MODELING UNCERTAINTY
An Examination of Stochastic Theory, Methods, and Applications

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MODELING UNCERTAINTY
An Examination of Stochastic Theory, Methods, and Applications

Edited by

MOSHE DROR
University of Arizona

PIERRE L'ECUYER
Université de Montréal

FERENC SZIDAROVSZKY
University of Arizona

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Preface

This volume titled MODELING UNCERTAINTY: An Examination of Stochastic Theory, Methods, and Applications, has been compiled by the friends and colleagues of Sid Yakowitz in his honor as a token of love, appreciation, and sorrow for his untimely death. The first paper in the book is authored by Sid's wife – Diana Yakowitz – and in it Diana describes Sid the person, his drive for knowledge and his fascination with mathematics, particularly with respect to uncertainty modelling and applications. This book is a collection of papers with uncertainty as its central theme.

Fifty authors from all over the world collectively contributed 30 papers to this volume. Each of these papers was reviewed and in the majority of cases the original submission was revised before being accepted for publication in the book. The papers cover a great variety of topics in probability, statistics, economics, stochastic optimization, control theory, regression analysis, simulation, stochastic programming, Markov decision process, application in the HIV context, and others. Some of the papers have a theoretical emphasis and others focus on applications. A number of papers have the flavor of survey work in a particular area and in a few papers the authors present their personal view of a topic. This book has a considerable number of expository articles which should be accessible to a nonexpert, say a graduate student in mathematics, statistics, engineering, and economics departments, or just anyone with some mathematical background who is interested in a preliminary exposition of a particular topic. A number of papers present the state of the art of a specific area or represent original contributions which advance the present state of knowledge. Thus, the book has something for almost anybody with an interest in stochastic systems.

The editors have loosely grouped the chapters into 8 segments, according to some common mathematical thread. Since none of us (the co-editors) is an expert in all the topics covered in this book, it is quite conceivable that the papers could have been grouped differently. Part 1 starts with a paper on stability in queuing networks by H.J. Kushner. Part 1 also includes a queuing related paper by T.L. Lai, and a paper by I. Pinelis on asymptotics for large deviation probabilities. Part 2 groups together 3 papers related to HIV modelling. The first paper in this group is by W.-Y. Tan and Z. Xiang about modelling early immune responses, followed by a paper of B. Barnes and J. Gani on the impact of re-using hypodermic needs, and closes with a paper by D.S. Stoffer. Part 3 groups together optimization and regression papers. It contains 4 papers starting with a paper by A. Nemirovski and R.Y. Rubinstein about classical stochastic approximation. The next paper is by B. Kedem and K. Fokianos on regression models for binary time series, followed with a paper by H. Walk on properties of Nadarya - Watson regression estimates, and closing with a paper on sequential predictions of stationary time series by L. Györfi and G. Lugosi. Part 4's 6 papers are in the area of economics analysis starting with a nonlinear oligopolies paper by C. Chiarella and F. Szidarovszky. The paper by A. Haurie and F. Moresino examines a differential game of debt contract valuation. Next comes a paper by D. Porter, followed by a paper about complex systems in relation to affordable upgrades by J.A. Reneke, M.J. Saltzman, and M.M. Wiecek. The 5th paper in this group, by F.-Y. Wang and G.N. Sardis, concerns optimal control in stochastic dynamic systems, and the last paper is by L. Gerencsér is about stability of random iterative mappings. Part 5 loosely groups 3 papers starting with a paper by V. Solo on Monte Carlo methods for adaptive algorithms, followed by a paper on random search with noise by L. Devroye and A. Krzyżak, and closes with a survey paper on randomized quasi-Monte Carlo methods by P. L'Ecuyer and C. Lemieux. Part 6 is a collection of 3 papers sharing a focus on Markov decision analysis. It starts with a paper by G. Yin, Q. Zhang, K. Yin, and H. Yang on singularly perturbed Markov chains. The second paper, on risk sensitivity in average Markov decision chains, is by R. Cavazos–Cadena and E. Fernández–Gaucherand. The 3rd paper, by G.G. Roussas, is on statistical inference in a Markovian framework. Part 7 includes a paper on order statistics by P.J. Boland, T. Hu, M. Shaked, and J.G. Shanthikumar, followed by a survey paper on routing with stochastic demands by M. Dror, a paper on fast Fourier and Walsh transforms by P.J. Sanchez, J.S. Ramberg, and L. Head, a paper by J.C. Spall on parameter estimation with limited data, and a tutorial paper on data compression by J.C. Kieffer. Part 8 contains 2 'reflections' papers. The first paper is by M. Sniedovich – an ex-student of Sid Yakowitz. It reexamines Bellman's principle of optimality. The last paper in this volume on statistical methods for complex stochastic systems is reserved to M.F. Neuts.

