Contributions to the Theory and Application of Statistics

A Volume in Honor of Herbert Solomon

Edited by Alan E. Gelfand

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Herbert Solomon

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Alan E. Gelfand

Department of Statistics
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Preface

This volume arises from a desire on my part to attempt a partial repayment of all the generosity that Herbert Solomon has extended to me over the past twenty years. In conjunction with a twenty-fifth anniversary dinner at Stanford given in Herb's honor in June 1984, I was able to announce, with the gracious support of Academic Press, that a volume of contributed papers dedicated to him would be prepared. Two years later it has finally come together.

That Herb is deserving may be seen by examination of his biographical sketch and list of publications. The distinguished roster of contributors were unanimous in their encouragement of this project. Indeed, I must thank them for being so supportive and responsive. It is noteworthy that for each paper at least the lead author shares both a professional relationship and a friendship with Herb. Details may be found in the section on the contributors wherein I attempted to capture some of the authors' affection for him.

The volume contains twenty papers which have been grouped into four sections. Each section defines an area in which Herb has made a contribution. Papers are ordered alphabetically by author within sections. The first group consists of four papers in the area of operations research and applied probability. The second group gathers six papers looking into problems in distribution theory and geometric probability. The third group has five applied articles in the areas of law and justice, medicine and psychology. The final group of five papers looks at several inference issues.

The strength of this volume lies in the distinction of its contributors, each of whom prepared a paper especially for it. To further insure high quality, all contributions were subjected to refereeing, revision, and editing. The articles encompass both theory and application, new results

and survey material, spanning a broad spectrum of statistics. For example, the reader will find extensive discussion of modeling ideas for categorical data in the Goodman paper, a survey of probabilistic issues in juror challenges by DeGroot, promising inference methods for hierarchical Markov process models in the Gaver and Lehoczky paper, and clever geometric and analytic insights for the probability problems examined in Diaconis and Efron.

I would like to thank the following individuals for providing invaluable service as referees: D. Baldus, M. Berliner, H. Block, P. Brockwell, A. Cohen, N. Cressie, J. Deken, D. Dey, N. Duan, W. Fairley, A. Feinstein, J. Fleiss, E. George, J. Glaz, S. S. Gupta, I. Guttman, J. Hill, J. T. Hwang, J. Kadane, T. Leonard, J. Naus, I. Olkin, S. Reed, A. Siegel, H. Smith, S. Zacks, A. Zellner, J. Zubin. I would also like to thank Janice Bittner for the development of the camera ready copy and Alice Kristoff and Jeanne Young for their secretarial assistance. Finally, I must thank the staff at Academic Press for their help—in particular, Terence Toohey for providing the initial support for this project and William Sribney for bringing it to completion.

Alan E. Gelfand
Storrs, Connecticut
October 1986

A Biographical Sketch of Herbert Solomon

Herbert Solomon's statistical career spans nearly half a century, and this biographical sketch will document his extensive achievements. However, those closer to Herb view him with a special affection. The following representative remarks from contributors to this volume highlight this feeling:

> M. DeGroot: "He combines deep insight into the subject of statistics and its applications with an appropriately humorous outlook. Herb's wit and wisdom are legendary amongst statisticians."
>
> M. Stephens: "Many of us have benefited from his encyclopedic knowledge of statistics and his ability to appreciate mathematical elegance while remaining firmly aware of the practical importance of a problem. His easy humor and fund of anecdotes have entertained scores of visitors to Sequoia Hall."
>
> E. George: "Herb Solomon was and still is the complete advisor. He continues to be a key mentor, a constant source of encouragement and wisdom and someone I know I can always count on."
>
> J. Kadane: "He has been a friend, advisor, companion, but mostly a friend."

Herbert Solomon was born on March 13, 1919, in New York City, the eldest of three sons. His parents, Max and Tillie Solomon, had come to the U.S.A. at rather young ages around the turn of the century. Like other Jewish immigrants from Eastern Europe, their families had left Russia, where life could be unpleasant, to seek a better existence. In 1947 he married Lottie Lautman, whom he met when both were graduate students at Columbia University. Lottie, as those who know her will attest, is a warm and gracious lady blessed with considerable musical talent as a violinist and as a choral director. Their marriage has produced three children—Naomi, Mark, and Jed; both sons are lawyers in the San

Francisco Bay Area, and Naomi is a Vice President in International Business Systems for a large West Coast bank.

