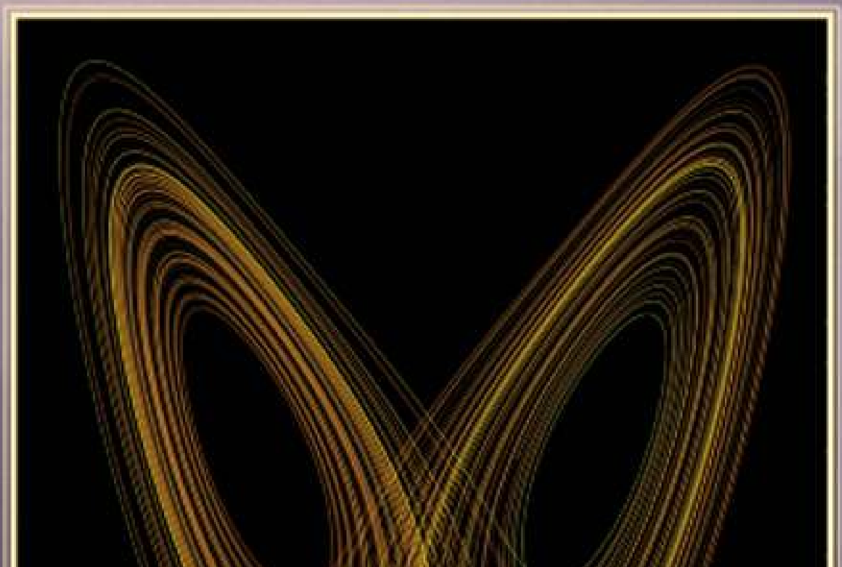
Handbook of
THE PHILOSOPHY OF SCIENCE

General Editors: DOV M. GABBAY, PAUL THAGARD, AND JOHN WOODS

PHILOSOPHY *of* COMPLEX SYSTEMS



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Cover picture shows the Lorenz attractor: Projection of trajectory of Lorenz system in phase space with "canonical" values of parameters r=28, σ = 10, b = 8/3. Reprinted under GNU Free Documentation License.

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Volume 10

Philosophy of Complex Systems

Edited by

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GENERAL PREFACE

Dov Gabbay, Paul Thagard, and John Woods

Whenever science operates at the cutting edge of what is known, it invariably runs into philosophical issues about the nature of knowledge and reality. Scientific controversies raise such questions as the relation of theory and experiment, the nature of explanation, and the extent to which science can approximate to the truth. Within particular sciences, special concerns arise about what exists and how it can be known, for example in physics about the nature of space and time, and in psychology about the nature of consciousness. Hence the philosophy of science is an essential part of the scientific investigation of the world.

In recent decades, philosophy of science has become an increasingly central part of philosophy in general. Although there are still philosophers who think that theories of knowledge and reality can be developed by pure reflection, much current philosophical work finds it necessary and valuable to take into account relevant scientific findings. For example, the philosophy of mind is now closely tied to empirical psychology, and political theory often intersects with economics. Thus philosophy of science provides a valuable bridge between philosophical and scientific inquiry.

More and more, the philosophy of science concerns itself not just with general issues about the nature and validity of science, but especially with particular issues that arise in specific sciences. Accordingly, we have organized this Handbook into many volumes reflecting the full range of current research in the philosophy of science. We invited volume editors who are fully involved in the specific sciences, and are delighted that they have solicited contributions by scientifically-informed philosophers and (in a few cases) philosophically-informed scientists. The result is the most comprehensive review ever provided of the philosophy of science.

Here are the volumes in the Handbook:

Philosophy of Science: Focal Issues, edited by Theo Kuipers.

Philosophy of Physics, edited by Jeremy Butterfield and John Earman.

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Details about the contents and publishing schedule of the volumes can be found at http://www.elsevier.com/wps/find/bookdescription.cws_home/BS_HPHS/description#description

As general editors, we are extremely grateful to the volume editors for arranging such a distinguished array of contributors and for managing their contributions. Production of these volumes has been a huge enterprise, and our warmest thanks go to Jane Spurr and Carol Woods for putting them together. Thanks also to Lauren Schulz and Gavin Becker at Elsevier for their support and direction.

