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## Editors' introduction

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This Handbook has been in preparation since June 2013 when the first emails were exchanged with Edward Elgar, but the long journey has been worth it. What we have achieved is a truly comprehensive coverage of research methods in complexity science.

The Handbook is addressed to both academic researchers and practitioners and attempts to cover most research methods based on the sciences of complexity, and applying them to practical cases. Its six parts include 26 chapters, contributed by 52 authors and each part includes different types of research methods. They range from Research Philosophy (Part I) to Qualitative Techniques (Part II), Visual Methodologies (Part III), Modelling and Statistical Analysis of Empirical Data (Part IV), Multi-Level Networks (Part V) and Mixed Methods (Part VI). The research methods complement each other and most are presented in a way that other researchers and decision makers may be able to use.

Each chapter has been peer-reviewed, and although the process was a long one, it has provided us with a Handbook of much higher quality than would have been the case without the contribution of our reviewers.

The Handbook includes not just the usual qualitative and quantitative research methods, but also unusual ones based on art and psychology; also ambitious methods that explore multi-level networks. The case studies are truly astonishing in the changes achieved by using a complexity science approach. They range from the regeneration of communities to musical performance; from complex governance networks to psychotherapy; from gender dynamics to agent-based modelling and appropriate response to pandemics. They also explore important concepts such as exaptation, emergence, self-organization and co-evolution. As the author of Chapter 24 (referencing Edmondson and McManus, 2007) points out, the choice of a research method should be based on the kind of question being asked, rather than the method most familiar to the researcher. The rationale for this Handbook is based on that principle and it is hoped that both researchers and practitioners will be inspired to explore new research methods to address the complex challenges they are facing.

Each of the six parts has its own introduction which highlights the contribution of each chapter and we will therefore not be repeating that exercise in the Editors' Introduction. Instead we would like to offer an overview, by describing briefly what you should expect from the volume and how the different parts complement each other and offer a wide spectrum of approaches underpinned by complexity science. By studying the Editors' Introduction and the introductions which precede each part, the reader should be able to judge which chapters would be relevant to their needs. We would, however, also strongly recommend that readers explore other methods that just excite their interest.

**Part I** '*Complexity Science Research Philosophy*' offers some reflections on the

contribution that complexity science has made to our understanding of physical, biological and social systems and how approaches have developed from cross-disciplinary to trans-disciplinary and unified efforts to address very complex problems. These problems are discussed in Chapter 1 ‘*Introduction to the Strategy and Methods of Complex Systems*’ and include the study of biomolecular interaction, the workings of the mind, global socio-economic risks, pandemics and environmental disasters. Chapter 2 ‘*Complex Evolving Social Systems: Unending, Imperfect Learning*’, contrasts the ‘hard science’ approach in the natural sciences, where repeated experiments allow us to discover general laws and patterns and to make predictions about ‘similar’ situations elsewhere, with complexity science, which acknowledges that such experiments are not feasible in social co-evolving systems. Furthermore complexity reveals the limits to knowledge and the impossibility of guaranteed prediction not only in the social world, but also in the physical and biological one. In other words, complexity science has changed our way of seeing the world, in terms of whole systems within a co-evolving context, focusing on relationships of the interacting entities and their emergent patterns. This is in sharp contrast to a reductionist approach, which looks at increasingly smaller sub-divisions of individual entities. Complex systems, especially in the social realm, also include individual agents with reflection and intentionality capable of changing their behaviour on the basis of new knowledge. Finally, Chapter 3 ‘*Information Theoretic Measures of Causality: Music Performance as a Case Study*’, looks at causation and probabilistic approaches to causality measures, informed by studies of time series on the brain and finance. The application is an unusual one and the authors discuss the findings of the analysis of music performance, where causation amongst the musicians and audience was studied by using EEG time series.