Herb is the product of a New York City public education. He attended DeWitt Clinton High School in the Bronx and received a B.S. in mathematics from the City College of New York (CCNY) in 1940 (contemporary with K. J. Arrow, H. Chernoff, and M. Sobel). He began his graduate studies at Columbia University in the fall of 1940 studying under H. Hotelling, A. Wald, and B. O. Koopman, obtaining an M.S. in statistics and probability in 1941.

World War II intervened, and by 1943, through Hotelling's efforts, Herb joined the Mathematics Research Group at Columbia, transferring to the Statistics Research Group a year later. This period marked the beginning of a long and continuing affiliation with the research organizations of the military services.

The end of World War II enabled him to pursue a Ph.D. on an intermittent basis beginning at Columbia and finishing at Stanford (awarded in 1950) where he concurrently helped to develop a statistics program. Between 1948 and 1952 he served in the Office of Naval Research (ONR) where he was named the first head of a newly created statistics branch. During this period he began a career-long research interest in geometrical probability problems (2). His efforts at ONR, however, focused primarily on an innovative concept for Defense agencies—supporting the development of basic research programs in statistics and probability at universities. He is one of the few in our field who has mixed government and university service so successfully. For two years, 1978 and 1979, he served as Chief Scientist for the Office of Naval Research in London.

Many university programs now in existence were put in place by his efforts at ONR. Through his relationships with ONR and other Defense agencies over the years, university research and development in statistics and probability has had a good friend and strong supporter.

From 1952 to 1959 he served on the Columbia University faculty. During this period he began to develop an interest in several psychometric problems developing foundational papers in such areas as group and individual performance models (4, 13, 75), item analysis (8, 14, 74), and classification techniques (16). Beginning in 1952, he secured support for work in mathematical models in the behavioral sciences, and, working through the Bureau of Applied Social Research at Columbia, he organized a group of scholars consisting of P. Lazarsfeld, T. W. Anderson, H. Raiffa, E. Nagel, and D. Luce to look into this kind of model building. Much of this work is collected in three volumes (73, 74) and the book by Luce and Raiffa entitled *Games and Decisions.*

A visit to Stanford in 1954 rekindled an interest in acceptance sampling and quality control resulting in several papers on continuous sampling and survey sampling (7, 9, 11, 12, 20). H. Chernoff notes that the joint paper with Lieberman (7) initiated the field of Markov decision problems. He returned to Stanford in 1958–59 for a sabbatical year and then was invited to serve as chair of the Statistics Department. He continues as Professor of Statistics in the Department. In his early years at Stanford he furthered his effort on psychometric issues (15, 16, 17, 18, 21, 22) and also pursued more theoretical problems involving the distribution of quadratic forms in normal variables (5, 19).

By the mid 1960s, his work in behavioral and social science problems led rather naturally to research activity in quantitative law and justice issues (23, 31, 47, 59, 68), an area he dubbed jurimetrics. His paper (23) in the Neyman Festschrift Volume is one of the earliest on statistical thinking in the measurement of evidence. In particular, his interest in group performance models readily transferred over to analysis of jury decision making. Such models had lain dormant for nearly 150 years, but several momentous Supreme Court decisions beginning in 1970 revived interest in this matter and added greater relevance to a resultant series of articles (35, 37, 41, 50, 64).

Also in the mid 1960s he returned to geometric probability, looking into random packing (25, 29, 40, 60) and random lines in the plane (32, 43). The latter problem was stimulated by models for traffic flow. This effort culminated in a monograph (72) that appeared in 1978. Articles on random packing and the Sylvester problem (69, 70, 71, 72) appeared subsequently.

A third ongoing major research topic continues to be multivariate data analysis. Motivation for this stemmed from the aforementioned interest in psychological measurement and was subsequently abetted by data in other disciplines. In addition to earlier work in classification, he has produced a sequence of articles in cluster analysis (24, 30, 42, 49). Much of this material is collected in an applied multivariate analysis volume (73) that was published in 1980. He has also exploited the use of multidimensional contingency table analysis in several areas of application (47, 66).

Over the past 20 years he has also produced significant work on such problems as stochastic process models (36, 38, 44, 58), estimation in 0–1 processes (48, 54), distribution approximations (33, 52, 53, 56, 61), and selection of a largest multiple correlation coefficient (34, 46). His paper (45) yields important results for clinical trial assessment. All of the above is lucid testimony to his statistical breadth.

