized, before the bulletin was suppressed for economic reasons. The Bulletins are an excellent material to retrace SFI/complexity history, network and theoretical content.

As for the approach followed here, to study scientific communities' organization in general – and complexity sciences' in particular – it is important to have a multiscale, multidimensional and dynamical perspective (Abbott, 2010). To make sense of the scientific group under study, a specific and a general frame have been adopted. The specific frame is the definition that Gingras (1991) and other social scientists give of the discipline as a *professional autonomy* device (Hufbauer, 1971; Goldstein, 1982; Whitley, 1984; Guntau and Latkau, 1991; Lenoir, 1997; Fabiani, 2006; Bulpin and Molyneux-Hodgson, 2013). Accordingly to the authors, one or another of the following elements can be more or less emphasized: the role of education and degrees, courses, and PhD curricula in order to perpetuate a field by the training of neophytes; the institutionalization of a field through the classical venues of science (societies, conferences, journals, departments, committees, facilities, etc.); and the role of social support, which can come either by the State, the industry, the general public or all of them. From this perspective inspired from sociology of work, the role of scientists is analysed under the professional dimension – certified competences are requested for specific tasks (education, research, industry, governmental needs, etc.) and are rewarded through ad hoc occupational categories, social functions, salaries and budgets. The second frame is more generic and gets inspiration from STS at large, according to which epistemic, ontological and social levels are interdependent

and indissoluble (e.g. Felt et al., 2017; Law, 2010; Vermeulen et al., 2012; Woolgar and Lezaun, 2013). This is the reason why, in order to present the specificity of complexity sciences in the fourth section, I have isolated three axes: epistemic (theoretical objectives and inquiry tools), ontological (view of complex systems) and social (institutions and meeting spaces).

History and geography of complexity sciences

This section is dedicated to a quick historical and geographical panorama of complexity sciences, from their inception at the SFI in the 1980s to the present-day, where six dozens institutes scatter around the world.

During the founding meetings that took place in 1982-1984, SFI's architects only agreed on the will of using the computer to foster interdisciplinary research, but diverged as for everything else: the size of the institute, its scope and even its research topic (Li Vigni, 2020c). Some of them advocated for the study of artificial intelligence, a few were for cognitive sciences, while others wanted the institute to focus on life sciences. As one of the founders, physicist Murray Gell-Mann, retrospectively explained in 1994, "In the beginning, we couldn't see clearly what sorts of emerging scientific syntheses we should seek" (SFI, 1994: 25). Only after several discussions, complex systems were established as the general object to make the institute community work on. The institute was then settled in 1984 under the name of Rio Grande Institute, before getting its actual name one year later (Cowan, 2010). The establishment of the "science of complexity", as SFI's founders initially used to call it, was a top-down social engineering process that relied on several strategies. A very important one consisted in mobilizing Senior Fellows' own economic, social and symbolic capitals. Not only the founders were the first important donors to get the institute off the ground, but – as the official bulletin of the SFI later wrote – they also "knew everybody. They could just pick up the phone" (SFI, 2004: 8). Through the founders' social networks, the institute obtained the first public contribution from the National Science Foundation, as well as the first private

money from foundations (like MacArthur) and companies (like Citicorp). The symbolic capital of the Senior Fellows had been consciously mobilized to increase the credibility of the SFI's endeavour, as the first president George Cowan explained to one of the bulletin writers: "We have a roster of National Academy types and Nobel winners, which suddenly did something very important for the whole notion [of complexity], that is, to make it look more respectable" (SFI, 1988: 5). Another important strategy consisted in fostering a positive mediatic coverage of the institute[4]. Moreover, SFI has importantly directed its fund raising efforts towards the private world (Li Vigni, in preparation), but has always addressed academia to lay down its scientific existence and continuity, through scientific publications and pedagogic devices like the summer schools[5]. While the scientific society dimension has not been invested by the SFI, it represented one of the most structuring tools of the European community[6].

Today there are more than sixty complexity institutes in the world. Physicist and entrepreneur Stephen Wolfram has published on his blog an approximative list of these centres, which are present on all continents, except Africa, with a particular concentration in the US, in the UK and in France[7]. These institutes have passed from a couple to more than ten between 1980 and 1994 (14 years), from ten to twenty between 1994 and 2001 (7 years), then from twenty to forty between 2001 and 2005 (4 years), and finally from forty to sixty between 2005 and 2010 (5 years). After the boom of the first 2000s – very likely due to the success of network theory (Pastor-Satorras and Vespignani, 2001; Barabási, 2003; Watts, 2003; Newman, 2018) – the curb reached a plateau and is today probably entered in a degrowth trend (in the sense that some centres close down). The SFI self-attributes the credit of such a dissemination: "imitation is the sincerest form of flattery" (SFI, 2007b: 7). Yet, while there is no doubt that it has indeed inspired many of these centres through its mediatic coverage and direct effort in the international outreach, the laboratory visits I realized in a dozen complexity institutes in Europe and the US suggest the need to nuance this point. Among such institutes, there are at least six different types.

The first category is that of the centres which preceded the SFI: even if they integrated some of SFI's characteristics after its appearance, these institutes have never shared the totality of the tools, discourses, objectives and organizational features as the American institute[8]. The second category includes the faithful SFI epigone centres, which interpret a restricted version of complexity, sticking to the boundaries that have been established by the American ancestor, and which also follow the original model in what concerns the type of institutional funding philosophy – mainly addressed to private actors such as enterprises and foundations[9]. Some centres have been established or renovated to imitate the SFI, but still keep some distinctions on the institutional level (mainly based on public funds) and on the theoretical one (some SFI approaches are missing and new ones are introduced). While explicitly aligning themselves with the "SFI tradition", these centres wish to innovate complexity sciences[10]. Moreover, some centres know and explicitly get inspiration from the SFI, without sticking to its epistemic discourses and objectives, and settle up very different institutional organizations where, contrarily to the SFI who only hosts theoreticians, the latter coexist with practitioners in the same environment[11]. The fifth category gathers centres that adopt the term of complex systems more for institutional convenience than for adherence to the American ancestor. In these cases, the label is perceived as an efficacious hat that can federate heterogenous and multidisciplinary teams[12]. In the sixth and last place, it is important to mention all the other complex systems institutes that make no reference to the SFI and whose members often ignore and sometimes despise it: in these public centres, the reference to complexity mainly draws from statistical and condensed matter physics, where the term of complexity has been in usage since the 1970s without a flagship rationale[13]. Whatever their category, most of these laboratories operate as visiting institutions, so that the number of resident researchers is often small. The majority of their affiliates are temporary associates that either spend a short stay and then go away, or – like in the case of the SFI and its followers – are formally associated to the institute for a long time, but only spend a few weeks per year there.