The efforts of many workers have gone into this volume, and would not have been possible without the collective work of all the authors and reviewers who read the papers and commented constructively. We would like to take this opportunity to thank the authors and the reviewers for their contributions. This book would have required a more difficult 'endgame' without Ray Brice's dedication and painstaking attention for production details. We are very grateful for Ray's help in this project. Paul Jablonka is the artist who contributed the art work for the book's jacket. He was a good friend to Sid and we appreciate his contribution. We would also like to thank Gary Folven, the editor of Kluwer Academic Publishers, for his initial and never fading support throughout this project. Thank you Gary !

Moshe Dror Pierre L'Ecuyer Ferenc Szidarovszky

Contributing Authors

B. Barnes
School of Mathematical Sciences
Australian National University
Canberra, ACT 0200
Australia

Philip J. Boland
Department of Statistics
University College Dublin
Belfield, Dublin 4
Ireland

Rolando Cavazos–Cadena
Departamento de Estadística y Cálculo
Universidad Auténoma Agraria Antonio Narro
Buenavista, Saltillo COAH 25315
MÉXICO

Carl Chiarella
School of Finance and Economics
University of Technology
Sydney
P.O. Box 123, Broadway, NSW 2007
Australia
carl.chiarella@uts.edu.au

Luc Devroye
School of Computer Science
McGill University
Montreal, Canada H3A 2K6

Moshe Dror
Department of Management Information Systems
The University of Arizona
Tucson, AZ 85721, USA
mdror@bpa.arizona.edu

Emmanuel Fernández–Gaucherand
Department of Electrical & Computer Engineering
& Computer Science
University of Cincinnati
Cincinnati, OH 45221-0030
USA

Konstantinos Fokianos
Department of Mathematics & Statistics
University of Cyprus
P.O. Box 20537 Nikosia, 1678, Cyprus

J. Gani
School of Mathematical Sciences
Australian National University
Canberra, ACT 0200
Australia

László Gerencsér
Computer and Automation Institute
Hungarian Academy of Sciences
H-1111, Budapest Kende u 13-17
Hungary

László Györfi
Department of Computer Science and Information Theory
Technical University of Budapest
1521 Stoczek u. 2,
Budapest, Hungary
gyorfi@szit.bme.hu

A. Haurie
University of Geneva
Geneva Switzerland

Larry Head
Siemens Energy & Automation, Inc.
Tucson, AZ 85715

Taizhong Hu
Department of Statistics and Finance
University of Science and Technology
Hefei, Anhui 230026
People's Republic of China

Benjamin Kedem
Department of Mathematics
University of Maryland
College Park, Maryland 20742, USA

John C. Kieffer
ECE Department
University of Minnesota
Minneapolis, MN 55455

Adam Krzyżak
Department of Computer Science
Concordia University
Montreal, Canada H3G 1M8

Harold J. Kushner
Applied Mathematics Dept.
Lefschetz Center for Dynamical Systems
Brown University
Providence RI 02912