Herb's many honors include: Fellow (1955) and President of the Institute of Mathematical Statistics (1964–65), Fellow (1954) of the American Statistical Association (ASA), recipient of the S. S. Wilks medal from ASA (1975), the Townsend Harris Medal from CCNY (1977), and the Navy Department Distinguished Public Service Medal (1978). He was a John Simon Guggenheim Fellow in 1958–59 and a Phi Beta Kappa Visiting Scholar in 1981–82.

In 1984 he celebrated his 65th birthday and 25 years at Stanford. During his career he has sponsored nearly 20 Ph.D.s, many of whom have produced "grandchildren" and even "great grandchildren". His unique combination of accomplishments—keen appreciation of statistical application in a wide variety of areas including seminal research efforts in many of these areas along with the development of research groups and statistical programs (including the innovation of federal research support for basic research in statistics) assure him a distinct place in the statistics world. His warmth, humor, generosity, and zest for life enable those who know him to enjoy these accomplishments even more.

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The Invited Contributors

Mark Brown
Mark Brown serves as Professor of Mathematics at The City College of New York (CCNY). His research interests include probability theory, applied probability models, reliability theory and inequalities. He received his B.S. from City College and his M.S. and Ph.D. from Stanford University. **Brown on Solomon**: "I met Herb when I was a first-year graduate student at Stanford. He was warm and understanding and generous in his wise advice. Since that time he and I have had a close personal and working relationship. I have a great deal of love, respect, admiration, and appreciation for him."

Herman Chernoff
Herman Chernoff received his B.S. from City College of New York and his Ph.D. from Brown. He has made major contributions to the fields of sequential analysis and optimal control. He has taught at the University of Illinois, Stanford, and M.I.T. He is now Professor of Statistics at Harvard University. **Chernoff on Solomon**: "Herb and I were fellow members of the CCNY Mathematics Club during 1939–40 when he was an important upper-classman and I a mere freshman. This difference in station prevented us from getting to know each other well. However, our friendship and professional relationship flourished during the years we were colleagues at Stanford."

Morris H. DeGroot
Morris H. DeGroot received his B.S. from Roosevelt University and his M.S. and Ph.D. from University of Chicago. He is presently University Professor of Statistics and Industrial Administration at Carnegie-Mellon University. He has served as Theory and Methods Editor for *JASA* and is currently the Executive Editor of *Statistical Science.* **DeGroot on Solomon**: "I have known Herb for more than twenty years as a professional colleague and friend. There is no more delightful learning experience

than to hear him expound with increasing expertise and liveliness on world politics, national politics, local politics, and—the culmination—university politics."

Persi Diaconis
Persi Diaconis is Professor of Statistics at Stanford University and consulting statistician at Stanford's Linear Accelerator. He received his B.S. from City College of New York and his Ph.D. from Harvard University. He has made important contributions on foundational problems in data analysis and in Bayesian statistics. **Diaconis on Solomon:** "The personal qualities of Herb's that come to mind are his sense of humor and his loyalty as a friend. Herb is a great story-teller and a constant careful observer of the passing scene. His stories are often laden with the wit and wisdom of Jewish tradition, which has played such a part in his life."

Bradley Efron
Bradley Efron is Professor of Statistics and Biostatistics and Family, Community, and Preventive Medicine at Stanford University. He received his B.S. from the California Institute of Technology and his M.S. and Ph.D. from Stanford University. He has made major contributions to the foundations of inference, geometry in statistics, adaptive inference, and sample reuse methods. **Efron on Solomon:** "Herb has been a mainstay of the Stanford Statistics Department from its beginning. In addition to an enormous amount of financial support, he has offered continual encouragement to the younger faculty. Herb even offers encouragement to aging faculty! Finally, he is, by far, the best joke-teller in the department."

Joseph Gani
Joseph Gani is Chairman of the Statistics Program at the University of California, Santa Barbara. He had previously been at the University of Sheffield, CSIRO, and the University of Kentucky. He received a B. Sc. from Imperial College, a Ph.D. from the Australian National University and D.Sc. from London University. He is the Editor of the *Applied Probability* journals and works in stochastic models with biological and engineering applications. **Gani on Solomon:** "I have valued Herb's friendship and professional association for over twenty years, first as a visitor to Stanford and later during his visit to England as ONR Chief Scientist."

