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Toward a Science of Interaction

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**Cambridge
Scholars**
Publishing

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This book first published 2017

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN (10): 1-4438-9496-6
ISBN (13): 978-1-4438-9496-8

In memory of Cem Ertur

Cem Ertur, full Professor of Economics at University of Orléans, France, sadly passed away in October 2016. As scientific director of the project "Analysis and modeling of interactions in complex systems", he took part in the preparation of the book since its earliest step and impulsed a lot of energy to promote multidisciplinary work. Cem Ertur was a brilliant researcher, always willing to extend the frontiers of knowledge and to better understand the complex world in which we live. His research, recognized by the international scientific community, focused on two fields: structural spatial econometrics with contributions in macroeconomics and international trade on the first hand and methodological contributions in spatial econometrics on the other hand. He will be deeply missed by all those who once have had the privilege to meet him.

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Preface

In common language, an interaction is "the mutual action or influence which may exist between two or more objects, two or more organs, and even two or more phenomena", and it is always followed by one or several effects. In the experimental sciences, physics, chemistry, biology and geology, an interaction "aims to produce a change in the state of the interacting objects, such as particles, atoms or molecules". In the social sciences, Edgard Morin has defined interactions as "mutual actions affecting the behaviour or the nature of the objects, bodies, phenomena on influence"[1]

Complex systems and the inherent interactions between their components are present in almost all scientific fields. For instance, in the social and human sciences, interactions are at the heart of human behaviour, both in their individual and collective dimensions. No matter whether we consider cognitive, economic, linguistic or social dimensions, human behaviour may be conceived as resulting from a self-organizing process, which itself results from the interaction between the constitutive elements of a complex system.[2] As this complexity characterizes all organizational levels, a non-complex, one-dimensional and mono-disciplinary approach may seem quite limited for understanding human behaviour.[3] The study of complex systems in which individuals or groups of individuals interact becomes a major challenge in the social and human sciences and cannot be performed without a true interdisciplinary work, where the interactions between the researchers in the social sciences and in the fundamental sciences appear as the guarantee of an in-depth work with both methodological and conceptual cross-fertilizations.

Another example concerns the life sciences: from the individual perspec-

[1] Translated from Morin (1977), *La Nature de la nature* (vol. 1), *La Méthode*, Seuil, Paris.

[2] H. ATLAN, *Le vivant post-génomique ou qu'est-ce l'auto-organisation ?* Odile Jacob, 2011.

[3] E. MORIN, *Introduction à la pensée complexe*, Seuil, 2005.

tive, after decades of development of biological tools for approaches at the cellular and molecular scales, the advent of "omics" technology (genomics, proteomics ...) allows measuring a great number of individual parameters in many different situations (pathology, environmental ...). These "omics" approaches generate a large quantity of data, the analysis and interpretation of which constitute new challenges for biologists. If the functioning of cells becomes well understood, the interactions between intracellular regulation pathways or between cells within tissue or organs is addressed in only a limited way. Each level constitutes a complex system and a multi-scale integration represents a considerable challenge. When studying populations, the understanding of interactions taking into account the temporal and spatial dimensions integrates mathematical approaches and particularly in ecology and population dynamics. These approaches represent a major challenge for understanding and predicting global environmental changes.

The scientific project called "Analysis and modeling of interactions in complex systems" (AMICS), which started at the University of Orléans in 2012, constitutes the roots of this book. The AMICS project was supported by the National Center for Scientific Research (CNRS) through its interdisciplinary mission in the framework of a University-wide exploratory project. Around 20 researchers were directly involved in this project.

The first step of AMICS consisted in a monthly seminar about different approaches and methods to investigate interactions in various scientific domains: mathematics, physics, computer science, robotics, the life sciences, geoscience, economics, linguistics, the humanities, and the science of education. Around 20 talks were organized. The objective of these seminars was to compare the various ways interactions are addressed in each discipline using their own theoretical background and methodology. A crossed fertilization was expected, and the impulse of interdisciplinary collaborations, by promoting contacts and scientific collaborations.

The second step in AMICS was the organization of an international conference dedicated to interactions in complex systems. It took place from June 17 to June 19, 2013 and this conference involved about 130 participants from 14 different countries.