While the fieldwork which this article lays upon was limited to some European countries and American states, a quick Internet tour shows that certain complex systems institutes in the world seem not to be active anymore[14]. As for the topics, some seem specialized in physics, others in robotics or engineering, others yet in biomedicine[15]. The variety of the subdisciplines involved and of the institutional forms taken by these networks, as well as their ephemerality, suggest porous and instable boundaries. Furthermore, while more or less technical introductory books on complexity sciences are numerous (Byrne, 1998; Kaneko and Tsuda, 2000; Miller and Page, 2007; Mitchell, 2009; Fieguth, 2016; Thurner et al., 2018; Tranquillo, 2019; Peletier et al., 2019), handbooks (Gros, 2015; Mitleton-Kelly et al., 2018) and university teachings are few[16]. SFI's summer schools in complex systems continue to exist and additional ones have appeared elsewhere, but dedicated PhD programs stay rare[17]. Masters in complex systems appear to be a little more numerous and faithful to the SFI's tool belt[18]. These programs are far from being present in all countries and universities. In general, teachings in complexity sciences seem to focus on a few specialties and never include all those inscribing in the label.

Complexity scientists' self-perception and context

Before analysing complexity sciences, I will investigate how its members think of themselves and how they conceptualize their field. Exploring this question will lead us to evoke the question of the historical moment in which complexity has emerged and developed.

Today almost no-one of the scientists inscribing in this label believe that a discipline of complexity exists or will ever exist: out of the 115 people interviewed, only six still endorsed the project, and they were all scientific entrepreneurs but one. In a 2007 report for the European Commission, one of them wrote that "The promise of the *science of complexity* is to provide, if not a completely unified approach, at least *common tools* to tackling complex problems arising in a wide range of scientific domains" (Weisbuch, 2007: 3, emphasis in the original). But since the end of the 1990s,

the SFI bulletin started talking about complexity more as a "way of thinking" than as a discipline (with some exceptions here and there). Moreover, the overwhelming majority of my interviewees use the plural to talk about complexity sciences and employ different formulas to qualify this field. Some talk about it as a "sort of framework or frame of mind" (interview with an SFI bioinformatician, 27.03.15), or as "a philosophy and an approach […] that can be used in many different disciplines" (interview with an SFI bioinformatician, 21.09.16). Others talk about it as a "comfortable umbrella for interdisciplinarity" (interview with a Lyon Complex Systems Institute physicist, 15.09.15), or as a "perspective" (interview with an SFI anthropologist, 23.09.16). A French computer scientist describes complexity as an "a priori on the way [he] see[s] things" (interview with a Parisian Complex Systems Institute computer scientist, 31.01.17).

Like the institutes, individual researchers show different attitudes vis-à-vis the field. While complexity founders can be seen as militants faithful to the initial project of a new science – or to a renovated project of a "transcience" which be capable of synthesizing different fields (SFI, 2011: 2) –, other members of the community have very different postures. Some scientists have jumped into complexity only temporarily in order to operate a disciplinary reconversion, such as from physics to computational epidemiology or to social sciences. Others have used it to renovate their own discipline by applying established physical and computational tools to new study objects – e.g. quantitative geographers applying power laws and agent-based modelling to cities' dynamics. For certain researchers, complexity represents a place where to "have fun" out of their disciplinary frames, within which they need to stay if they want "a career progression" (interview with a Parisian Complex Systems Institute computer scientist, 23.03.16). Yet another category of researchers is that of the scientists who "shy away from mentioning complex systems science" within their (often adoptive) disciplinary community, because "they're afraid, in a way, to be offensive" when bringing their "revolutionary" tools into the welcoming subdiscipline (interview with a European Commission scientific project

officer, 20.03.17). Lastly, in all my laboratory visits I have met PhD candidates and post-doctoral researchers who, when asked about their reason of being there, never mentioned the study of complexity in itself. They were rather attracted by the development of a given approach, by the use of a certain technical instrument, by the presence of a particular researcher or an established subdiscipline. Except the scientific entrepreneurs who actively pursued the creation of funds and institutions for the development of complexity sciences as such, many of the researchers interviewed often avoid to employ the "complex systems" keywords, because, as a German biophysicist explained,

> The label "complexity" and "complexity science" sometimes get a kind of ambiguous reputation. [...] We were making a project, then came the question whether to put complexity in the title, and everybody said it was "too oversold, we cannot associate with that, we have to come up with something else". (Interview with a German biophysicist from the University of Cologne, 18.11.15).

The paradoxical existence of complexity sciences lays in the fact that researchers adhere to them intermittently or without a full engagement, as well as in the fact that candidates to project funding can happen to fake or twist their approach to adapt to the call. As a scientific project officer from Brussels explained to me, complexity sciences have sometimes appeared as a "sexy" field so to attract "people saying they have ideas from complex systems science while they don't" (interview with a European Commission scientific project officer, 20.03.17). Such elements are better understood by taking into account the historical context started in the 1980s in which complexity sciences have evolved (Li Vigni, in preparation). According to several historians and sociologists, the technological and scientific worlds have entered, in the last forty to fifty years, a new "regime of knowledge production", characterized by the State retraction from university and research, by the increasing submission of these to market imperatives, as well as by the generalization of a funding strategy based on the logic of projects (Pestre, 2003; Busch, 2017). The latter has in particular been accompanied by a shrink-

age of funds for investigation, by an invitation to interdisciplinary work (Gibbons et al., 1994; Weingart and Stehr, 2000), and by a frequent turnover of "fashionable" topics. Similar to fads, labels such as nanotechnologies, Artificial Intelligence, Internet of things or complex systems are submitted to cycles of funding: in Europe for example that corresponds to the different Framework Programmes for Research and Technological Development. In the case of European complexity, the golden age of project funding labelled "complex systems" was the decade going from 2004 to 2015, during which the Commission has supported the field with more than 100 million euros (e-mail interview with a British mathematician and evaluator of such projects, 23.03.18.).