**Part II** ‘*Case-Based Qualitative Techniques*’ offers a very rich palette of qualitative methods applied to a wide range of successful cases. Chapter 4 ‘*Addressing Global Challenges: the EMK Complexity Methodology*’ offers new material on a highly effective methodology, able to address apparently intractable organizational, societal, and global problems. The author provides detailed advice on how to use the approach and illustrates it with one case, specifically showing how the two parts of the methodology were used effectively in a very difficult context. The first part was the identification of the *multi-dimensional problem space* (where the dimensions may be social, cultural, political, economic, physical, financial, technical and other) and the *co-evolutionary dynamics* between the dimensions, which provide a starting point for decision-making. The second part of the methodology acknowledges that complex problems do not have single solutions, but need a broader *enabling environment*, capable of addressing the challenge over time as it changes and evolves.

Chapter 5 ‘*Complexity Informed Social Research: From Complexity Concepts to Creative Applications*’, describes and demonstrates a complexity informed qualitative social research approach, associated methods and techniques and concomitantly explains the translations and interpretations made in utilizing complexity to effectively comprehend human social experience and sense making. The perspective assumed in the chapter is that qualitative research, like complexity, takes a radically relational approach to interpreting interrelationships between sense makers, fragments of knowledge, cultures, histories, futures, aspirations and so on. It introduces *Vortical postmodern ethnography* as an inquiry approach, along with the narrative generating method of *coherent conversations*

and the narrative analysis techniques of *fractal narrative analysis* and *attractor narrative analysis*. The approach is used in an indicative research project, on community enabling.

For decades, costly interventions have tried and failed to 'fix' Britain's most disadvantaged communities, where poverty, crime, unemployment and poor health are rife. Chapter 6 '*From Isolation to Transformation with C2*', offers a very effective, not costly and practical seven-step approach, underpinned by complexity science, called 'C2' (Connecting Communities), which does offer a solution. The C2 intervention is delivered on site and in the classroom by a small team of experienced practitioners, working alongside local residents and service providers to enable them to implement the framework. The key to the effectiveness of the approach is the direct involvement of community leaders, academics and frontline primary healthcare professionals, who have helped transform many communities across the UK in the last decade, using this approach.

Chapter 7 '*Using Complexity Principles to Understand the Nature of Relations for Creating a Culture of Publically Engaged Research within Higher Education Institutes*', discusses how to secure culture change within higher education institutes such that public engagement becomes part of how research is done within that institution. In 2008 RCUK funded six 'Beacons for Public Engagement'. Support was provided for each funded partner organization to create a culture of engaging with the public to inform the design and delivery of research. Using maximum variation sampling, seven case studies were selected. Analysing the findings from a complex systems perspective, the researchers conceptualized an 'engagement cycle' with three phases or elements: (a) creating the conditions; (b) co-creation of research; and (c) feedback loops to inform ongoing and future research. The chapter shows how it is possible to understand the dynamics of successful public engagement with research, using complexity theory, and what implications this has had for the methods used.

**Part III** '*Visual Methodologies*', is unusual in that it discusses visual methodologies using art, psychology, dynamic network topologies and two tools used to examine governance networks. The work described in Chapter 8 '*The Art of Complexity: Using Visual Artefacts and Dialogue to Bridge the Gap between Strategic Plans and Local Actions in Organisations*' started fourteen years ago when an artist started working with the Complexity team at the London School of Economics. What emerged and evolved was the visual representation of organizational strategy combined with facilitated dialogue ('Visual Dialogue') as a complexity-inspired tool for culture change and organizational development. The approach has since been implemented in over 100 large organizations. The process creates spaces for employees and leaders to come together to make sense of what is happening, what needs to change, and what actions are required. It helps people connect strategy to action, learn about each other's roles and take ownership of the parts each has to play in successful implementation. The process creates the conditions from which learning, innovation and self-organization can emerge. As the process evolved the artist/researchers learned that its principal impact lay in improving the quality of conversations about change between leaders and front line employees, working to create *enabling environments* that fostered mutual sense making, rich connection and creativity.