For this conference, 6 keynote speakers were invited, each one a specialist in a different scientific field:

- Henri Beresticky (EHESS- Ecole des hautes études en sciences sociales, CAMS - Centre d'analyse et de mathématique sociales, UMR 8557 CNRS), "Propagation in inhomogeneous media: From epidemics to contagion of ideas"

- Karin Fischer (University of Southern Denmark, Institute for Design and Communication), “Complex processes in human–robot interaction”
- Serge Galam (SciencesPo, CEVIPOF - Centre d’Etudes de la Vie Politique Française, CNRS), “Interacting with a few random liars can jeopardize the democratic balance of a public debate”
- Philippe Gaussier (Université de Cergy-Pontoise, Image and Signal processing Lab – ETIS, UMR 8051 CNRS), “Emergence of capacities of social interactions in autonomous robots”
- Eric Goles (Université Adolfo Ibanez, Santiago, Chili), “Regulatory and segregation networks”
- Alan Kirman (Université d’Aix-Marseille III, GREQAM, and EHESS-Ecole des hautes études en sciences sociales), “Ants and Non-Optimal Self Organization: Lessons for Macroeconomics”.

Thanks to the success of the conference, and as the founding members of AMICS, we decided to produce a collective book made of a selection of papers that were presented either in one of the organized seminars or during the conference, and which aims at presenting different disciplinary approaches to deal with interactions in complex systems. In addition to a double blind referee process, as editors of this book we set up an innovative and more interactive process, using a specific platform on which each contributing author could comment and review any of all the other contributions (once the selection of the papers based on the more traditional referee process had been performed). It was difficult to motivate the contributors, probably surprised and certainly not accustomed to such a procedure, but to make the task easier, the editors proposed to each author to review two other papers rather distinct from his/her discipline.
This book is split into 4 parts, each one approaching the interactions in complex systems from a particular perspective. We have gathered contributions by approach rather than by the topic studied; the latter way being, from our viewpoint, less relevant to this type of book.
The first part of the book contains papers dealing with interactions at the **system level**. The included contributions address territory planning, the traveling of populations in the Neolithic era, and interactions in neuron populations.The second part collects articles studying **networks** and proposing different methods for their analysis. This part contains contributions on link prediction, on interaction analysis in learning communities, on the influence

of the type of update strategies (parallel or sequential) on the evolution of cooperation among humans, and opinion dynamics or the social function of gossip. Articles included in the third part focus on the analysis of interactions in **social communications**. As such, this part gathers papers studying teacher–student relations, the modeling of a teacher's evaluative speech to study students' interactions and their effects on learning, and the modeling of human communications. Finally, the last part of this book is devoted to the analysis of interactions between **economic agents** in different fields. One contribution develops a method to forecast the employability of students in Earth Sciences; another article studies the importance of language and the interactions between individuals as determinants of market equilibria; a mathematical model is derived to model money asset exchanges in the framework of a complex socioeconomic model in the third article, and the last article in this part examines the choice of study in an evolutionary game and shows under which conditions the population of students splits into two classes of strategies in equilibrium.

Thanks to this book, we realized all the difficulties but also the benefits gained from the confrontation of different methodological approaches in the general analysis of complex systems. Difficulties, because our knowledge is challenged: we are obliged to break free of our disciplinary perspectives and accept different views of the same objects and phenomena, other than those conveyed in each separate field. This experience was also enriching, because it is the disciplinary confrontation that allows the emergence of a thorough understanding of a question, but also the generation of new ideas, methodologies, or even scientific approaches.

We expect that the cross views of interactions in complex systems presented in this book will themselves generate scientific interactions by arousing curiosity and interest in working with colleagues in different disciplines.

We finally would like to thank the "Maison Interdiscplinaire des Systèmes Complexes" (Structure hosted by the University of Orléans (France) and François-Rabelais (Tours-France) dedicated to the promotion of research in complex systems), the Research team DYNACSE , laboratory EPSYLON, (University of Montpellier-France), the Department of Mathematics of the University of Orléans (MAPMO - UMR CNRS 7349) and the "Mission pour l'Interdisciplinarité" of the CNRS for their financial support.