Complexity sciences as a scientific platform

This section describes complexity sciences around three axes – epistemic, ontological and social. The first three subsections highlight, for each of these points, what is shared by the several subdisciplines at presence within the complexity label even before they decide to come together; they also show how these commonalities are strategically used by the scientists in order to make complexity exist and expand. The fourth subsection presents some of the main concepts to think about scientific communities (discipline, specialty, etc.) and points out their limits in giving account of complexity sciences. The last subsection describes this field as a *scientific platform* and indicates other examples which this concept may be applied to.

Epistemic axe

The epistemic elements that complexity sciences share are basically the study object of 'complex systems', the so-called "holistic" approach, a set of numerical inquiry tools and the epistemic project of formalizing all "soft" sciences (Li Vigni, 2020a).

It is notorious that biologists do not agree on the definition of life and that neither psychologists agree on that of intelligence. In the case of complexity sciences, the definition of the common object is left generic, vague and open from the outset, with the aim of letting virtually

any discipline get in. While life scientists will put the accent on 'self-organization' and the 'evolutionary' aspects of their complex systems, physicists will mainly address 'phase transitions' and 'attractors', while geographers will focus on cities' 'trajectories' and 'bifurcations'.

Complexity "holistic" approach is intended to overcome the "analytical" one, which is seen as separating inseparable things. Holism is presented as the useful perspective to seize systems "emergent" properties. In such view, the microscopic level is too difficult to be studied in detail, and by the way useless, since what counts is what results from the interactions. The general conviction of complexity researchers is similar to that of deterministic chaos – a philosophy that Murray Gell-Mann has famously epitomized as follows: "Surface complexity arising out of deep simplicity" (Pines, 1988: 3).

Among the generally shared tool belt within complexity sciences, a dozen of mathematical, physical and computer methods appear to be the most recurrent[19]. Except Christopher Langton's agent-based model strain (Langton, 1997; Helmreich, 1998), all these tools have been conceived outside and before the SFI was founded. Complexity scientists have revised, appropriated, further developed and applied these tools in unusual ways. It is important to remark that these methods are ontologically flexible – almost all of them have, at one time or another, been applied to simulate any kind of system, from magnets to stock options, from forests to electors, from proteins to robots.

Interestingly, the holistic study is conducted through a series of tools that physicalize, mathematize and computerize the different kinds of complex systems – an operation that has sometimes encountered internal resistances (Jensen, 2018). Statistical physics and agent or network simulations – today the most spread tools of the complexity belt – are often philosophically based on methodological individualism (O'Sullivan and Haklay, 2000), but actually make sense on a meta-population viewpoint (Colizza and Vespignani, 2008). Complexity scientists indeed focus on "aggregates", "clusters" and "populations". The "individuals" simulated are the computational instantiation of a *class* of individuals.

They are a form of statistical embodiment with a fictional singularity. Individuals' freedom of will and/or unpredictable variability are synthetically represented through the introduction of a certain degree of stochasticity. Agents are otherwise strictly submitted to a more or less small number of "rules", "laws", or "mechanisms" depending on the subdiscipline (Treuil et al., 2008).

How is all this used strategically? The vagueness of the term "complex systems" is one of the glues that keep this heterogeneous group together. It can either refer to a cell, an ant colony, a social network, or a financial market. At this intersection, the definition is not directly operational, because every member will mean very different things with the same term. The concept remains sufficiently general to justify the copresence of very diverse researchers in the same place (be it an institute, a research program, a workshop or other). The term is used in federative moments, such as the fund raisings and the outreach. Both at the SFI and in the French community, complexity scientists regularly meet in brainstorming workshops to collectively reflect on, and establish a common definition of complexity (Cowan et al., 1994; Bourgine et al., 2009; Bertin et al., 2011).

By sharing a definition, an approach and an epistemic project, complexity scientists let open the possibility to include into their field as many specialties as possible under the same mission and flag. Their theoretical discourse is presented as a revolutionary novelty in science: according to George Cowan, SFI's vocation was to produce a sort of "twenty-first century Renaissance man […] able to deal with the real messy world, which is not elegant, and which science doesn't really deal with" (SFI, 1988: 4). Complexity approach was also intended to conquer new territories of knowledge through numerical tools: "in recent decades the mathematics of chaos and the ubiquity of computers have produced a convergence of interests between the [social and natural sciences]" (Cowan, 2010: 131). Apparently the exchange between the "two cultures" is conceived symmetrically (Bourgine and Johnson, 2006: 6). In fact, the epistemic framework – strictly numerical – is charged to formalize "soft" sciences: "mathematics, computer science and statistical physics can bring new formalisms for representing

complex systems dynamics in an elegant and useful way" (Bourgine and Johnson, 2006: 14).

These tools permit those who master them to either renovate an existing specialty (e.g. quantitative geography) or incept a new one within a given field (e.g. computational epidemiology). To give an example, quantitative geography appeared in the 1960s at the initiative of some Swedish, Anglo-American and French researchers (Berry and Pred, 1965; Robson, 1973; Cuyala, 2014; Varenne, 2017; Pumain, 2020). This subdiscipline of geography gets its main inspiration from physics and, in some cases, aspires to provide decision making support to private and public actors. Starting from the 1980s, this specialty has renovated itself drawing from complexity sciences. On the other side, computational epidemiology was founded in the 2000s by a small number of physicists experts of complex networks and statistical physics. In order to shape their expertise and better integrate the public health array of specialties, computational epidemiologists get inspiration from meteorology and aspire to build up national and international infrastructures for real time epidemic forecasting (Grüne-Yanoff, 2011; Moran et al., 2016; Opitz, 2017). These two domains share the fact of having a relatively marginal position within the larger disciplinary field they are embedded to. Complexity tools can be perceived differently depending on the discipline. In the case of quantitative geography, digital methods are criticized by qualitative geographers for being reductionist, theoretically useless, or ontologically empty (interview with a French quantitative geographer, 17.09.15). In the case of computational epidemiology, public health practitioners were initially reluctant in considering a group of statistical physicists with a computational talent as their peers. Gradually, the predictive success of their models and simulations, and their socialization with public health officers, have brought some of them to be acknowledged as part of the community (Li Vigni, 2021).