Most social science research applying complexity principles has concentrated on complex systems in the external world. Chapter 9 '*Inner Complexity: Using Landscape of the Mind to Catalyse Change in Organisations*', uses a tool based on psychology to look at the inner complexity of humans, by identifying their preference profiles. In other

words how individuals and teams prefer to make decisions, learn, innovate and so on. At the same time that an artist started working with the Complexity Group at LSE so did a psychologist using the visual methodology called *Landscape of the Mind* (referred to as LoM) which is described in this chapter. Case studies and examples illustrate its practical applications and show how it can be used to catalyse change in organizations, with particular reference to the implications for leadership and innovation.

The tools and methods described in Chapters 4, 8 and 9 have often been used together to look at complex organizational problems as they provided a much deeper understanding of the problem space than a single approach could on its own. Together they used qualitative analysis based on interviews to identify the multidimensional problem space; art and visual dialogue to explore conversations about change; and psychology to look at preference profiles. The first two were qualitative, but LoM offered quantitative data on the change process. The combination of the three tools and methods was quite unique and provided an effective means not only of understanding the deep nature of the problem, but to also facilitate the co-creation of enabling environments to address the challenge. This Handbook is offering many more tools and methods, which could be used together to support and complement each other.

Chapter 10 '*On the Visualization of Dynamic Structure: Understanding the Distinction between Static and Dynamic Network Topology*', looks at the structure of complex networks. In the past decade there has been a significant increase in interest in complex network data, and specifically in biological and social networks. These types of networks are highly interconnected and large scale; there is therefore a need for tools that enable us to make sense of these structures. The chapter explores how, for a given network, there are a range of emergent dynamic structures that support the different behaviours exhibited by the network's various state space attractors. A selected Boolean Network was used to calculate a variety of structural and dynamic parameters, and to explore the various dynamic structures that are associated with it (using both space-time diagrams and power graphs), to consider the activities (Shannon entropy) associated with each of the network's nodes when in certain modes/attractors. This work contributes to the development of robust complexity-informed tools to support the wealth of tools associated with Network Theory, with particular emphasis on network dynamics. Chapter 11 '*Network Text Analysis and Social Network Analysis in Investigating Complex Governance Networks: Applications of AutoMap and ORA*', also examines networks; it discusses how network text analysis and social network analysis can be used to investigate complex *governance networks*. The importance of examining their complex structural properties and the roles actors play in them is explored and two tools are described and illustrated. They are AutoMap (network text analysis software) and ORA (dynamic network analysis software), which were used in the cases of an urban governance network and that of statewide policymaking processes. The protocol used for the applications of AutoMap and ORA is given in the appendix to the chapter.

**Part IV** '*Modelling and Statistical Analysis of Empirical Data*', moves fully into quantitative approaches and is the longest part of the volume with six chapters. Chapter 12 '*Using Maximum Likelihood Estimation Methods and Complexity Science Concepts to Research Power Law-Distributed Phenomena*', looks at extreme events that skew what we consider 'average' and explores the basic causes of skewed distributions, specifically power laws and also examines horizontal scalability processes. These processes are gener-

ated by scale-free mechanisms (that is, the same cause at multiple levels of analysis) that result in self-similar fractal structures within organizations. Bak's (1996) 'self-organized criticality' is used to explain how and why the addition of small inputs, once beyond some critical threshold, have the potential to cause extreme outcomes and co-evolutionary effects at multiple levels of analysis. Using three longitudinal datasets of entrepreneurial ventures at different states of emergence, the authors demonstrate a method to determine whether data are power law distributed and, subsequently, how critical thresholds can be calculated. The chapter offers a conceptual-empirical link for moving beyond loose qualitative metaphors to rigorous quantitative analysis so as to enhance the generalizability and utility of complexity science theories.