Introduction

« Most likely, if our investigation methods
become more and more efficient,
We will discover the simplicity underneath the complex,
Then the complexity underneath the simplicity, thereafter
The simplicity underneath the complex, and so on,
Without being able to predict which term would be the last.
It has to land somewhere,
And for science to be possible,
We must stop when we find simplicity.
It is the only ground on which we will be able to raise
the structure of our generalisations.
This simplicity being only apparent,
Can we consider this ground will be strong enough?
This is what needs to be searched. »
Henri Poincaré (1902)[1]

Bearing in mind the complexity of biological, physical, chemical, sociological, economics, psychological, ... phenomena implies considering that they are made of heterogeneous elements, yet inseparably tied (Morin 2005), in other words, in close interaction. This also means accepting that these phenomena with apparent disorders may be affected by random events, and structure themselves on various time scales (short-term, long-term, fast, slow answer), spatial scales (local, global) as well as different organizational levels (micro, meso, macro) (Dahan & Aubin, 2007). This also implies not being able to consider any study without blending distinctive scientific

[1] Translated from Poincaré, H. (1920). La science et l'hypothèse. Ernest Flammarion, Ed., Paris, 2ème édition, (1ère édition 1902), p. 176.

fields, by attempting to identify the most relevant scientific collaborations (multi-, inter-, trans-disciplinary). Thus, the study of complex systems results from a strong paradigmatic commitment which is part of a true revolution in the meaning of Kuhn (1962) and, as we know, did not occur at the same time and under the same conditions for all scientific disciplines. Nevertheless, at this time, it is difficult to disagree with the fact that the scientific community cannot grasp the “Why” and “How” of the phenomena without integrating them into a broader context of action, feedback and interaction.

This explains why it is important for us to introduce this work that gathers a collection of multidisciplinary or interdisciplinary studies dealing with complex systems and their interactions. Throughout this study, numerous definitions of complex systems and their interactions will be brought through diverse perspectives. All of them will nevertheless agree on the fact that a complex system is composed of a large number of components (from *cumplexus*, tied with, tangled up, Morin, 2005) interacting in a non-linear manner and feedback loop, in a way that interactions between local components generate a behavior at a global scale.

The interactions between the different components present properties of self-organization, which appear essential to understand the behavior of the system. The self-organization that can just as well be seen in environmental processes, in embryogenesis and epigenesis, but also in the cognition, the formation of speech, in ethology, in economics ... (Bourgine & Lesne, 2006; Favereau 1989; Odeyeur, 2013, Theraulaz, 1997), may appear structural but equally functional[2] (Atlan, 2011) and responds to two modes of adaptation; on the one hand a spontaneous adaptation of the system facing internal and external constraints which weigh it down and on the other hand an adaptation of a long course which is realized by the phenomena of evolution of Darwinism (Zwirn 2006; Atlan, 2011). But how can we analyze the interactions and the emergence of behavior as well as their adaptive evolution? In these interactions what is the part of the random (Varela 1989) knowing that the random integrates in complex systems such as the necessary element of self-organization, as a source of novelty by the game of disorganization/reorganization it generates (Atlan 2011); it is far from the balance that the interactions of the self-organization can really be put in place (Prigogine, 1994, Bourgine and Lesne, 2006).

To understand the interactions in a complex system it is therefore a question of considering these few properties that we have just skimmed through and of which will find all their magnitudes and depths in the different studies presented. However beforehand, it appears necessary to introduce an epis-

[2] The first being of course easier to study and model than the second.

temological and ontological point of view (Morin, 2005; Dahan and Aubin, 2007; Ricard, 2008) in order to draw the contours and the disciplinary issues of what the study of complex systems and their interactions really is. We could legitimately ask ourselves why these philosophical considerations introduce this publication?

The first lies in the fact that all scientific work is part of a certain epistemological positioning of the researcher, who does not refrain from asking himself philosophical questions and participates therefore in his own construction as a researcher, but also as an individual. The construction and the transmission of knowledge involve registers of ontology and ethics, of which it is difficult to ignore the supporters, the limits and the aspirations. Scientific research is not and must not be a decontextualized and disembodied exercise, in which case it would no longer be the work of a researcher, but of a technician only. Research not only demands particularly rigorous scientific and theoretical positioning, but also a commitment to reality from the being involved himself.