Ontological axe

Complexity scientists mostly share the same *mathesis universalis* view of nature (Israel, 2005). Ontology is the other important element that unites different subdisciplines within the same space. According to an important early member of the SFI, "A key property of complex adaptive systems is their ability to process information – to compute – in order to adapt and thrive in an environment" (SFI, 2014: 18). The European roadmap for complexity sciences claims something similar: "Many complex systems can in themselves be seen as implementing computational processes" (Bourgine and Johnson, 2006: 31). In their view, almost everything is a computational network and as such it can be studied; the opposite is also true: since many systems can be studied through network computations, these systems *are* computational networks:

> When you bring networks down to their minimal description and get them rid of the different disciplinary terminologies [...] what we discover of, say, biological networks can be partly applied to sociology and computer science. (Bersini, 2005: XVIII-XIX, my translation).

Without a common interpretation of the organization which the different complex systems are made of, it would probably be difficult, for complexity scientists, to share the same inquiry tools. Moreover, the ontological argument can be used to support the epistemological one:

> [The simulation] is an abstraction of the form. If a real form exists, the form of the simulation is an abstraction of the real form. [...] When [the simulation] works, it means that the phenomena that I have captured within it are effectively the real phenomena. (Interview with a French computational epidemiologist, 09.05.17).

From a strategic viewpoint, the computational, mathematical and/or physical view of natural and social systems is often opposed by complexity colleagues within their own individual subdisciplines. Nonetheless, this has not prevented the relative institutional success of some digital platforms that have been developed under their label. In the US, Christopher Langton's agent-based model platform called "SWARM" (SFI, 1998a: 19), as well as MIT computer scientist Mitchel Resnick's "Starlogo" (SFI, 1998b: 2), were both open source and have been utilized in several contexts for very different objectives – from optimizing agro-

industrial companies production to school science education, from theoretical biology research to military planning at DARPA.

In France, the Parisian Complex Systems Institute has developed a platform which, through a workflow and the lending of computing time at a national or international grid, serves to test, challenge and statistically analyse the individual models of a heterogeneous community of modelers from different university and research departments within the country (Reuillon et al., 2013). The ontological commonality that allows physicists, ecologists, embryologists and social scientists to use the same codes and models, also allows the mutualization of digital platforms for their development and testing – ontology sharing permits economies of scale.

Social axe

Complexity sciences can be seen as a sort of confederation, where each 'nation' keeps its autonomy while associating with other autonomous 'nations'. The label provides an area of intellectual exchange, but also an intermittent alliance in order to reach common social and institutional objectives. Complexity specialists meet at a series of places, such as institutes, conferences, workshops, summer schools and scientific societies, where they can discuss, collaborate, trade and collectively conceive shared strategies in order to exist and expand, all together or individually and in parallel. An important device invented and used by the SFI to create interdisciplinary collaborations is what it calls the "integrative workshop". Halfway between a conference and a brainstorming, such device can last from one to two weeks, and gather two to three dozen participants. Each attendant is a speaker and contributes by presenting his or her contribution. In the following phase of synthesis, attendants propose possible bridges between the different contributions (SFI, 1990a: 10). Complexity institutes are generally conceived as visiting institutions to "legitimate this kind of interdisciplinarity, to give it the means to develop, to allow people to meet, to assert themselves and not to 'hide away'" (interview with a French computer scientist at the Parisian Complexity Institute, 23.03.16). Since the beginning, the SFI self-described "as a growing, extended family

whose members stay in touch by phone and computer and who return frequently to sit around the table at [the institute]" (SFI, 1992: 28).

For complexity specialists, the domain launched by the SFI represents a stimulus or a pretext in order to challenge hegemonic approaches in their belonging fields. This is either to "revolutionize" or at least "innovate" a part of their discipline, where they can be minoritarian (which does not necessarily mean marginal and dominated: certain network specialists for example are central and dominant in physics and computer science). These scientists search for allies, inside and outside their own discipline, in order to legitimize and strengthen their scientific efforts. To give a representative example, such a strategic way of thinking is shared by the international members of the Network for Ecological Theory Integration (NETI) – a group of ecologists, mathematicians and physicists from the US, Europe, Australia and Chile, most of whom are SFI's members who periodically meet at integrative workshops and write common publications, to produce general mathematical theories for ecosystems. In their view – inspired from physics –, science has to produce not only local models, but also general theories – where theory is defined "as a hierarchical framework that contains clearly formulated postulates, based on a minimal set of assumptions, from which a set of predictions logically follows" (Marquet et al., 2014: 701).

Terms to conceptualize scientific domains

This section introduces the available concepts to give account of scientific groups on the disciplinary level. In the light of the plethora of texts about subdisciplines, disciplines, interdisciplinary, transdisciplinary fields, etc., it is impossible to provide an exhaustive review of the literature (cf. e.g. Sugimoto and Weingart, 2015; Klein, 2008). In the following, the concepts of 'discipline', 'specialty' or 'subdiscipline', 'interdiscipline', 'transdiscipline' and 'studies' are discussed and the reasons why they do not seem suited to make sense of complexity are given.