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Part I

General Foundations

INTRODUCTION TO PHILOSOPHY OF COMPLEX SYSTEMS: A

Cliff Hooker

Part A: Towards a framework for complex systems

1 INTRODUCTION

Every essay in this book is original, often highly original, and they will be of interest to practising scientists as much as they will be to philosophers of science — not least because many of the essays are by leading scientists who are currently creating the emerging new complex systems paradigm. This is no accident. The impact of complex systems on science is a recent, ongoing and profound revolution. But with a few honourable exceptions, it has largely been ignored by scientists and philosophers alike as an object of reflective study.[1] Hence the scientist participants; while the small band of concerned philosophers is well represented in this volume, scientists in the midst of creating the revolution are often better placed to reflect on it than others. (Needless to add, many more of both were invited than ultimately participated.)

In consequence, I have sired a cross-border bastard, properly belonging to neither philosophy or science but an inheritor, and supporter, of both. Being an ex-scientist turned philosopher, it is a bastard of my own kind. No matter its perceived legitimacy, a bastard is always a sign of fruitful productivity. And in this case the offspring is needed, for it is born into a time of revolutionary foment

[1] For a substantial introduction see [Scott, 2004]. Scientists of course just get on with making and using specific innovations as needed, and that suffices. Honorable exceptions who have also reflected on the issues involved include the scientists Kenneth Boulding, Herbert Simon and Richard Levins (see wwweb information) and among philosophers include William Wimsatt and myself, all active across the last 4+ decades that mark the explosion of complex systems into the heartland of science. Wimsatt's work goes back to his early concerns with modelling methodology and explanation when confronted with complex systems and to some extent with systems ontology, with redduction/emergence bridging between them, now all reprinted and summed up in [Wimsatt, 2007]. [Hooker, 1978] showed that when the then-standard philosophical arguments about sense data in perception were embedded in a dynamical systems process setting, as the science already required, it re-cast them so as to make obvious their defects, [Hooker, 1981b, Part III] provided a first analysis of functional reduction in complex systems (subsequently updated in [Hooker, 2004; cf. this volume]) and [Hooker, 1995] a first attempt to recast philosophy of science itself as a dynamical systems process, see section 4.1.3 below.

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whose constructive resolution is best eased forward by straddling both the philosophy and the science. This bastard will, I hope, be widely adopted and in turn prove fertile.

This present essay and its matching closing essay ([Hooker-b, this volume][2]) are intended to be complementary and between them provide at least a first presentation of an intellectual framework for understanding the foundational and philosophical issues raised by the complex systems revolution. The present essay is designed to introduce and broadly review the domain of complex systems, with an eye to identifying the historical setting (section 2), the key systems properties at issue (section 3) and a collection of sub-domains that do not receive treatment in a dedicated essay (section 4). The closing essay is an attempt to systematically survey the specific components and issues that make up a scientific paradigm (section 5) and philosophy of science (section 6) that together comprise a foundational/philosophical analysis of the role of complex systems in science, as they currently appear.

Readers at least somewhat familiar with complex systems should find the essays to follow reasonably accessible, with references that invite further exploration. Those entering the field for the first time might like to first consult one or more of the books referenced at note 6 below and/or the websites referenced at [Hooker-b, this volume, note 15] (or any of the hundreds of other instructive books and websites available).

Ultimately, the goal is to develop mature foundations/philosophy of complex systems. But attempting this is premature at this time. First, despite enormous progress over the past 30 years, there is no unified science of complex systems. There are increasingly general insights and frameworks, the mathematical and operational mastery of chaos provides an early example, the current emergence of generalised network dynamics provides a contemporary example (cf. [Green and Leishman, this volume]). However, by themselves these do not a completed science make (cf. sections 4.2.6, 5.1.1 below), and at present they remain largely separate (if with multiple specific links — a typically complex situation!). Around them lie a patchwork of specific models and applications that presently remain irreducibly various. One aspect of the variability is the variety of complex systems phenomena engaged: in one application it may be counter-intuitive dynamics — such as the survival of cooperation in a sea of cutthroat competition — in another, self-organisation — such as rhythmic entrainment among food-stressed slime mould amoebae — in still another the onset of chaos — such as in local climate fluctuations — and so on. Another aspect of the variability is that characterising complex system principles is often a 'wicked' problem where the key dynamics generating a phenomenon is itself a function of the application conditions. To take a simple