Chapter 13 '*Multifractal Signatures of Intersectionality: Nonlinear Dynamics Permits Quantitative Modeling of Hierarchical Patterns in Gender Dynamics at the Cultural Level*', focuses on gender studies, but moves away from qualitative approaches and offers an introduction to multifractal analysis; it suggests that cascade dynamics and multifractal analysis might provide the logical formalism and corresponding statistical framework to make intersectionality a quantitatively tractable model for gendered experience. The authors review recent cognitive science advances, where multifractal analysis laid bare key features of the cascades driving cognitive performance, and provide a demonstration of similar cascade structure in gender dynamics through multifractal analysis of web-traffic data for gender terms on Wikipedia. The chapter proposes that cascade formalisms and multifractal analysis may provide new avenues for gender studies that balance both logical formalisms and dynamic concepts.

To improve reliability and resilience in infrastructures, it is necessary to adopt a 'complex, smart territory' modelling strategy, acknowledging the importance of social complexity. Chapter 14 '*Modeling Social Complexity in Infrastructures: A Case-based Approach to Improving Reliability and Resiliency*', discusses a case study on a segment of the United States power grid with a simple goal: to create a first proof-of-concept, to show how thinking about infrastructures in 'complex systems' terms, especially in their social aspects, can prove beneficial. The case study uses the SACS Toolkit, which is part of the new approach to modelling complex systems, called case-based complexity. As a technique, the SACS Toolkit is a computationally grounded, case-comparative, mixed methods platform for modelling complex systems as sets of cases. The chapter provides an overview of the research process, and a summary of the novel insights the approach was able to achieve.

Chapter 15 '*Phase Transitions and Social Contagion as Enabling Mechanisms for Coordinated Action in Populations: A Mathematical Framework*', presents a general mathematical framework to study discontinuous change in human interaction dynamics. There are two complementary perspectives, the macro and the micro. Regarding the macro context, the authors propose that levels of ordered structure in complex human organizing can be represented by a category theoretic representation that reflects informational influence acting on individual agents from two sources. First, external to the population, resource and competitive conditions in the ecosystem provide generalized influence on the actions of individuals. Second, internal to the population, relational and cooperative conditions provide localized influence on individual action. These independent influences interact to change the set of interaction rules that are enacted locally. Regarding the micro context, contagion is given as the mechanism whereby a common organizing state

is adopted across multiple agents. The chapter shows that the ordered structure, which emerges within a population, can be indexed as the number of active degrees of freedom embedded in local rules of interaction that are guiding groups of agents. The authors argue that like the natural sciences, research in social science should use category theoretic mathematical approaches to suggest deductive hypotheses that can be tested empirically with definitive results.

Chapter 16 '*Applying Complex Adaptive Systems to Agent-Based Models for Social Programme Evaluation*'. Measuring the effectiveness of social programmes is a significant challenge and forecasting the outcomes of these programmes can be difficult to justify to funders and other key stakeholders. Understanding the logic and assessing the impact behind the intervention can be difficult because commonly-used tools are based primarily on linear methods that assume that a set amount of input, throughput, and output will result in a set outcome. This chapter takes a complexity science approach and facilitates the use of agent-based modelling. It provides the requisite background for evaluators and researchers to frame their efforts as complex adaptive systems; a requisite in moving to the next step of developing agent-based models. The authors address both qualitative and quantitative aspects of complexity through two applications of agent-based modelling that consider related social policy issues.

Chapter 17 '*Complexity, the Bridging Science of Emerging Respiratory Outbreak Response*' looks at the incidence of emerging infectious diseases (EIDs) which is increasing. Despite the best efforts to prepare for such events, real-time management of emerging disease outbreaks is often marked by confusion and uncertainty. During these outbreaks, decision makers were challenged to make impactful decisions with little time and incomplete information. Health authorities typically approach such threats by focusing on the safety and effectiveness of individual-level interventions, such as vaccines and antivirals. This does not, however, detail how these countermeasures should be used to optimally benefit population health as a whole. Decisions around how to best use the limited supply of pharmaceuticals, targeted and/or social interventions in these situations require a unique combination of scientific fields, and integrating these fields in real time requires a bridging science. Mathematical modelling of complex systems represents that bridging science. Chapter 17 discusses the conceptual design and structure of mathematical models of communicable diseases, using transmission dynamics in the context of respiratory-borne pathogens within human populations. The authors then demonstrate the necessity of assembling appropriate expertise related to mathematical modelling, epidemiology, public health, virology, and clinical management to ensure valuable quantitative decision-support tools to assist policymakers at the time of crisis.