In a 2000 paper, French sociologist Gilles Klein realized an interesting review of the literature on the concept of discipline (Klein, 2000). According to him, philosophers, sociologists and historians

of science contributions can be organised around three different foci: cognitive[20], institutional[21] and societal[22]. Furthermore, Klein highlights the fact that several authors have deconstructed the concept of discipline, by pinpointing that science is always evolving through competition and collaboration into endless ramifications[23]. These authors criticize the concept of discipline for being too static to describe ephemeral and plastic networks of researchers that reconfigure incessantly. The concept of "specialty" is sometimes invested to show that disciplines are conglomerates of subfields and that researchers work on similar problems with similar practices into local contexts (Favre, 1995; Zuckerman, 1988; Leclerc, 1989; Monneau and Lebaron, 2011). From this perspective, disciplines are associations of specialties, such as, say, biology which differentiates into genetics, microbiology, zoology, etc. Despite the constant ramifications of sciences, many authors still consider the discipline as a useful concept[24]. But if the constitutive elements of a discipline are a common standardized knowledge, a generalized pedagogical cursus at universities and the existence of institutional channels of professionalization, then complexity science is not a discipline. The frontiers of the latter are porous; educational curricula, stabilized handbooks and official professional devices lack. Indeed, while there is no doubt that complexity sciences agglomerate several specialties under their label, these are not coordinated under a homogeneous discipline. Complexity looks like an alliance of a set of subdisciplines which come from, and still operate within, separated disciplinary contexts. In this sense, they operate as a *crossroad* where statistical physicists, theoretical ecologists, computer scientists, quantitative geographers and others meet to share and pursue a common epistemic, ontological and social project.

The second concept to be addressed is less richly covered by the literature, but apparently very pertinent for our case here. 'Interdiscipline' is not to be confounded with the concept of 'interdisciplinarity', whose polysemy and ambiguity makes it impossible to offer a satisfying literature review here (cf. e.g. Klein, 2008, 2010; Porter and Rafols, 2009; Madsen, 2018). American sociologist Scott Frickel defines 'interdisciplines' as "hybrid-ized knowledge fields that are constituted by intentionally porous organizational, epistemological, and political boundaries" (Frickel, 2004: 269; see also Friman, 2010). Frickel explains that interdisciplines are more epistemologically and organizationally variable and instable, less institutionally powerful, as well as more focused on problem solving than disciplines. In his case study – genetic toxicology – he shows that geneticists have retained control of the emergent field, and that the interdiscipline in question has reconfigured existing knowledge in established fields instead of producing entirely new knowledge. Some similarities between Frickel's case and complexity sciences do exist. Like genetic toxicology, the latter have porous boundaries; they are epistemologically and institutionally variable, weak and instable; they also have mainly focused on the reconfiguration of existing knowledge in established fields; finally they are characterized by the internal domination of two fields (namely physics and computer science) over the others (life and social sciences).

Yet, divergences between Frickel's definition and the reality of complexity are more substantial. First of all, the field launched by the SFI does not unite only two fields but many more. Complexity has been clearly conceived as an ecumenic alliance between very many different domains in order to renovate science in general. Second of all, despite the domination of physical and computational approaches over the other subdisciplines at presence, it must be noted that epistemic and institutional conflicts between complexity scientists are quite rare, essentially for two reasons. First, life and social scientists joining the field have an advanced knowledge of numerical tools or wish to gain it through their participation into an interdisciplinary endeavour like this. Second, it is common that complexity exponents, at least in the initial phase of their commitment into the field, suffer from a relative marginality within their own discipline, and have an interest in associating to other scientists in order to gain legitimacy and create the conditions of their existence and expansion[25]. Finally, even if some of the specialties which avail themselves in complexity are now frequently welcomed or even solicited by governmental, entrepreneurial and civil society instances,

complexity sciences have been conceived and organized since the beginning as a theoretical domain, not as a problem-solving field like genetic toxicology.

Let us focus on the term 'transdisciplinarity' now. This is defined in different ways: *a*) the study or the action "on real world challenges in a mode of inquiry commonly referred to as problem solving"; *b*) "a practice of transgression that challenges existing institutional structures and disciplinary methods of research that are not apt to deal with complex real world problems"; *c*) "the quest for unity of knowledge by integration and synthesis using concepts of holism, systems thinking and deep structures" (Lawrence, 2015: 2; see also Alvargonzález, 2011 and Zierhofer and Burger, 2007). While the first two meanings imply the collaboration between scientists and extra-academic actors for the resolution of complex sociotechnical issues and parallel the concepts of 'Mode 2' (Gibbons et al., 1994) and of 'post-normal science' (Funtowicz and Ravetz, 1993), the third one corresponds to the epistemological project pursued by some thinkers (Morin, 1977, 1980; Nicolescu, 1997; Klein, 2004). In all these cases, the normativity of this term does not suit the descriptive goal of the present article.

Less common, the concept of 'transdiscipline' has not been rigorously thematized by sociologists of science, but circulates in certain streams of evaluation studies, informing science, engineering and psychology (Coryn and Hattie, 2006; Ertas, 2010; Cohen and Lloyd, 2014; Moir, 2015). In particular, Scriven (1991, 2003) considers it as a useful term to characterize logic, statistics, ethics, computer science, information science, evaluation studies, and other similar fields which are standalone disciplines, but are at the same time used as tool belts in several other disciplines. Scriven (2008: 65) distinguishes a second similar meaning of transdiscipline: "a theory, point of view, or perspective that has some application in several disciplines. This [...] was applied by people in reference to both Marxism and feminism, since both points of view can affect one's stance in many traditional disciplines such as sociology, psychology, and economics". Either way, complexity sciences make use of three transdisciplines – i.e. mathematics, physics and

computer science – but cannot be considered as a transdiscipline in themselves. Even if the current president of the SFI aims at fostering what he calls "transcience" (SFI, 2011: 2), the different subdisciplines at presence in complexity institutes and conferences remain anchored within their disciplinary fields.