[2]Other essays in this volume are indicated by '[Name, this volume]' and readers should turn directly to the indicated essay. The essays by Hooker in the volume are indicated by '[Hooker-a; b; c, this volume]', a = present essay, b = closing essay, c = reduction/emergence essay. These references to Hooker in this volume are also entered in the essay bibliography to disambiguate the intended reference.

example, traffic jams on expressways may be caused by any of entry/exit rates, truck/car proportions, flow density, driver pathway correlations, etc. Moreover, the dynamics of jam formation for each of these conditions is significantly different. For instance, truck/car speed differential is important near lane-change originated jams but less important for high density braking-originated jams, and unimportant for pathway convergence jams. So there is no usefully generalisable, detailed dynamical rules for traffic jam formation. In sum, the empirical domain of complex systems is itself complex — at this time irreducibly complex![3]

Irrespective of this developmental complexity, let us be clear about the extent of the complex systems revolution now taking place. When I trained in science (physics — PhD 1968) the contemporary icon for complex systems, chaos, was in process of discovery and few or no courses on complex systems were offered, those few problems considered involved several interacting bodies and were boxed as idiosyncratic special cases of applied mathematics. Today (2009) many of the most prominent scientific disciplines could not exist but for the complex systems models and methods on which they depend, among them synthetic and systems biology, climate science, control engineering, neurophysiology, developmental neuropsychology, astrophysics, geo-dynamics, traffic engineering, ... (cf. [Scott, 2004]). And there cannot be a single scientific discipline that has not now felt the complex systems winds of change blow through it to some extent — as this book testifies this now applies even to anthropology, Chinese medicine and warfare. The very way that science is transforming itself as complex systems penetrates it, is itself an excellent example of complex systems emergence through self-organisation, and one that, like many other instances, is re-defining the relationships between the emergent entity and the encompassing environment from which it emerged (see also section 4.1.3 below).

The scale and sweep of the change is truly vast — entire disciplines or subdisciplines have come into being, departments and institutes of hundreds of scientists now exist that did not exist two decades ago, and Google entries under complex systems headings run into the tens of millions of pages — far too many for any individual to consult, even in a lifetime, thus creating an emergent reliance on systemic institutional structure and processes to generate scientific coherence, yet another facet of complex systems in science. (The same institutional structure needs to construct effective quality controls for generating this information deluge or, speaking impolitely, it is often a major challenge to winnow insight from the false, trivial and groundlessly speculative and the powerful crap detector required by all new, fecund fields is required here too.) Complementing this, policy analysis, industrial development and large scale financial planning all require complex systems modelling while vast enterprises in bio-agriculture, bio-medicine, manufacturing design and so on have arisen and flourished on the backs of these

[3]And here a philosophical issue already raises its head: contrary to common opinion, a general model/theory of traffic jams will evidently be vaguer and less empirically precise and less explanatory than any of its specific sub-cases. So is scientific unification not to be preferred? See further [Hooker-b, this volume, section 6.2.6].

developments and are steadily transforming our lived world. Increasingly, people whose education does not include relevant competency in complex systems are excluded from science, policy and large scale business or find themselves increasingly dependent on those who have it.

Nor should the depth of the complex systems revolution be under-estimated. As the essays in this volume (including this one) attest, complex systems impacts every aspect of a science, from experimental design, what counts as evidence and the treatment of errors, through basic theoretical concepts of component, interaction, individuality, equilibrium (especially of dynamic versus static equilibrium), organisation and self-organisation, dynamic thresholds and irreversible form transitions, to deep limits on prediction and control and the relations of laws, explanation and confirmation to realisation conditions. (These notions will be explained in what follows.) And on a larger scale complex systems dynamical models naturally facilitate new disciplinary foci (such as systems biology) and new interdisciplinary interrelationships (such as synthetic biology and computational anthropology) while at the same time raising foundational issues concerning complexity and the representation of dynamics. In short, the complex systems-driven revolution is as deep as the revolutions in physics a century ago, but much wider in impact, even if they do not disturb our sense of fundamental reality in the same way.

