Cognitive Information Processing in Space Physics and Astrophysics

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To my family: Maj-Britt, John and Per

Foreword

Physics is inherently reductionistic. To analytically describe processes in nature the number of governing factors has to be reduced. Ever since Newton successfully formulated the fundamental laws of kinetics, physicists have struggled to set up equally simple mathematical expressions for all other processes in nature. Simplification and reduction are required to be able to solve the multivariate problems set up by nature. Modern computers have become very useful for solving complex multivariate algorithms, and they have also enabled the development of advanced simulations and modelling tools. However, analytical, iterative and modelling tools, despite their successful applicability in physics, are merely tools. Furthermore, there is always a danger in extending the applicability of physical laws in a broader sense. The quest for commonalties (the theory of everything) is a risky business. Because equations do not represent the intrinsic properties of nature, they represent our tools to understand nature. The only truth that exists is presented to us by Nature itself.

Nature is intrinsically multiparametric, complex and chaotic – yet deterministic. Life invented the most useful approach to manage such complexity and chaos - learning from experience. The learning may be a long and slow process where knowledge is forwarded to future generations by genetic codes. Rapid learning is also required to cope with the variability of the natural habitat. It takes some time to learn to walk, but once the learning is done walking is not much of an effort anymore, even walking in rough terrain soon becomes piece-of-cake. From the physics/mechanics point of view the feat of walking on two legs is a highly non-linear problem, quite difficult to model on a smooth surface and becoming an extremely difficult real-time problem in rough terrain. The cognition method is certainly superior to traditional physics in this kind of problem solving.

The biological life has become an expert in solving complex and chaotic problems. Even a small ant with a brain of some hundreds of neurones is capable of solving mechanical and motional problems of apparently immense complexity. The ant doesn't care about why, as long as it works. It recognises familiar objects by its senses; it reacts on unfamiliar and potentially hazardous situations. It socialises and knows how to survive. This marks a fundamental difference in strategy between physics and cognition on predicting and acting.

Two conclusions can be drawn from the above discussion. (1) Predictions may be done better by not solving the physical problem and instead using cognition methods. (2) Natural systems are frequently so complex that it may become misleading to apply traditional reductionistic methods.

Ludwik Liszka describes in this book the use of multivariate diagnostic and modelling tools on a variety of physical problems. Recognising patterns is fundamental for nature, but it is equally important in physical sciences that has to cope with large data volumes – like space sciences. Ludwik Liszka describes methods that are widely accepted in some disciplines (e.g. psychology) but more rarely used in other. It has taken long for the PCA (principal component analysis) and Neural Network methods to find their way into the physics community. But these methods, capable of distinguishing signal to noise ratios less than 1/100 are now gradually becoming part of the toolbox in physics. The very powerful Wavelet Transform method is another example of a modern tool that makes it possible to extract information from data where traditional statistical methods fail. Ludwik Liszka has extended the wavelet technique, introducing new useful concepts such as ampligram to interpret minor perturbations in multivariate data.

Neural computing methods have turned out to be very successful in modelling chaotic non-linear process. The example with modelling the jet engine test bed illustrates this. Neural computing and ”biointelligence” represents in my opinion a computational method for the future. The method is useful for solving complex and highly non-linear multivariate problems, thereby facilitating the understanding of the physical processes as well.

This is overall an excellent book recommended as textbook for specifically physicists and technicians on PhD- and Masters level, but also to anyone with sufficient mathematical and physical background wanting to familiarise with complex systems and their diagnostics. Several examples are provided to make the reader acquainted with the system tools. The software itself is described at the end and the tools may be downloaded directly from the net.

Professor Rickard Lundin
Director of the Swedish Institute of Space Physics
Member of the Swedish Royal Academy of Sciences

Preface

At the end of 1980:ies, an explosive development of non-linear data analysis methods started. This development was possible due to the rapidly evolving computer technology. At the same time, increased amounts of data collected in different space experiments became available. It was therefore possible to adopt these new data analysis tools for applications within the area of space research and astrophysics. The objective of this development was to facilitate efficient knowledge extraction from the immense amounts of data collected in space research. When people started to work with these tools, it appeared that they may also be applied to numerous areas of science and technology.

It is sometimes difficult to introduce new methods into the scientific community. The most efficient way to approach this problem is by teaching the new generation of scientists and engineers. We started to teach these new data analysis tools at both the undergraduate and graduate level at the Department of Applied Physics and Electronics at the University of Umeå, Sweden and at the Swedish Institute of Space Physics during 1993. The need for a comprehensive textbook triggered the work with this book. Since the courses were strictly practically oriented, the essential part of the course was used for hands-on exercises with computers. It was, many times, difficult to find suitable software for these applications. This made it necessary for us to develop our own software. The software is described in the Appendix of this book and may be downloaded without charge from the homepage of the Swedish Institute of Space Physics.

This book would not have been possible without the help of my co-workers and friends: Pär-Ola Nilsson, Jan Karlsson and Fredrik Rutqvist. Pär-Ola wrote all the software associated with the PCA and matrix handling and Jan was responsible for developing the software for the wavelet analysis. Pär-Ola was also responsible for the tedious work of editing this manuscript. The people who encouraged me to write this book were the former and present directors of the Swedish Institute of Space Physics, Professors: Bengt Hultqvist and Rickard Lundin. I am indebted to Professor A.W. Wernik of the Space Research Center of the Polish Academy of Sciences, Warsaw, Poland, for his advice and support in the area of wavelet analysis. Discussions with Professor A. G. Pacholczyk and Dr. W. R. Stoeger at Steward Observatory, University of Arizona, in the area of astrophysical applications were most useful. Also, discussions with Professor Clark Glymour and Dr. Peter Spirtes at the Department of Philosophy, Carnegie Mellon University, Pittsburgh, PA, were most helpful during the work with applications of causal modelling. I am also indebted to my former graduate student, Dr. Joakim Waldemark, Optronic AB, for his contribution in parts of Chapters 6 and 7. Several sections of this book have made use of data obtained through the High Energy Astrophysics Science Archive Research Center Online Service, provided by the NASA/Goddard Space Flight Center.

The manuscript of this book was reviewed by my son, John Liszka-Hackzell and my friend John A. Carlsjö; their contribution was most helpful.

I am also grateful to my family for their patience during the years I spent working with this book. Finally, I would like to thank all the people who supplied me with data that was used in the examples in this book.

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