Another term which deserves attention for its application to interdisciplinary domains is the concept of 'studies'. Such term has been increasingly used to name all sorts of pluri-disciplinary conglomerates that get together for the inquiry of the same theme. It is important to say that not all pluri-disciplinary and object-oriented fields are qualified as studies – a term particularly employed for social sciences. Fields such as nanotechnologies, biotechnologies, cognitive sciences, and complexity sciences are not called 'studies', even if they can contain social sciences. Yet, all these examples share the same characteristics of being pluralistic – since many disciplines, methodologies, paradigms, professional roles and institutional forms co-exist within them – and of having a common interest for the same phenomenon. The problems with this concept is that it is mostly used by the studies members themselves as a backup solution to qualify their association and that it remains weakly theorized by social scientists (Monteil and Romerio, 2017). While few scholars belonging to this or that field of studies aim at transforming it into a discipline, it is evident that in the vast majority of cases the disciplinary identity of their exponents stay strong. The term of studies can thus be seen as a synonym of 'interdisciplinary fields'. Yet, these domains have some recurrent cognitive and social characteristics that deserve to be isolated and highlighted. For example, as the readers of this journal know well, STS regroup basically all the humanities working on technoscience. They do it with very different, sometimes mutually exclusive approaches. Yet they fundamentally agree on a set of basic tenets (see below). Exploring complexity is useful to conceptualize this kind of interdisciplinary fields that couple a loose unity with an ineliminable heterogeneity.

Scientific platform, a general concept?

"To give a name to a scientific domain, to make it exist, and to align oneself with it, is not a neutral enterprise" (Popa, 2019: 114). Defining a field is at the same time an epistemic and a political act (Bourdieu, 1975). It implies the construction of boundaries, the designation of adversaries, the struggle for the legitimation of new institutions and for the creation of new professional roles and competences (Gieryn, 1983; Favre, 1983; Feuerhahn, 2013). But, while complexity scientists do create new boundaries and struggle for legitimation, their frontiers are more permeable than those of classical disciplines and specialties. Also, they fail to establish a certified professional category.

What is thus its *raison d'être*? The label can federate and reinforce individuals who are isolated and weakened in their respective domains. In this sense, complexity is not a 'field' in the Bourdieusian sense, since internal competition is dozed off and rather replaced by collaboration for reinforcing the individual struggles of participants against what they sometimes call "disciplinary inertia" or "institutional conservatism". To describe complexity sciences, I thus conceive and propose the concept of *scientific platform* as an articulated description of such multidimensional strategy. If the indigenous qualifications of 'sciences' and 'studies' do not suit for the description, it is because these terms tend to put the accent on their study object more than on their social and institutional strategies of existence. The term of *scientific platform* is intended to re-politicize the emergence of this interdisciplinary domain. As Casilli (2019) remarks, the term of platform was firstly used in the military and architectural fields, it then entered the political and theological spheres, and it recently became widely used to refer to economical actors such as Facebook or Uber, whose digital platforms connect people and make them function on a large geographical scale. Here the term is mainly used metaphorically with reference to its initially architectonical meaning. Similarly to what Popa (2019: 115) has remarked for the 'area studies', complexity sciences appear capable of "offering an intellectual and institutional 'flagship' and at the same time enough margins of manoeuvre to the actors that seize it". A certain "fragile coherence" (Schut and Delandre, 2015: 84) can be observed in disciplines in general, but, in the case of complexity sciences, the weakness of the glue that keep them together can paradoxically represent a form of strength, for it permits to certain mavericks to have a social space instead of nothing. While often marginal or minoritarian in their disciplinary homes, the researchers that inscribe within this label seem to believe and realize the proverb "there is strength in unity". A platform as intended here is a meeting point where people ally temporarily to get back to their home with more strings to their bows. The term is a rich metaphor because of its polysemy. In train stations a platform is the raised structure from which passengers can enter or leave a wagon; in astronautics it is a structure which dispatches resources; in car industry it is a set of components shared by different vehicle models; in short, it generally refers to a common foundation. The complexity label and the concrete spaces it recovers permit to its heterogeneous members to mutualize resources and increase collective legitimacy. Complexity meeting spaces are indeed used by scientists as a trampoline to carry on different kinds of struggle in the academic field at large – e.g. competing for federal or international funding such as NSF scholarships or as European Commission research programmes –, and in the specific disciplinary fields where they are individually inscribed. Nonetheless, researchers' inscription in complexity comes – if at all – at the second, third or fourth place in their CVs and self-presentations. A French quantitative geographer testifies of this in a way which is representative of basically the totality of my interviewees: "I guess that [complexity] is a totem to make people working on very different topics gather together […] I don't feel more complexity scientist than geographer" (interview with a French quantitative geographer, 12.04.17). Yet, when the "complexity" etiquette is important to attract funds, it can be used in the first place, as the following quotation from the European roadmap illustrates:

> The new science of complex systems […] is part of every discipline. […] It will benefit industry, the public sector, and all social actors. Complex systems science will be the foundation of Europe's wealth and influence in the 21st century. (Bourgine and Johnson, 2006: 2).

Now, if we take other interdisciplinary domains, we may find the same strategic operations as those observed with complexity. For lack of space and in the absence of an ad-hoc empirical fieldwork in other fields, I will speculate on the possible generalization of such a term by taking the example of STS. While its study object is sciences and technologies, the disciplines at presence include virtually all social sciences. From an epistemic viewpoint, in STS – like in complexity sciences – a set of principles, inquiry methods and approaches are recurrent despite the intellectual pluralism of its scholars: for exemple, the role played by non-humans and the importance of empirical fieldwork as compared to classical philosophy of science. From an ontological viewpoint, several nuances exist but science and technology are generally seen as inseparable from the rest of society. The sphere of ideas is always described as embedded to material, sociocultural, economic and political ones. From an institutional viewpoint, few STS departments and degrees exist in the world, and there again the power of disciplines remain strong, albeit some researchers aspire to overcome them (Cozzens, 2001). Like complexity, STS community has not managed to create a professional autonomy: its students are hired, in academia or outside, for their sociological, anthropological, historical backgrounds. At the same time, STS, like complexity, struggle for legitimacy and, because unity is strength, they often manage to confer a better touch to social scientists who inscribe in them. In many cases, STS scholars remain minoritarian in their home disciplines and such label is for them a second skin, both inside the STS community and outside. Functioning as a platform, STS exist intermittently, because researchers can retract from it when felt appropriate. Ultimately, I guess that many "studies", as well as cognitive, Earth system and sustainability sciences – among others – can be apprehended as *scientific platforms*. Such fields benefit from different degrees of success (e.g. STS and cognitive sciences seem to be better implanted than complexity), but they all seem to have the same instable, intermittent and strategic existence that get them closer to confederations than to thoroughly new nations.