**Part V** '*Multi-Level Networks*' examines such networks and Chapter 18 '*Multilevel Systems and Policy*' defines what these networks mean for the implementation of computer models to investigate the multi-level consequences of policy. In order to inform policymaking part-whole aggregation and taxonomic aggregation are described as methods of representing multi-level structure, and it is shown how they are interleaved in the construction of vocabulary to describe multi-level systems. This enables complex nested structures to be represented as a kind of backcloth that supports patterns of aggregate and disaggregate numbers that describe the day-to-day traffic of people, resources and responsibility that are essential for systems to function.

Chapter 19 '*Complex Scenarios in Socio-economic Data: A Comprehensive Analytical*

*Study*', explores the analysis of socio-economic conditions of different countries, which reflect the country's social, economic, political, ideological, ethical, cultural and communicative habits, using new methods based on complexity science. To show the effectiveness of different nonlinear tools in analysing socio-economic data, the authors have implemented three nonlinear tools –  $\tau$ - recurrence rate, Mean conditional recurrence (MCR), Complex networks (CN) to analyse country level GDP and population data, and successfully validated the derived results with the standard conclusions based on general theories of economics.  $\tau$ - recurrence rate is used to show how two non-identical systems get synchronized through their phase spaces. MCR detects the driver and response system in synchronized states and CN reflects the overall scenarios of the complex systems by its various statistical measures. The datasets are collected from NASA's Earth Observing System Data and Information System and are downscaled projected based on Special Report on Emissions Scenarios (SRES).

Chapter 20 '*Employment of Tools and Models Appropriate to Complex, Real-world Situations*' advises practitioners how to judge which tools and methods are appropriate to use and when, where and how to apply them. The chapter provides a model of practice, and a framework for judging appropriateness of tools based on that model (with three examples of the framework in use). It also offers a critique of two sets of example tools: examining the applicability of autonomous agents and multi-agent systems to a range of situations; and explains how to employ multi-modal, multi-level influence networks to bring about ongoing change. Finally, the chapter presents a list of principles of practice, drawn from experience in the field, to be used to inform real-world decision- and policymaking.

Chapter 21 '*Leadership Network Structure and Influence Dynamics*', describes a quantitative methodology for the analysis and modelling of leadership networks which leverages research in complex systems, in particular nonlinear dynamical systems theory and network science. A prototype software package, PORTEND, is introduced which implements the methodology using data from expert analysts in order to help assess policy and factional outcomes with respect to the internal dynamics of a system of political actors. The methodology includes structural analysis methods, such as algorithms for analyzing issue positions and community structure, and a simulation of nonlinear social influence dynamics. PORTEND's capabilities are illustrated for an application to Iran involving 15 leadership elites and seven issues. The factional structure of the Iranian leadership group is analysed first based on their issue positions, then with respect to the network of inter-actor influence relationships, and finally by a synthesis of the issue and network data. An application of the nonlinear social influence simulation to the nuclear issue is presented and its implications are discussed with respect to Iranian decision-making concerning the 2013–2015 nuclear negotiations.

**Part VI** '*Mixed Methods and Complex Analogies*' not only offers several examples of the use of mixed methods, but also explores some complexity principles in depth. Chapter 22 '*Complex Analogy and Modular Exaptation: Some Definitional Clarifications*', discusses the *complex analogy* between biological evolution and technological innovation, focusing in particular on the novel construct *modular exaptation*. The chapter defines *exaptation*, which is a biological concept whose technological analogue is useful in innovation studies and explores its epistemological bases, arguing that the *etioloical* concept of function – a biological tenet – is valid also in the technological domain. The complex analogy extends

to biological and technological *functional modules*, providing the main building block on which *modular exaptation* can be founded. Establishing a complex analogy enables the description of the two *domains* via the same *relational structure*. In turn this allows the transferability of knowledge from the *base* domain to the *target* domain, and vice-versa. The complex analogy can therefore be considered a methodological tool for understanding complex systems in general and technological innovation in particular.