What best to do? We have a revolution occurring in our midst, moreover one too complex and widespread for any one individual (a fortiori for me) to master in any detail across the board, and as yet lacking in any settled, or even well established, philosophical framework. Of course, I have tried to engage the sparse relevant philosophers (inevitably, not always successfully, for the usual practical reasons) and there are excellent essays herein that bear witness to those efforts. However, I had anyway concluded that, in the circumstances, to come to proper grips with the revolution and its challenges it would be necessary to engage the scientists themselves in the enterprise of reflecting on their own activities as they willy nilly develop complex systems based science. They are in the best position to comment on what the complex systems revolution involves for their discipline, and what its prospects are, and will remain so for many decades to come, even while complex systems philosophy of science develops.

Engaging eminent scientists has typically proven still more difficult than it was for philosophers, and understandably so: they are not only busy teaching, publishing and (these days) administering, as philosophers are, but have in addition to run their laboratories and field studies; moreover, they are rewarded for producing science, not for reflecting on that production, and it is often an intellectual wrench to take up the latter approach. Nevertheless, many scientists have willingly given their time and intellectual energy and many of the outstanding essays of this volume — essays that in themselves break new ground — have resulted from their collaboration.

In consequence, I have often played a more active role as editor than would be typical if this were a standard philosophy work, although many of the philosopher authors too have happily engaged in rounds of drafting discussion. Editorial activism was always welcomed (and often at author request) as especially scientists sought (sometimes 'fought' would be more apt) to shift to the reflective mode and bring a complex maze of practical activity into focus. In doing so I have not sought to dictate the content of an essay (this attempt would anyway have been self-defeating) but to assist authors to organise, clarify and enlarge upon what they intuitively want to contribute. That collaboration often ran through many drafts, and it has been one of the most rewarding aspects of editing the volume. I have learned a lot along the way and had the privilege and joy of some of the most stimulating discussions of my career. My deep thanks to all those, scientists and philosophers, who gave so unstintingly to this pioneering volume.

The result is a volume quite different from the bulk of publishing in the area which typically focuses on a range of technical articles by scientists either developing particular techniques or applying them to practical situations, all material that could equally appear in the relevant disciplinary journals. Sometimes there will be added to front or rear a few very general articles about the 'complexity world view' or the like, at home in any general cultural discussion. This is true, e.g., of the recent Handbook on Simulating Social Complexity and the Encyclopedia of Complexity and Systems Science, both 2009 and no criticism of their primary aims and content. However, this volume fits instead exactly into the intermediate space left by such efforts: the detailed reflective discussion of the differences that employing the concepts, principles and methods of complex systems makes to the methodology and theorising of those sciences and the challenges posed to scientific metaphysics, epistemology and methodology arising therefrom. All the while it retains the connection to current examples and practices to vivify and discipline the reflections. At this stage it is premature to attempt a fully developed philosophy of science for the use of complex systems modelling, what might be achieved is briefly and schematically surveyed in [Hooker-b, this volume]. What this book does is provide the proper preliminary foundation of rich, higher order reflection on the changes and challenges as they are currently experienced in the sciences, material from which a more mature view will eventually emerge in the fullness of time — as is only fitting for a complex framework emerging from the complex adaptive process that is science.

Shalizi [2006] distinguishes four components to the content of complex systems work: **patterns** — the classification and study of the characteristic patterns in state space, e.g. period doubling before chaos onset, made by the trajectories of complex systems when they are displaying their distinctive complex dynamical behaviours; **topics** — the array of complex systems features (e.g. chaos) and exemplary cases (e.g. logistic population dynamics) frequently discussed; **tools** — the mathematical methods for data analysis that are appropriate for analysing data pertaining to complex dynamics, e.g. data mining techniques to discover relationships, especially in high dimensional, low density data distributions, and time series analysis (see [Rickles, this volume]); we are some distance yet from general tools for revealing system structure, though particular methods are developing for local conditions; **foundations** — the mathematical foundations of complex systems dynamics, unfortunately currently very patchy, confined to theoretical fragments and particular applied models (see section 5 below). While this book is closest to the tools component, it is not primarily about any of these components — although some of its essays employ examples from patterns and topics and discuss issues that the tools and foundations raise. Rather, it is a reflection on what is distinctive to the conduct of science, especially as it pertains to metaphysics, epistemology and method, what this might amount to foundationally/philosophically, and what challenges are thus posed to science and philosophy.