This given ontology conditions our account of the world, and therefore the methods that we will invest in to report on the complex reality of this world. This is not without link with what Heisenberg (1984; 2010) considers the regions of reality. When trying to understand a problem, indeed, one is confronted with different regions of reality. Each region of reality is determined by a specific behavior and closed by the explanatory limit of concepts that can apprehend this reality. The considerations of science must therefore aim “to see the regions of reality but also to give exact formulation and without omission of the entirety of the connections which signifies the region” (ibid., p. 35). But it must also be considered that the different regions meet and overlap, and that is the important thing, the discernment of different regions and their occurring laws , according to Heisenberg (1984; 2010), goes through the progression of the objective toward the subjective[3], because "Ultimately, one must still and always realize that the reality that we can talk about is never the reality "in itself", but only a reality of which we can have knowledge, or even in many cases a reality to which we ourselves have given form" (ibid., p. 39). More broadly, our report on knowledge is

[3] "So shall he/she (the researcher) start with a part of reality that we can fully detach from and where we can entirely disregard the methods by which we come to a knowledge of its content. But at the top of the arrangement are held, as in the sketch of Goethe, the creative faculties with which we transform ourselves and give form to the world [...]. The "subjective" word one wishes to specify indicates that it may not be possible in a complete description of the connections of a region, to ignore the fact that we ourselves are involved connections. (...) We cannot ignore the fact that our body and the devices we use for observation are subject to the laws of atomic physics. " (Heisenberg, 1984; 2010 p.37)

not independent of the way in which the man is in the world (Bachelard, 1931). This consideration is essential, because it puts the researcher in subjectivity and in all his/her complexity that are both a necessary condition to the creativity and source of obfuscation. It is a warning which is to remind us that the researcher must be alert and conscious and discern in relation to the measures, the scales of analysis and purpose and their level of integration and dependence to understand reality and its laws. This is not without remembering the caution of Bacon (1620; trad. 1857) when he evokes the idols or "false concepts that have already invaded the human spirit and who threw away deep roots, they not only occupy such intelligence that the truth may be accessed with difficulty" (ibid., p. 12). Although warned of all these idols or epistemological obstacles which are confined to the rigorous conduct of the research, the researcher is not protected, especially during the emergence of new paradigm or of the decline of the one that has participated in the construction of any of his scientific career. In connection to this Bacon tells us how "the human spirit as soon as we are seduced by some ideas, either by their charm, or under the influence of the existing traditions and faith, forces all the rest to return to these ideas and to agree with them" (ibid., p. 14). As researchers, we are led to live from the emergence of the interior or the inscription of normal science (Kuhn, 1962) of a new paradigm, that of complex systems (or of complexity) and the decline of others. This experience is sufficiently rich and noteworthy so that we are relatively protected from infatuated personnel and of the entry into "religion" that it provokes. It is therefore a question of asking and understanding the scientific "topic" (eg. the researcher with its purpose of study) as being psychological, social, and even biological. On the basis of this hypothesis, epistemology and ontology constitute from the imprescriptible point of departure a job of disciplinary research for complexity.

From a disciplinary point of view, although the sciences of complexity appear as transdisciplinary (Morin, 2005), the issues relating to the quantification of the level of complexity of a system of any kind and to the understanding of emerging phenomena cannot divest work that is methodological and conceptually interdisciplinary (Resweber, 1991, Dahan & Aubin, 2007). These different tools and conceptual frameworks are derived from scientific fields as varied as cybernetics, dynamic systems, systemic, Artificial Intelligence… and support their interest on any different topics (self-organization, multi-hierarchical levels, interactions, transitions, emergent properties, variability…) (Lucas, 2000). Also it may appear to be more relevant to talk about complexity in the plural, and thereby place the focus methodologically and conceptually.

