SPRINGER BRIEFS IN COMPLEXITY

Anna Zafeiris
Tamás Vicsek

Why We Live in Hierarchies?

A Quantitative Treatise

Springer

SpringerBriefs in Complexity

Editorial Board for Springer Complexity

Henry D.I. Abarbanel, La Jolla, USA
Dan Braha, Dartmouth, USA
Péter Érdi, Kalamazoo, USA
Karl J. Friston, London, UK
Hermann Haken, Stuttgart, Germany
Viktor Jirsa, Marseille, France
Janusz Kacprzyk, Warsaw, Poland
Kunihiko Kaneko, Tokyo, Japan
Scott Kelso, Boca Raton, USA
Markus Kirkilionis, Coventry, UK
Jürgen Kurths, Potsdam, Germany
Andrzej Nowak, Warsaw, Poland
Ronaldo Menezes, Melbourne, USA
Hassan Qudrat-Ullah, Toronto, Canada
Peter Schuster, Vienna, Austria
Frank Schweitzer, Zürich, Switzerland
Didier Sornette, Zürich, Switzerland
Stefan Thurner, Vienna, Austria

SpringerBriefs in Complexity are a series of slim high-quality publications encompassing the entire spectrum of complex systems science and technology. Featuring compact volumes of 50 to 125 pages (approximately 20,000–45,000 words), Briefs are shorter than a conventional book but longer than a journal article. Thus Briefs serve as timely, concise tools for students, researchers, and professionals.
Typical texts for publication might include:

A snapshot review of the current state of a hot or emerging field
A concise introduction to core concepts that students must understand in order to make independent contributions
An extended research report giving more details and discussion than is possible in a conventional journal article,
A manual describing underlying principles and best practices for an experimental or computational technique
An essay exploring new ideas broader topics such as science and society

Briefs allow authors to present their ideas and readers to absorb them with minimal time investment. Briefs are published as part of Springer's eBook collection, with millions of users worldwide. In addition, Briefs are available, just like books, for individual print and electronic purchase. Briefs are characterized by fast, global electronic dissemination, straightforward publishing agreements, easy-to-use manuscript preparation and formatting guidelines, and expedited production schedules.

We aim for publication 8–12 weeks after acceptance.

SpringerBriefs in Complexity are an integral part of the Springer Complexity publishing program. Proposals should be sent to the responsible Springer editors or to a member of the Springer Complexity editorial and program advisory board (springer.com/complexity).

More information about this series at http://www.springer.com/series/8907

Anna Zafeiris · Tamás Vicsek

Why We Live in Hierarchies?

A Quantitative Treatise

Springer

Anna Zafeiris
Department of Biological Physics
Eötvös Loránd University
Budapest
Hungary

Tamás Vicsek
Department of Biological Physics
Eötvös Loránd University
Budapest
Hungary

ISSN 2191-5326 ISSN 2191-5334 (electronic)
SpringerBriefs in Complexity
ISBN 978-3-319-70481-4 ISBN 978-3-319-70483-8 (eBook)
https://doi.org/10.1007/978-3-319-70483-8

Library of Congress Control Number: 2017957663

© The Author(s) 2018, corrected publication 2018
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

Much of our life is driven by a deep contradiction: We all dream of working in flat organizations, where we have uninhibited access to our peers, status does not impede the flow of ideas, and communication is effective, allowing our creativity to flourish. Yet, we spend much of our life—from childhood to retirement—in hierarchical systems, like schools, universities, and corporations.

Touting the benefits of flat organizations is in fashion these days. Reducing hierarchy can lead to more satisfied employees and speedier decision-making. Zappos, a major Internet start-up aimed at revolutionizing how we shop for shoes, eliminated its organizational hierarchy altogether, encouraging each employee to act like an entrepreneur. Other companies have simply fired their managers after realizing that they stand in the way of innovation.

But building a truly flat organization is excruciatingly difficult in practice. The reason is not incompetence. Rather, as Anna Zafeiris and Tamás Vicsek explain in this short book, we are challenging our own biology and culture every time we fight hierarchies.

Indeed, hierarchies precede us as humans. They are common in groups of animals, and they are organizational forms deeply ingrained in our biology. Most importantly, hierarchies are a common outcome of self-organization in complex systems.