Needless to say, there is yet much missing from this volume that would legitimately belong to it. Many domains contain numerous sub-domains of application of complex systems models. Biology, e.g., includes at least genome, cellular, multicellular, developmental, ecological and evolutionary modelling with further intra- and inter- sub-domain modelling specialities. But even were their separate inclusion practical (it is not) it would typically not add to the basic reflective issues thrown up. However, because of their prominence in their disciplines, I particularly regret the absence of essays on dynamical models in engineering, chemistry and social group dynamics. These and other disciplinary essays (e.g. on geodynamics, physiology, archaeology, business management and science itself) were vigorously sought but for one reason or another failed to materialise. While we lose the richness of their idiosyncratic responses to the entry of complex systems to their fields, most or all of the more general issues involved will have been well covered by the other essays. Some brief comments are made on most of these missing items in section 4.2 below, plus 4.1.3 (science) and [Hooker-b, this volume, section 5.3] (archaeology). Balancing these absences, on the other hand, are strong essays on Anthropology, Traditional Chinese Medicine, Military Policy and Planning and Public Policy and Planning that represent welcome surprises, areas beyond those normally attended to where the application of complex systems is delivering genuine insight and practical advantage.

Equally regretful is the absence of an essay on the primary mathematical issue raised by complex systems theory, namely the challenge it poses to standard analytical mathematical dynamics and the correlative disarray in unified mathematical underpinnings for complex systems. In my view, the suppression of this issue in many contemporary textbooks on analytical mechanics constitutes something of an intellectual scandal. There is currently no coherent mathematical framework for complex systems theory, as noted earlier there is instead a collection of diverse specific complex systems models and an equally diverse range of at best weakly interrelated mathematical research groups (see also 4.2.1 below). Perhaps this explains why it proved impossible to persuade anyone to write about it (and often even to respond), despite many invitations, especially to leading mathematicians. This is to be particularly regretted since the situation can instead be regarded as a stimulating challenge to future research. At any event the issue is unavoidable when trying to understand the nature of many key complex systems features, such as self-organised emergence. The basic issue is thus presented briefly, and within my limitations, in the essay on reduction and emergence in complex systems ([Hooker-c this volume], cf. [Bickhard, this volume; Bishop, this volume]). But its consequences re-appear throughout the review of our several foundational ignorances in section 5.

This essay plus its complementary closing essay attempts to provide what is possibly the first comprehensive review of the philosophical-cum-foundational issues deriving from the impact of complex systems in science. The review is consciously schematic, deferring to the other essays herein to fill in domain and discipline specifics. My intention is to clarify where possible and start as many hares running as possible. And there are plenty of the latter, the essays are awash with topics worth investigating. Even so, they are also certainly incomplete.

Finally, while there will be plenty of controversial issues arising, I hope for the most part that my authorship per se plays no major intervening role, except perhaps in the reach/lack-of-reach and synthesis of material presented. Here there is a clear bias in these essays toward thinking in physical terms and using physical examples. I am trained as a physicist and there are fewer social examples than another researcher might use. (But natural science examples, being uncluttered with the complications of human capacities, are often also clearer.) The keenest lack is not a matter of domain emphasis, which I think has small effect here, but of tools: there is a relative absence of computational analyses and computational examples. Mea culpa, I can only point out that I do recognise computational analyses on occasion and refer the reader to the review by [Green and Leishman, this volume] for a glimpse of how remaining bias might be corrected. Beyond this, as fair forewarning to readers, my philosophical orientation makes itself felt in two particular ways in what follows. First, there is my preference for dynamical analysis over logical and semantic analysis when it comes to fundamental concepts and principles. I deeply believe that, especially in the domain of complex systems science, this is the only productive way forward. Correlatively, second, there is an occasional willingness to close off philosophical debate where I judge science has provided a clear dynamical indication of how best to proceed (but always flagged, so that debate may ensue).

2 HISTORICAL NOTES ON THE DEVELOPMENT OF COMPLEX SYSTEMS IN SCIENCE[4]

Preparations for the emergence of complex systems in science — both their study and use — have been over 150 years in the making. Even so, the explicit recognition of complex systems concepts, principles and models in science is a recent phenomenon. And the explosion of its application into widespread use, with all the consequences explored in this volume, is a still more recent matter of the last 25 years. Especially because of its sudden, late emergence its history is worth

[4]The following historical discussion is excerpted and adapted with modifications and additions from [Hooker, 2009a, section C.5, 6], where it first appeared.