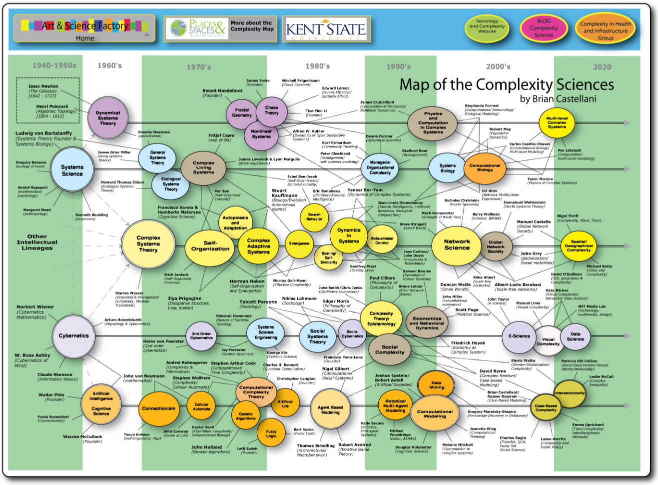

Figure 1: Representation of disciplines with the purpose of the study being the complexity of systems from the Castellani Map of complexity science. Source: http://www.artsciencefactory.com/complexity-map_feb09.html.

Figure 1 presents rather accurately not only all the disciplinary fields rendering account of the complexity, but also the interactions that allow them to inform and to feed each other.[4] When he evokes the sciences of complexity and its paradigmatic status, Edgar Morin invites us in some way not to be tied with any discipline (Morin, 2005). This is in two ways: On the one hand in the direction where it is a question of understanding the complexity looking beyond all disciplines, incorporating all disciplines by exceeding them. It would then be a question of opting for a transdisciplinary glance (Morin, 2005). On the other hand in the sense that if one accepts to investigate the complexity, it is question of accepting the same discomfort, the contradictions, the disorder, and thus take a number of steps from the interdisciplinary side, a form of indiscipline which by a game of harmony and disharmony would account for what is the "true" reality of phenomena.

The study of complex systems has in singularity a strong dependence on mathematical tools. Scientific advances in the field of human, economic and social sciences deal with complexity that does not seem possible to us only in close collaboration between the different disciplines, who are interested

[4] Science in general and the sciences of complexity in particular do not escape from the diversity of disciplinary fields and interactions that they can maintain.

from near or from far in the modeling of complex dynamic systems. Applied mathematics are in this sense a privileged partner and this publication presents a large number of studies that show the purpose or method of analysis in the mathematical modeling of complex phenomena. This new look of the borderless science, undisciplined (Morin, 2005), is the promise of real progress at the scientific level. While, all seminars and calls for funding for research on national or international projects on interdisciplinary or thematic transdisciplinary are additional signs. However, the qualifiers multi- inter- or transdisciplinary are often used indiscriminately to qualify the research collaborations (Resweber, 1991). Yet there are very marked differences, which are not without direct methods and the quality of the interactions (Mondada, 2005) and the results which necessarily flow.

While much of the research is part of an explicit interdisciplinary rationale (one may also consider the ever growing number of research groups, groupings of laboratory, name of labs … Using the term interdisciplinary), researchers despite this are working all the more often on a multidisciplinary level. The multidisciplinary work consists of encountering different disciplines around the purpose of a common study, but this remains within the limits of their methodology and their conceptual framework. The disciplines are then in a strategy of inquiry which has the function of relativizing the part of truth, the portion of truth which each bears witness. It also focuses on an awareness of the limitations of each discipline. This awareness is favourable in the transition towards interdisciplinary work, where the knowledge will therefore enter more directly in contradiction.

Interdisciplinary work is about understanding the «language » of the other discipline, its methodology and conceptual framework, as well as thinking beyond the alternative dialogue of perspectives (multidisciplinary work) in order to truly look at the object of study with a common questioning (Resweber, 1991). Once this confrontation strategy has been applied, a transdisciplinary collective work may effectively gather experts around a joint project, with the aim of « creating new frames of knowledge, broad enough to integrate the interpretations previously discussed » (Resweber, 1991, p. 47). Accessing a transdisciplinary work is a major scientific challenge. New frameworks and new methodologies likely to assimilate and exceed (to transcend in some ways) those already approached appear as the path to breakthroughs. It may sound presumptuous or premature to mention transdisciplinarity yet while it remains a goal to achieve. However in many ways, interdisciplinarity already constitutes a remarkable stage by itself, fraught with challenges. Researchers who have tried will confirm it is time consuming and requests much attention and effort at both levels, epis-