Donald Gaver
Donald Gaver is Professor of Operations Research at the Naval Postgraduate School, Monterey. His education took place at M.I.T. (B.S. and M.S.) and Princeton University (Ph.D.). His interest is in operations research with emphasis on applied probability modeling and on statistical

data analysis and inference. **Gaver on Solomon:** "My relationship with Herb began in 1960 when I first visited Stanford. Later contacts with him have been stimulating, entertaining, and even life-enhancing. I wish him the best and hope to enjoy his company often in the future." (Gaver notes that Herb is a snazzy dresser and that Herb and Lottie are smooth dancers, he having once won a dance contest!—Editor)

Seymour Geisser
Seymour Geisser is Professor and Director, School of Statistics, University of Minnesota. He received his B.A. from City College of New York and his M.A. and Ph.D. from the University of North Carolina. He has made major research contributions in Bayesian statistics and in sample reuse methods. **Geisser on Solomon:** "I have known Herb for more than 25 years professionally and have much enjoyed summer visits to Stanford arranged by him."

Alan Gelfand
Alan Gelfand is Professor of Statistics at the University of Connecticut. He received his B.S. from City College of New York and his M.S. and Ph.D. from Stanford University working under Herb Solomon. His research interests include decision theory, statistical modeling, and general systems theory with applications in law and justice statistics and marketing. **Gelfand on Solomon:** "For nearly twenty years Herb has been a source of challenging problems in such areas as jury decisionmaking, archaeology, and quality control. More importantly, he is a source of support, guidance, and friendship. He is a special person."

Edward George
Edward George is Associate Professor of Statistics at the Graduate School of Business of the University of Chicago. He obtained an A.B. from Cornell University, an M.S. from SUNY, Stony Brook, and a Ph.D. from Stanford under the direction of Herb Solomon. His research interests are in decision theory and geometrical probability. **George on Solomon:** "I remember the first time I showed Herb some of my own sketchy ideas on an unsolved problem he had described in a lecture on geometrical probability. He was remarkably enthusiastic with suggestions on how to continue. Because of his support I was able to sustain my efforts and turn these ideas into a thesis."

Leo Goodman
Leo Goodman is the Charles L. Hutchinson Distinguished Service Professor of Statistics and Sociology at the University of Chicago. He received his Ph.D. from Princeton University. He is a leading scholar in the development of categorical data analysis and other related areas of research in statistics. **Goodman on Solomon:** "When I started work in

the real world at the University of Chicago, I discovered that I had a guardian angel, Herb Solomon, at ONR in Washington supporting my research. Our fine relationship has continued while Herb was at Columbia University and through these many years he has spent at Stanford."

Jay Kadane
Jay Kadane received his B.S. from Harvard and his Ph.D. from Stanford. He is the Leonard J. Savage Professor of Statistics and Social Sciences at Carnegie Mellon University. His broad research includes interest in many areas of application, in statistical theory, especially Bayesian ideas, and in computer science. **Kadane on Solomon:** "I met Herb in the first semester of my graduate studies at Stanford. Ever since he has been a friend. I am glad to contribute to a volume in his honor."

Marvin Kastenbaum
Marvin Kastenbaum is Director of Statistics for The Tobacco Institute in Washington, D.C. Previously he was special advisor on statistics to the director of the Oak Ridge National Laboratory. His undergraduate degree is from City College of New York. He received his Master's and Ph.D. from North Carolina State University. **Kastenbaum on Solomon:** "I first met Herb in 1950 when I was sharing a rooming house in Washington with his younger brother, Hank, a budding economist. Our professional association evolved over the years involving a common interest in such topics as sphere-packing and jurimetrics. More recently we have shared our views on the impact of diagnostic errors on official vital statistics."

David Kaye
David Kaye is Professor of Law and Director of the Center for Law, Science, and Technology at Arizona State University. He holds degrees from M.I.T., Harvard University, and the Yale Law School. A former editor of the ABA's *Jurimetrics Journal,* his research blends law, philosophy, and statistics. **Kaye on Solomon:** "When I became interested in applications of probability and statistics in the legal system, I discovered several papers that Herb had written. Curious to learn more about a study cited in one of these papers, I wrote to him. The result was a series of intriguing references to other work, a warm and generous correspondence, and a distinct improvement in my own thinking about the emerging field of forensic statistics."