Conclusion

Complexity sciences appear at the same time as a compact and well identifiable but at the same time crumbly and floating domain. Scholars passing by it may have trouble in finding a job, which, within the professional autonomy frame, is the clearest example of why complexity is not a discipline. After the profusion of research projects launched by the European Commission between 2004 and 2015, and after the wave of complexity institutes foundations around the world in the first decade of this century, the push of this field seems to be slowing down. Such a fact – along with the others exposed here – seem to give reason to some of my most critical interviewees, and to certain observers who have defined complexity as a "fad" (Sardar and Ravetz, 1994). Yet, complexity has not disappeared: there is still a community which finds there a second identity. How then to explain the persistence of complexity sciences over the decades and its relative institutional instability?

This article has showed that complexity can be seen as a socio-epistemic space where scientists from different subdisciplines meet and collaborate intermittently to reach a series of common objectives (increasing legitimacy, exchanging knowledge, searching for funds, etc.), on the basis of the loose commonality of a series of discourses, practices and values. Complexity is a heterogenous and loose space, which – despite its fuzzy boundaries and institutional weakness – provides a discursive unity that can function as a strategical foothold. This allows the specialties at presence under its label achieve a series of theoretical, social and political objectives. Complexity can also be seen as a "conglomerate" more than a unique and coherent entity (Favre, 1983; Popa, 2019). Yet, this term is too static to give account of the existential processes that lean upon the common ground represented by the label. The aim of the present article was to propose a concept which be sufficiently large and descriptive so to grasp the dynamism of a social phenomenon, without normatively reifying its boundaries, strategies and intellectual contents. Interdisciplinary domains adopt different tactics according to their objectives and sociohistorical contexts. Those that

work similarly to complexity sciences configure themselves as socio-epistemic spaces, whose unity is loose enough to embrace variable and pluralistic discourses and practices, with the aim of providing a temporary refuge or a perennial home to scientists who may be hardly classable. The concept of *scientific platform* may be useful to mean that complexity scientists find in their intermittent alliance the intellectual and institutional resources to return strengthened to their disciplinary fields, where they generally occupy a minoritarian position. Scientific platforms also provide theoretical, social and political support through which to carry existential or expansive efforts. In conclusion, whether the concept proposed here is pertinent to apprehend other similar interdisciplinary domains can only be answered through new empirical fieldworks.

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Notes

1   Like medicine, biology, sociology, economics, or political sciences (Urry, 2002; Foster, 2005; Martin and Sturmberg, 2009; Castellani and Hafferty, 2009; Geyer and Carney, 2015).

2   https://www.santafe.edu/.

3   https://iscpif.fr/.

4   The prestige of the Senior Fellows and the ambition of the institute's promissory discourse attracted more than one scientific journalist to tell the history of the fledgling 'complexity science' in a captivating way (Waldrop, 1992; Lewin, 1992; Kluger, 2008). Some of SFI's founders and first members also contributed to the fabrication and spread of this promotional narrative (Kauffman, 1993; Casti, 1994; Goodwin, 1994; Gell-Mann, 1994; Holland, 1996). Besides books, the research centre has always given much attention to media in general, because of their cascade effects on funding, members enrolment and credibility (e.g. SFI, 2006: 2; SFI, 2007a: 0).

5   In 1990, some of its members launched a scientific journal called *Complexity* through John Wiley (SFI, 1990a). The journal lacked of success because, as several interviewees explained, they prefer to publish in traditional specialized journals with higher impact factors (see also Williams, 2012: 171). Another kind of publication had more success. For the first fifteen to twenty years, the institute published a book series in joint venture with Addison-Wesley first and the Oxford University Press later on (SFI, 1987; SFI, 1998a). Some of the most sold titles were the proceedings of the Complex Systems Summer Schools (CSSS) – another important strategic device to establish the field started in 1988 (SFI, 1988). From the start, the institute attributed to this educational device an important place – first to produce new complexity adepts in the US and around the world, and second to fix the international standards of complexity science tools (SFI, 1991: 14). These have varied through time, but a certain number of them are now considered as paradigmatic. At the beginning of 2000s, the institute exported its summer school to other countries in the world, with the aim of extending its influence abroad (SFI, 2000a, 2001, 2005, 2008). Several summer and winter schools were organized in Eastern Europe, Asia, and South America, which indirectly led to the founding of new complexity institutes in these countries.

6   In 2004, a small group of scientific entrepreneurs – essentially polytechnicians and physicists, with the support of two scientific program officers from the European Commission in Brussels – organized in Turin the first European Conference on Complex Systems, which triggered the foundation of the

European Complex Systems Society (https://cssociety.org/events/15). The conference was the first of a long series and was financed, along with several international research projects, by different European programs. As one of the interviewees explains, the conferences were "a powerful instrument which became a place for visibility, a place for real discussion, a place for lobbying", capable of creating "a public notion of group identity" (interview with an Italian physicist and data scientist, 17.02.17).

7 http://blog.stephenwolfram.com/2012/05/its-been-10-years-whats-happened-with-a-new-kind-of-science/.

8 One can think of the Interdisciplinary Center for Nonlinear Phenomena and Complex Systems founded in Brussels by physicist Grégoire Nicolis around the figure of Ilya Prigogine in 1991 (http://cvchercheurs.ulb.ac.be/Site/unite/ULB164UK.php), or of the defunct Centre de Recherche en Épistémologie Appliquée founded in 1982 at the French École Polytechnique by philosophers Jean-Pierre Dupuy and Jean-Marie Domenach (Lavallée, 1992).

9 It is for example the case of physicist Yaneer Bar-Yam's private centre called the New England Complex Systems Institute, based in Cambridge (MA) and founded in 1996 (http://necsi.edu), and that of physicist Ricard Solé's Complex Systems Lab, based in Barcelona (Spain) and founded in 1998 (http://complex.upf.edu).

10 Some examples of this type are Paris and Lyon Complex Systems Institutes, launched in 2005 by French polytechnicians Paul Bourgine and by French physicist Michel Morvan, as well as the Institute for Scientific Interchange of Turin (Italy) which has a much longer history and which specialized in complexity since the beginning of the 2000s.