The reason why animal and social systems both converge toward this form of organization is simple: Hierarchy has merits. If we try to optimize any complex system's activity toward a desired outcome, hierarchy emerges each time, particularly if there are limits pertaining to costs and available resources. For example, humans have a limited ability to process all of the information hitting us. We are unable to keep track of all of the functions our company must address. By offering a chance to specialize, hierarchies shield us—allowing us to deal only with the information relevant to our expertise. In hierarchies, as a researcher, I can focus on research, leaving the university's accountant to handle the financial and accounting issues. Beyond efficiency, hierarchies satisfy our psychological need for responsibility and order.

Despite the prevalence of hierarchies, knowledge about hierarchical systems is scattered through the multiple literatures. Animal researchers have accumulated a great deal of insight into the role of hierarchies in animal societies; since Taylor, organizational researchers have written extensively about the benefits of hierarchical organizations in manufacturing. In the past decade, the emergence of network science has fostered a new ability. We can now capture the detailed interactions between a system's components—be that a network of pigeons in a flock or employees in an organization. These interactions have offered a fresh, big-data-driven quantitative perspective on hierarchy.

This book accomplishes an amazing feat—it integrates all of this knowledge and presents it in a brief, easy-to-understand treatise. It is the first text to offer a data-driven quantitative look at hierarchies, and it is more than a monograph. It is how to material, answering the practical questions everyone encounters in the face of a hierarchical system: How do I map it out? How do I measure the degree of hierarchy in the system? How do I uncover its origins? How do I visualize it? It offers a precise language through which we can converse about a wide range of characteristics of hierarchical systems, understanding their origins, benefits, and drawbacks.

The fact is that hierarchies both enable and restrain. When, how, and why they do these things are the million dollar questions. This short book opens the door to the answers and gives us the tools to find them.

Boston, USA

Albert-László Barabási
Northeastern University

Preface

Hierarchy is a fundamental concept regarding the structure and organization of complex systems in nature. It possesses several basic aspects, such as self-similarity, dominance, directed (top-to-bottom) sets of interactions. In addition to its various types of manifestation, hierarchy is present in almost all kinds of situation surrounding us, from the building blocks of matter (ranging from the elementary particles through atoms and solar systems to the universe) to large organizations (such as, universities or entire societies). Indeed, a large number of articles and books have been devoted to interpreting hierarchy, although apart from a very few exceptions, these works have approached the topic from the point of view of its qualitative features, instead of presenting quantitative results originating from models and/or calculations.

Networks associated with the complex set of connections among the units of a system have successfully addressed the structure of interactions of entities as parts of a living system. A few important new concepts involving the scale-free and small world nature of these networks have been proposed and extensively investigated over the past two decades. Networks have also been useful for shedding light on the intimate relationship between complexity and the widely varying roles the units of life (from proteins to people) can assume.

In this book, we aim to connect the above two essential aspects of life and treat the related phenomena in a quantitative manner. Establishing the relation of the two concepts (hierarchy and real-life networks) can be achieved by considering networks with predominantly directed edges, resulting in a globally directed and hierarchical structure with a number of distinct levels. To make the studies quantitative, we extensively discuss the possible definitions for the measures of hierarchy and then go on to present models and experiments that serve as interpretations/explanations of why and how hierarchy emerges and functions in a large class of phenomena.

One of the main conclusions of the studies of hierarchical systems we present—and it answers the question raised in the title of our book—is that *systems with a hierarchical structure perform better*, or in other words, are more efficient. In a way, they result in more benefit for less cost. This is true for the entire system, but in almost all cases, it also holds that *even the individual units gain benefit from this sort of cooperation*: They gain advantage (as compared to acting in isolation or being members of a fully egalitarian group) by voluntarily or forcefully becoming a member of a hierarchically organized structure.

In summary, we believe that having quantitative tools is helpful for getting a deeper insight into the origins of hierarchy and will be useful for those who are dealing with or planning to design complex systems that perform efficiently.

This book is based in part on our related research and numerous illuminating discussions with a number of colleagues. Anna Zafeiris is grateful for the opportunity to be a part of a seminal research group in which all the conditions for carrying out successful research are present. She is also thankful to her colleagues for the many helpful comments and discussions concerning diverse topics. Tamás Vicsek very highly appreciates the chance to have fruitful collaborations with a number of his coauthors. His principal collaborators in the context of hierarchy research include Zsuzsa Ákos, Dora Biro, Mones Enys, Tamás Nepusz, Máté Nagy, Gegely Palla, Benj Pettit, Péter Pollner, Gábor Vásárhelyi, Hai-Tao Zhang, and Maryam Zamani. The invaluable contributions by a number of further one-time or graduate student coauthors are also acknowledged. In addition, Tamás Vicsek has had extremely valuable interactions concerning the hierarchical organization of networks with a few outstanding colleagues, such as Albert-László Barabási and János Kertész.