Tze Leung Lai
Stanford University
Stanford, California

Pierre L'Ecuyer
Département d'Informatique et de Recherche Opérationnelle
Université de Montréal, C.P. 6128, Succ. Centre-Ville
Montréal, H3C 3J7, Canada
lecuyer@iro.umontreal.ca

Christiane Lemieux
Department of Mathematics and Statistics
University of Calgary, 2500 University Drive N.W.
Calgary, T2N 1N4, Canada
lemieux@math.ucalgary.ca

Gábor Lugosi
Department of Economics,
Pompeu Fabra University
Ramon Trias Fargas 25-27,
08005 Barcelona, Spain
lugosi@upf.es

F. Moresino
Cambridge University
United Kingdom

Arkadi Nemirovski
Faculty of Industrial Engineering and Management
Technion—Israel Institute of Technology
Haifa 32000, Israel

Marcel F. Neuts
Department of Systems and Industrial Engineering
The University of Arizona
Tucson, AZ 85721, U.S.A.
marcel@sie.arizona.edu

Iosif Pinelis
Department of Mathematical Sciences
Michigan Technological University
Houghton, Michigan 49931
ipinelis@math.mtu.edu

David Porter
Collage of Arts and Sciences
George Mason University

John S. Ramberg
Systems and Industrial Engineering
University of Arizona
Tucson, AZ 85721

James A. Reneke
Dept. of Mathematical Sciences
Clemson University
Clemson SC 29634-0975

George G. Roussas
University of California, Davis

Reuven Y. Rubinstein
Faculty of Industrial Engineering and Management
Technion—Israel Institute of Technology
Haifa 32000, Israel

Matthew J. Saltzman
Dept. of Mathematical Sciences
Clemson University
Clemson SC 29634-0975

Paul J. Sanchez
Operations Research Department
Naval Postgraduate School
Monterey, CA 93943

George N. Saridis
Department of Electrical, Computer and Systems Engineering
Rensselaer Polytechnic Institute
Troy, New York 12180

Moshe Shaked
Department of Mathematics
University of Arizona
Tucson, Arizona 85721
USA

J. George Shanthikumar
Industrial Engineering & Operations Research
University of California
Berkeley, California 94720
USA

Moshe Sniedovich
Department of Mathematics and Statistics
The University of Melbourne
Parkville VIC 3052, Australia
m.sniedovich@ms.unimelb.edu.au

Victor Solo
School of Electrical Engineering and Telecommunications
University of New South Wales
Sydney NSW 2052, Australia
vsolo@syscon.ee.unsw.edu.au

James C. Spall
The Johns Hopkins University
Applied Physics Laboratory
Laurel, MD 20723-6099
james.spall@jhuapl.edu

David S. Stoffer
Department of Statistics
University of Pittsburgh
Pittsburgh, PA 15260

Ferenc Szidarovszky
Department of Systems and Industrial Engineering
University of Arizona
Tucson, Arizona, 85721-0020, USA
szidar@sie.Arizona.edu

Wai-Yuan Tan
Department of Mathematical Sciences
The University of Memphis
Memphis, TN 38152-6429
waitan@memphis.edu

Harro Walk
Mathematisches Institut A
Universität Stuttgart
Pfaffenwaldring 57, D-70569
Stuttgart, Germany

Fei-Yue Wang
Department of Systems and Industrial Engineering
University of Arizona
Tucson, Arizona 87521

Margaret M. Wiecek
Dept. of Mathematical Sciences
Clemson University
Clemson SC 29634-0975

Zhihua Xiang
Organon Inc.
375 Mt. Pleasant Avenue
West Orange, NJ 07052
z.xiang@organoninc.com

D. S. Yakowitz
Tucson, Arizona

H.Yang
Department of Wood and Paper Science
University of Minnesota
St. Paul, MN 55108
hyang@ece.umn.edu

G. Yin
Department of Mathematics
Wayne State University
Detroit, MI 48202
gyin@math.wayne.edu

K. Yin
Department of Wood and Paper Science
University of Minnesota
St. Paul, MN 55108
kyin@crn.umn.edu, hyang@ece.umn.edu

Q. Zhang
Department of Mathematics
University of Georgia
Athens, GA 30602
qingz@math.uga.edu

This book is dedicated to the memory of Sid Yakowitz.