John Lehoczky
John Lehoczky is Professor and Department Head of Statistics at Carnegie Mellon University. He earned his B.A. at Oberlin College and his M.S. and Ph.D. at Stanford University, with Herb Solomon serving as his thesis advisor. He has wide ranging research interests in applied probability and statistics, operations research, and computer science. **Lehoczky on Solomon:** "Much of my research work undertaken during

the past sixteen years can be traced back to the influence of Herb Solomon. My strong interest in applied probability was stimulated by his research project on Traffic Flow Theory. Moreover, he also introduced me to problems of statistics and the law and statistical problems in psychology and psychiatry."

Juan Mezzich
Juan Mezzich is a psychiatrist trained at Cayetano Heredia Peruvian University with residence completed at Ohio State University. He also holds a Ph.D. in quantitative psychology from Ohio State. He is currently Professor of Psychiatry at the University of Pittsburgh and Director of the Clinical Information System of the University's Western Psychiatric Institute and Clinic. **Mezzich on Solomon:** "In 1974 while on the faculty of the School of Medicine at Stanford, I approached Herb for supervision on my dissertation on statistical methods in psychology. From this initial interaction we worked very closely on classification and clustering techniques. These meetings led not only to the completion of my dissertation but also to our book." (Entry 77 on Publications list—Editor)

S. James Press
S. James Press is Professor of Statistics at the University of California at Riverside. He received his Ph.D. from Stanford University. His diverse research interests include multivariate distribution theory, statistical inference with a Bayesian viewpoint, and law and justice statistics. **Press on Solomon:** "My professional relationship with Herb began in 1960–61 when I contacted him seeking admission to the graduate program in Statistics at Stanford. We maintained a friendship during my student days, during my post-doctoral years at the Rand Corporation, and during all of the intervening years as colleagues. Herb's contributions have been an inspiration to many of us."

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M. Haseeb Rizvi is president of Techrean Division of Sysorex International, Inc. He has taught at Stanford University and Ohio State University. His research interests incude ranking and selection procedures, nonparametric inference, multivariate analysis, and statistical graphics. He received B.Sc. and M.Sc. degrees from the University of Lucknow and a Ph.D. from the University of Minnesota. **Rizvi on Solomon:** "My association with Herb goes back to 1967 when I first came to the Statistics Department at Stanford. I have co-authored research articles with him and occasionally worked on research projects that have Herb as principal investigator."

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Andrew Siegel is Associate Professor of Statistics, Management Science, and Finance at the University of Washington, Seattle. He received his

A.B. from Boston University and his M.S. and Ph.D. from Stanford University under Herb Solomon. His research includes contributions in geometrical probability and contemporary data analysis. **Siegel on Solomon:** "In 1975, when, as a Stanford graduate student, I transferred to statistics from mathematics, Herb was on leave. An article on the bulletin board about him informed me that he did geometrical probability (and other things). When he returned I naively asked him 'What is geometrical probability?' He provided general discussion, references, and a few unsolved problems. Eventually, my work on these fascinating problems became accepted as a thesis under Herb's direction."

Michael Stephens
Michael Stephens is Professor of Mathematics at Simon Fraser University. He received a B.Sc. from Bristol, an A.M. from Harvard, and a Ph.D. from the University of Toronto. His research includes contributions in goodness of fit testing and in distribution theory problems, particularly for directional data. **Stephens on Solomon:** "I first met Herb when I gave a talk at Stanford early in 1967. He subsequently invited me to spend some time there in the summer, and I have been visiting ever since. It has been a wonderful privilege that I greatly value. I contribute my article for him with respect, much affection, and good wishes for the future."

Paul Switzer
After receiving a B.A. from the University of Manitoba and a Ph.D. from Harvard, Paul Switzer joined the Stanford faculty in 1965, where he is now Professor of Statistics. He is currently Theory and Methods Editor for *JASA.* His research contributions include work in multivariate analysis and geometrical probability. **Switzer on Solomon:** "I have enjoyed more than twenty years of colleagial friendship with Herb. Shared interests in clustering and discriminant analysis as well as geometric probability together with many shared views on the human condition have provided the basis for this friendship."

Shelemyahu Zacks
Shelley Zacks is Professor of Mathematics at SUNY, Binghamton. He currently serves on four editorial boards. He received his B.A. from Hebrew University, his M.Sc. from the Technion, and his Ph.D. from Columbia University. His research interests include estimation theory, sequential analysis, and statistical process control and reliability theory. **Zacks on Solomon:** "I met Herb while visiting at Stanford in 1963. Herb was Department Chair at that time. In 1967 we started to collaborate on research projects resulting in several joint papers, and with his support I have visited Stanford several times since."

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