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BOOK REVIEW

Introduction to the Theory of Complex Systems

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Introduction to the Theory of Complex Systems, by Stefan Thurner, Rudolf Hanel, and Peter Klimek, Osford University Press, 2018, pp. xiv + 431. $65.00, ISBN 978-0-19-882193-9 (Hardback). Scope: textbook. Level: postgraduate students and professional scientists and engineers.

Complex systems are all around us including, for example, biological cells, bee colonies, the brain, climate, telecommunication infrastructures, the stock market, and the economy. Typically, they consist of many distinct but interacting elements, and they may be characterised by states of the elements. But the states change as a result of the interactions, and the interactions themselves change corresponding to the states of the system. It is this chicken-and-egg situation that gives rise to the complex behaviour and the well-known difficulties in understanding it, let alone predicting it. In particular, it gives rise to features such as emergent behaviour that could not have been anticipated from a knowledge of the elements, however detailed.

The authors acknowledge that, despite impressive progress, the theory of complex systems is currently far from complete. They liken its present status to that of quantum mechanics in the 1920s, or to an archaeological dig where a mosaic floor has been discovered but is only partially revealed. They focus on conveying what is now known and understood, written in a consistent mathematical language, with the intention that the exposition should be understandable to anybody with a basic understanding of calculus, linear algebra and statistics.

The book opens with an introductory scene-setting chapter that is both thoughtful and thought-provoking, setting the theory of complex systems in its scientific and historical context. The authors argue that the way in which it draws on a combination of physics, biology and social science makes the study of complex systems a new discipline in its own right. They back up this contention with vignettes of each of these parent disciplines, discussing their histories and characteristic features and differences, and how they contribute jointly to the understanding of complex systems. One of the most important ideas is that of evolution which came originally (mainly) from biology but is crucial to the description of the diverse time-evolving systems under consideration. It is extended by the notion of co-evolution in the context of networks, where the network's state (topology and links) determines the evolution of the nodes and, in turn, the states of the nodes determine the future states of the network.

There follow highly-detailed and carefully-structured chapters on probability/stochastics, scaling, networks, evolutionary processes, and statistical mechanics/information theory. Judging from the information given in the last section of the introduction, this is the end the book as originally conceived.

The final two chapters look like late additions. Chapter 7 is a short essay entitled "The future of the science of complex systems?", and is signed off only by Stefan Thurber although written in the first-person-plural. It considers whether the development of the science of complex systems

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may have become stuck, how complex systems ideas relate to current enthusiasms like artificial intelligence, machine learning, and "big data", and how the apparent bottleneck in development may be overcome. To my mind, Chapter 8 on "Special functions and approximations" would more naturally form an Appendix.

Based on a two-semester course given at the Medical University of Vienna since 2011, the book is very well-written and (apart from the slight oddity of chapters 7 and 8) carefully and systematically structured. The main chapters each end with a summary and a dozen or so problems for the reader to solve, and they cite freely from the list of 420 references at the end. There are numerous grey text-boxes focusing on particular ideas or summarising conclusions.

It seems to me that the authors have succeeded admirably in their aims and that, by helping to train and enthuse the next generation of researchers on complex systems, their book will contribute substantially towards overcoming any possible bottleneck that is impeding further progress.

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