Chapter 1

PROFESSOR SIDNEY J. YAKOWITZ

D. S. Yakowitz
Tucson, Arizona

Sidney Jesse Yakowitz was born in San Francisco, California on March 8, 1937 and died in Eugene, Oregon on September 1, 1999. Sid's parents, Morris and MaryVee, were chemists with the Food and Drug Administration and encouraged Sid to be a life-long learner. He attended Stanford University and after briefly toying with the idea of medicine, settled into engineering ("I saved hundreds of lives with that decision!"). Sid graduated from Stanford with a B.S in Electrical Engineering in 1960.

His first job out of Stanford was as a design engineer with the University of California's Lawrence Radiation Laboratory (LRL) at Berkeley. Sid was unhappy after college but claimed that he learned the secret to happiness from his office mate at LRL, Jim Sherwood, who told him he was being paid to be creative. Sid decided that "Good engineering design is a synonym for 'inventing'."

For graduate school, Sid chose Arizona State University. By this time, his battle since childhood with acute asthma made a dry desert climate a mandatory consideration. In graduate school he flourished. He received his M.S. in Electrical Engineering in 1965, an M.A. in Mathematics in 1966, and Ph.D. in Electrical Engineering in 1967. His new formula for happiness in his work led him to consider each topic or problem that he approached as an opportunity to "invent".

In 1966 Sid was hired as an Assistant Professor in the newly founded Department of Systems and Industrial Engineering at the University of Arizona in Tucson. This department remained his "home" for 33 years with the exception of brief sabbaticals and leaves such as a National Academy of Science Post-doctoral Fellowship at the Naval Postgraduate School in Monterey, California in 1970-1971.

In 1969 Sid's book *Mathematics of Adaptive Control Processes* (Yakowitz, 1969) was published as a part of Richard Bellman's Elsevier book series. This book was essentially his Ph.D. dissertation and was the first of four published books. Latter Sid was instrumental in the popularization of differential dynamic programming (DDP). Overcoming the "curse of dimensionality" made possible the solution of problems that could at that time only be solved approximately, for example, high dimensional multireservoir control problems. His paper with then Ph.D. student Dan Murray in Water Resources Research (Murray and Yakowitz, 1979) demonstrated quite dramatically what could be done with DDP.

In addition to his own prolific accomplishments Sid had another important talent - the ability to recognize talent in others. He enthusiastically collaborated with colleagues on numerous subjects including hydrology, economics, information-theory, statistics, numerical methods, and machine learning.

Sid's international work started in 1973 with his participation in a joint NSF sponsored US-Hungarian research project. According to Ferenc Szidarovszky (Szidar), also involved in the project, his extraordinary talents in combining probabilistic and statistical ideas with numerical computations made him one of the most important contributors. Several papers on uncertainty in water resources management, conference presentations, and invited lectures were the result of this grant that was renewed until 1981. This was the period that he had the most intensive collaboration with his many Hungarian colleagues. This cooperation also resulted in the two textbooks on numerical analysis with Szidar, *Principles and Procedures of Numerical Analysis* (Szidarovszky and Yakowitz, 1978) and *An Introduction to Numerical Computations* (Yakowitz and Szidarovszky, 1986). Long after the project terminated, Sid continued to collaborate with Hungarian scientists who often visited him in Tucson enjoying his hospitality.

Sid's ability in combining probabilistic ideas and numerical computations made him an expert in simulation. His book *Computational Probability and Simulation* (Yakowitz, 1977) is considered one of the best of its kind. His paper on weighted Monte-Carlo simulation (Yakowitz et al., 1978) offered a new integration method that was much faster than the known classical procedures.