We also thank those organizations whose contributions provided us with excellent conditions for writing this book. Eötvös Lorand University and the MTA-ELTE Statistical and Biological Physics Group of the Hungarian Academy of Sciences supported us by contributing the necessary working environment, including access to a number of essential services. Financial support came from grants from the European Research Council, the USAF AFRL/AFOSR initiative, the János Bolyai Research Scholarship of the Hungarian Academy of Sciences (Z. A), and the Hungarian Scientific Research Fund (OTKA).

Finally, this Preface gives us a good opportunity to thank our family members who created a great supportive atmosphere for both of us while we were writing this book. Anna Zafeiris is grateful to her husband, Elias, for ensuring a seminal environment in which all sorts of ideas can be discussed. She is also very indebted to her daughters, Nina and Sophie, for presenting a perpetual experience concerning the meaning of "exerting an effect on the behavior of the other"—which is the essence of hierarchy. Furthermore, she is very thankful to her parents for their great help in taking care of her children, and thus providing the necessary time for working on the manuscript.

Tamás Vicsek, in addition to having the overall backing and inspiration of his family, enjoyed being involved in joint research on networks with his daughter Lilla and son András. His wife, Mária, helped a lot as well, in many different ways, including her excellent managing of the growing and supportive family and proofreading the text.

Budapest, Hungary

Anna Zafeiris
Tamás Vicsek

The original version of the book was revised: Author name and affiliation have been changed. The erratum to the book is available at https://doi.org/10.1007/978-3-319-70483-8_7

Contents

1 Introduction 1
1.1 General Considerations 1
1.1.1 Organisms Versus Agents, Entities or "Particles" 3
1.1.2 Collective Behaviour 4
1.1.3 Collective Motion 5
1.1.4 Networks 5
1.2 Motivation 6
1.2.1 What is Our Subject? 6
1.2.2 Why Do We Study? 6
1.2.3 How Do We Study? 7
1.3 Hierarchical Structures in Space and in Networks 7
References 9

2 Definitions and Basic Concepts 11
2.1 Describing Hierarchical Structures 16
2.1.1 Graphs and Networks 16
2.1.2 Measuring the Level of Hierarchy 19
2.1.3 Classification of Hierarchical Networks 29
2.2 Visualization Techniques 34
2.2.1 A General Overview 34
2.2.2 Techniques Reflecting the Overall Hierarchy Level 35
References 39

3 Observations and Measurements 41
3.1 Animal Groups 41
3.1.1 Dominance 41
3.1.2 Leadership in Motion 46
3.1.3 Leadership Versus Dominance 51
3.1.4 Collective Decision-Making 53
3.2 Hierarchy in Humans 61

3.2.1 Our Biological and Social Heritage . . . 61
3.2.2 Large-Scale Hierarchies in Societies . . . 62
3.2.3 Nested Hierarchy Structure of Human Societies . . . 67
3.2.4 Phenomenological Theory of Collective Decision-Making . . . 70
References . . . 75

4 Experiments on the Emergence and Function . . . 79
4.1 The Liskaland Camp Experiment . . . 79
4.1.1 The Liska Model of Economy . . . 79
4.1.2 The Experiment . . . 80
4.1.3 Results . . . 82
4.2 Picturask . . . 83
4.2.1 The "Game" . . . 83
4.2.2 Methods . . . 84
4.2.3 Results . . . 87
References . . . 87

5 Modelling Emergence and Control . . . 89
5.1 Emergence of Hierarchy in Model Systems . . . 89
5.2 The Complex Efficiency Landscape of Hierarchical Organizations . . . 93
5.2.1 Modelling Organizations . . . 94
5.2.2 Simulations and Results . . . 95
5.3 Controlling Hierarchical Networks . . . 98
5.3.1 Structural Controllability—Controlling Nodes . . . 98
5.3.2 Switchboard Dynamics—Controlling Edges . . . 99
References . . . 105

6 Conclusions . . . 107
6.1 General Features of Hierarchical Structures . . . 107
6.2 Origins of Flow Hierarchy . . . 108
6.3 Emergence of Hierarchy . . . 109

Erratum to: Why We Live in Hierarchies? . . . E1