11 The Center for Complex Systems and Dynamics, affiliated to the Illinois Institute of Technology in Chicago (https://web.iit.edu/ccsd), belongs to this typology. It was founded in 2003 under the impetus of two chemical engineers – Fouad Teymour and Ali Cinar – who conduct agent-based modelling to simulate biochemical and chemical-physical processes in collaboration with laboratory and industrial experimenters of the IIT.

12 It is for example the case of the Complex Systems Department of the Computer Science Laboratory at Pierre-et-Marie-Curie University in Paris (https://www.lip6.fr/recherche/team.php?acronyme=SysComp), as well as of the Namur Institute for Complex Systems at the University of Namur (Belgium) (http://www.naxys.be).

13 One can think of the Max Planck Institute for the Physics of Complex Systems in Dresden (Germany) (https://www.pks.mpg.de/institute/), and the Matter and Complex Systems Laboratory at the Diderot University in Paris (http://www.msc.univ-paris-diderot.fr).

14 https://www.phy.ncu.edu.tw/~ccs/research.html; http://english.ia.cas.cn/rd/200908/t20090807_27605.html; http://www.accs.uq.edu.au/index.html.

15 https://www.mq.edu.au/research/research-centres-groups-and-facilities/healthy-people/centres/australian-institute-of-health-innovation/Research-Streams/Complex-systems.

16 https://gradschool.duke.edu/academics/programs-degrees/non-linear-and-complex-systems.

17 The Open University in Milton Keynes (UK) offers one, with a focus on design and engineering (http://www.open.ac.uk/postgraduate/research-degrees/topic/complexity-and-design); the Vermont Complex Systems Center at the University of Vermont (USA) proposes another one with a focus on data science (https://vermontcomplexsystems.org/education/phd/); only the Department of Information Science and Technology at the University Institute of Lisbon seems to offer a program which resumes the main SFI's theories and tools (http://complexsystemsstudies.eu/?page_id=140).

18 For example, the international master in Physics of Complex Systems – jointly operated by three French universities and three Italian ones – is mainly focused on statistical physics and network theory (https://physics-complex-systems.fr/en/). The same is true for the Master in Complex Systems held by the École

Normale Supérieure in Lyon (France) (http://www.ixxi.fr/enseignement/master_systemes_complexes). The Master in Complex Systems Modelling at the King's College in London (UK) has a broader array of applicative fields – mathematical biology, nanotechnologies, financial markets, machine learning, etc. –, but remains focused on network theory (https://www.kcl.ac.uk/study/postgraduate/taught-courses/complex-systems-modelling-msc). The Master of Complex Systems at the University of Sidney teaches several computational techniques focusing around three majors – biosecurity, engineering and transport (https://sydney.edu.au/courses/courses/pc/master-of-complex-systems.html). The same is true for the Master held by the Centre for Complexity Science at the University of Warwick (UK) (https://warwick.ac.uk/fac/cross_fac/complexity/study/msc_and_phd/#phdprojects).

19   1. Dynamical systems, fractals and chaos; 2. Cellular automata; 3. Statistical physics; 4. Spin glasses; 5. Neuronal networks; 6. Genetic networks; 7. Network theory; 8. Graph theory; 9. Agent-based models; 10. Self-organized criticality; 10. Genetic algorithms; 11. Machine learning; 12. Statistical tools for Big Data. This list has been built using different sources, such as some scientometric and qualitative works done by complexity scientists themselves (Cointet and Chavalarias, 2008; Grauwin et al., 2012; Deffuant et al., 2015), complex systems summer schools, research projects, conferences and interviews with practitioners.

20   Some authors see the discipline as a logical space of construction of arguments which has an internal coherence and cohesion that excludes the researchers who do not share the same assumptions (Kuhn, 1962, 1977; Lakatos, 1970, 1978; Mullins, 1972; Mulkay and Edge, 1973; Law, 1976; Gilbert, 1976; Laudan, 1977; Berthelot, 1996; Galison, 1997; Bird, 2001).

21   For another group of authors, a discipline is characterised by the stabilization of a set of theories, practices and communities through their institutionalization in the form of university teachings and professionalization, scientific societies and journals, laboratories, certification procedures, etc. (Crane, 1967; Merton, 1973; Bourdieu, 1975; Long et al., 1979; Price, 1986; Ben-David, 1991; Cole, 1992; Dubois, 2014; Gingras, 1991; Schut and Delalandre, 2015).

22   Another group of authors focus on the societal control over disciplines which are seen as responding to social, economic and political interests (Foucault, 1969, 1980; Habermas, 1973, 1976; Van den Daele and Weingart, 1976; Krohn and Schäfer, 1976; Desrosières, 1998; Van Lente and Rip, 1998; Borup et al., 2006; Heilbron, 2004; Aguiton, 2018; Raimbault, 2018).

23   Such ramifications occur as a consequence of specialisation and interdisciplinarity (Holton, 1972; de Certaines, 1976; Gieryn, 1978; Collins and Restivo, 1983; Barnes and MacKenzie, 1979; Knorr-Cetina, 1982; Gibbons et al., 1994; Weingart and Stehr, 2000; Barry and Born, 2013; Grossetti, 2017)

24   They underly for example the fact that interdisciplinary collaborations can give rise to new specialties; that scientists struggle for the acquisition of the specific capital of a disciplinary "field"; and that the educational and recruiting institutional processes stabilize and perpetuate the traditional big bodies of knowledge (Cambrosio and Keating, 1983; Lenoir, 1997; Gingras, 1991; Fabiani, 2006; Bulpin and Molyneux-Hodgson, 2013). The definition of a new field is indeed the terrain of power conflict, because of its performative effects on intellectual and social boundaries, grant obtaining, institution building, recruitment, etc. (Gieryn, 1983; Klein, 1996; Small, 1999; Borup et al., 2006; Owens et al., 2006; Miller and O'Leary, 2007; Laurent, 2010).

25   Think for example of Stuart Kauffman in biology, Christopher Langton in computer science or Brian Arthur in economics.