Chapter 23 '*Emergence and Radical Novelty: From Theory to Methods*' questions the strong association between self-organization and emergence and explores how the self-organization model and the methods of researching complex systems stemming from it are misleading as to an accurate account of emergence. It further questions the assumptions underlying the idea of self-organization and the insufficiency of the concept in supplying a cogent account of the radical novelty characterizing emergent phenomena. Radical novelty is what supports the needed explanatory gap of emergence between the antecedent and lower micro-level and the consequent and higher macro-level. Although not mysterious nor calling for some kind of supra-natural explication, the explanatory gap is what challenges and motivates a conception of emergence which remains true to the fundamental claims made about emergence.

Chapter 24 '*Applying the 15 Complexity Sciences: Methods for Studying Emergence in Organizations*' introduces the 15 sciences of complexity, each one being an effective method, shown by an ongoing stream of research that uses it. Each of these sciences will be described in terms of its empirical method, its primary research question(s), and the data needed for analysis. These sciences and even broader conceptualizations of complexity can be organized into three main paradigms or approaches: (a) Computational Agent-based Modeling, developed through Holland's complex adaptive systems, and scientists at the Santa Fe Institute; (b) Natural Sciences and Idiographic Analogies, in which the dynamics of order-creation in, for example, physics, thermodynamics and biology, is applied through a symmetrical analogy to human systems; (c) Narrative and Multi-Method Studies. These have perhaps the most to offer for seeing and enacting complexity in the social world. Likewise, multi-method longitudinal studies allow for a deep understanding of a system's dynamics, through repeated measures and interviews taken over time. The chapter presents a set of complexity methods and models that researchers can use to help identify the appropriate complexity methods to use to answer a specific research question.

Chapter 25 '*Mixed Methods Research: A Method for Complex Systems*' illustrates the need for multiple perspectives, philosophically and theoretically, and new stances to solving paradigmatic dilemmas. Frameworks are compared to assist in the alignment with research questions and research purpose as well as recognizing practical influences on research design choice. Numerous mixed methods research designs demonstrating the integration of mixed methods are considered, as are techniques for integrating the data between traditional methods and the benefits and challenges of mixed methods research. Overall, mixed methods research has critical mass but continues to evolve and become ever more relevant to address complex systems problems.

Chapter 26 '*Dynamical Systems Therapy (DST): Complex Adaptive Systems in Psychiatry and Psychotherapy*' as the last chapter offers an ambitious application of complexity science to psychiatric treatment. The nonlinear dynamical systems approach to psychiatric nosology allows practitioners to shift from linear categorical diagnostic



and treatment algorithms to integrative process models, conceptualizing individual and group dynamics as *complex adaptive systems (CAS)* with emergent properties of subjective and cultural experience. Dynamical systems therapy (DST) represents a complexity derived treatment application that puts individual capacity for self-system coherence and flexible adaptation to changing environmental demands at the cornerstone of psychological health. Recurrent patterns of feeling, thinking and relating can be analyzed by using modified fitness diagrams (adaptive or *A-landscapes*), which integrate objective, subjective and intersubjective clinical data. They enable psychiatric practitioners to chart the patient's unique life trajectory through its malleable *attractor/repellor states* in health and psychopathology that uniquely informs both psychosocial and psychopharmacological treatments.

The 26 chapters cover research methods, which range from the philosophical to the visual; from the qualitative to the quantitative that includes modelling and statistical analysis, as well as multi-level networks. It ends with mixed methods approaches, but this last part also includes the exploration of the theoretical concepts of exaptation, self-organization and emergence as research methods; the Handbook is completed with an unusual application in psychobiology.