Sid had a very successful six year cooperation with Professors Columban Hutter, of ETH Zurich, and Szidar working on an NSF sponsored project on the mathematical modeling and computer solutions of ice-sheets, glaciers and avalanches. In this work, Sid's expertise on numerical analysis was the essential factor in solving large-scale differential equations with unusual boundary and normalizing conditions (Yakowitz et al., 1985; Hutter et al., 1986a; Yakowitz et al., 1986; Hutter et al., 1986b; Hutter et al., 1987; Szidarovszky et al., 1987; Hutter et al., 1987; Szidarovszky et al., 1989).

Sid's algorithmic way of thinking resulted in two major contributions to game theory. With Szidar he developed a new proof for the existence of a unique equilibrium of Cournot oligopolies, which is constructive, offering an algorithm to find the equilibrium. This paper, (Szidarovszky and Yakowitz, 1977) is one of the most cited papers in this field and has been republished in the Handbook of Mathematical Economics. They could also extend the constrictive proof for the case when the price and cost functions are not differentiable. They proved that even in the case of multiple equilibria, the total output of the industry is unique and the set of all equilibria is a simplex. They also considered the effect of coalition formation on the profit functions (Szidarovszky and Yakowitz, 1982).

Sid was an expert in time series, both parametric and nonparametric. On the nonparametric side he made contributions regarding nearest neighbor methods applied to time series prediction, density and transition function estimation for Markov sequences, and pattern recognition (Denny and Yakowitz, 1978; Schuster and Yakowitz, 1979; Yakowitz, 1979; Szilagyi et al., 1984; Yakowitz, 1987; Yakowitz, 1988; Yakowitz, 1989d; Rutherford and Yakowitz, 1991; Yakowitz and Lowe, 1991; Yakowitz and Tran, 1993; Yakowitz, 1993a; Morvai et al., 1998; Yakowitz et al., 1999). In particular Sid worked in the area of stochastic hydrology over many years including analyzing hydrologic time series such as flood and rainfall data to investigate their major statistical properties and use them for forecasting (Yakowitz, 1973; Denny et al., 1974; Yakowitz, 1976; Yakowitz, 1976; Szidarovszky and Yakowitz, 1976; Yakowitz, 1979; Yakowitz and Szidarovszky, 1985; Karlsson and Yakowitz, 1987a; Karlsson and Yakowitz, 1987b; Naokes et al., 1988; Yakowitz and Lowe, 1991).

On the parametric side, Sid applied his deep understanding of linear filtering of stationary time series in the problem of frequency estimation in the presence of noise. Here he authored several papers on frequency estimation using contraction mappings, constructed from the first order auto-correlation, that involved sophisticated sequences of linear filters with a shrinking bandwidth. In particular, he showed that the contraction mapping of He and Kedem, which requires a certain filtering property, can be extended quite broadly. This and the shrinking bandwidth were very insightful (Yakowitz, 1991; Yakowitz, 1993c; Li et al., 1994; Kedem and Yakowitz, 1994; Yakowitz, 1994a).

He found numerous applications of nonparametric statistical methods in machine learning (Yakowitz, 1989c; Yakowitz and Lugosi, 1990; Yakowitz et al., 1992a; Yakowitz and Kollier, 1992; Yakowitz and Mai, 1995; Lai and Yakowitz, 1995). As a counterpart to his earlier work on numerical computation, Sid introduced a course at the University of Arizona on Non-numerical Computation. This course, which resulted in an unpublished textbook on the topic, developed methods applicable to machine learning, games and epidemics. Sid loved this topic dearly and enjoyed teaching it. He continued to explore this area up to the time of his death.

In 1986 Sid met Joe Gani, and they worked together intermittently from that time until his death. Over a period of 13 years, Sid and Joe (together with students and colleagues) wrote 10 joint papers. Their earliest interest was in the silting of dams, which they studied (with Peter Todorovic of UCSB) (Gani et al.,