

THE ANNALS of PROBABILITY

AN OFFICIAL JOURNAL OF
THE INSTITUTE OF MATHEMATICAL STATISTICS

Articles

Supercritical contact processes on Z	RICHARD DURRETT AND DAVID GRIFFEATH	1
Attractive nearest particle system	THOMAS LIGGETT	16
Brownian motion with lower class moving boundaries which grow faster than $t^{1/2}$ R. F. BASS AND M. CRANSTON		34
A class of conditional limit theorems related to ruin problem	MICHIO SHIMURA	40
Gaussian measures in B_p	NARESH JAIN AND DITLEV MONRAD	46
The central limit theorem for stochastic integrals with respect to Lévy processes EVARIST GINÉ AND MICHAEL B. MARCUS		58
Small deviations in the functional central limit theorem with applications to functional laws of the iterated logarithm	ALEJANDRO DE ACOSTA	78
Some results on the cluster set $C(\{S_n/a_n\})$ and the LIL	A. DE ACOSTA AND J. KUELBS	102
Convergence rates related to the strong law of large numbers	JAMES ALLEN FILL	123
Remainder term estimates of the renewal function	HASSE CARLSSON	143
Dominating points and the asymptotics of large deviations for random walk on \mathbb{R}^d PETER NEY		158
Domains of attraction of multivariate extreme value distributions ALBERT W. MARSHALL AND INGRAM OLKIN		168
The domain of normal attraction of an operator-stable law WILLIAM N. HUDSON, J. DAVID MASON, AND JERRY ALAN VEEH		178
Sums of functions of nearest neighbor distances, moment bounds, limit theorems and a goodness of fit test	P. J. BICKEL AND L. BREIMAN	185

Short Communications

A remark on stochastic fundamental matrices	MARC A. BERGER	215
A method of investigating the longest paths in certain random graphs T. NEMETZ AND N. KUSOLITSCH		217
Strong law of large numbers for Banach space valued random sets MADAN L. PURI AND DAN A. RALESCU		222
An application of time reversal to Brownian local time	JOANNA B. MITRO	225

Vol. 11, No. 1—February 1983

THE INSTITUTE OF MATHEMATICAL STATISTICS

(Organized September 12, 1935)

The purpose of the Institute of Mathematical Statistics is to encourage the development, dissemination, and application of mathematical statistics.

OFFICERS

President:

Patrick Billingsley, Department of Statistics, University of Chicago, Chicago, Illinois 60637

President-Elect:

Ingram Olkin, Department of Statistics, Stanford University, Stanford, California 94305

Past-President:

Mark Kac, Department of Mathematics, University of Southern California, Los Angeles, California 90007

Executive Secretary:

Kjell Doksum, Department of Statistics, University of California, Berkeley, California 94720

Treasurer:

Bruce E. Trumbo, Department of Statistics, California State University, Hayward, California 94542
IMS Business Office, 3401 Investment Blvd., Suite 6, Hayward, California 94545

Program Secretary:

Richard Johnson, Department of Statistics, University of Wisconsin, 1210 West Dayton St., Madison, Wisconsin 53706

Editor: *Annals of Statistics*

Michael D. Perlman, Department of Statistics, University of Washington, Seattle, Washington 98195

Editor: *Annals of Probability*

Harry Kesten, Department of Mathematics, Cornell University, Ithaca, N.Y. 14853

Editor: *IMS Bulletin*

William C. Guenther, University of Wyoming, Box 3332, University Station, Laramie, Wyoming 82071

Editor: *IMS Lecture Notes—Monograph Series*

Shanti S. Gupta, Department of Statistics, Purdue University, West Lafayette, Indiana 47907

Managing Editor:

Jagdish S. Rustagi, Department of Statistics, The Ohio State University, Columbus, Ohio 43210

Membership. Membership dues including a subscription to one *Annals* and *The Institute of Mathematical Statistics Bulletin* are \$37 per year for all members. Special rates of \$17.00 per year are available to students. The dues are approximately 25% higher for members who wish both *Annals* as well as the *Bulletin*. Inquiries regarding membership in the Institute should be sent to the Treasurer at the business office.

Subscription Rates. Current volumes (four issues per calendar year) of the *Annals of Probability* are \$48.00. Single issues are \$13 each. Current volumes (four issues per calendar year) of the *Annals of Statistics* are \$55.00. Single issues are \$15.00 each. Members of the Institute of Mathematical Statistics pay different rates (see above). Back numbers of both *Annals* and the *Annals of Mathematical Statistics* (Volumes 1 through 43) may be purchased from the Treasurer.

The Annals of Probability, Volume 11, Number 1, February 1983. Published in February, May, August, and November by The Institute of Mathematical Statistics, IMS Business Office, 3401 Investment Blvd., Suite 6, Hayward, California 94545.

Mail to the *Annals of Probability* should be addressed to the Treasurer at the IMS Business Office as described above. It should not be addressed to Waverly Press.

Printed at the
WAVERLY PRESS, INC., BALTIMORE, MARYLAND 21202 U.S.A.

Second-class postage at Hayward, California and at additional mailing offices
Copyright © 1983 by the Institute of Mathematical Statistics

NOTICE

Beginning with the calendar year 1982, the two journals of The Institute of Mathematical Statistics are printed quarterly. The total numbers of pages per volume are approximately the same as before. Months of publication for 1982 and 1983 are as follows.

Annals of Probability: February, May, August and November

Annals of Statistics: March, June, September and December

THE ANNALS OF PROBABILITY

INSTRUCTIONS FOR AUTHORS

Submission of Papers. Papers to be submitted for publication should be sent to the Editor of the *Annals of Probability*. (For current address, see the latest issue of the *Annals*.) The original (or xerox copy) should be submitted with two additional copies on paper that will take ink corrections. The manuscript will *not* normally be returned to the author; when expressly requested by the author, one copy of the manuscript will be returned.

Preparation of Manuscripts. Manuscripts should be typewritten, entirely double-spaced, including references, with wide margins at sides, top and bottom. Dittoed or mimeographed papers are acceptable only if completely legible; xerox copies are preferable. When technical reports are submitted, all extraneous sheets and covers should be removed.

Submission of Reference Papers. Copies (preferably two) of unpublished or not easily available papers cited in the manuscript should be submitted with the manuscript.

Title and Abbreviated Title. This title should be descriptive and as concise as is feasible, i.e., it should indicate the topic of the paper as clearly as possible, but every word in it should be pertinent. An abbreviated title to be used as a running head is also required, and should be given below the main title. This should normally not exceed 35 characters. For example, a title might be "A Limit Theorem for Conditioned Recurrent Random Walk Attracted to a Stable Law," with the running head "Limit Theorem for Recurrent Random Walk" or possibly "Recurrent Random Walk Attracted to a Stable Law," depending on the emphasis to be conveyed.

Summary. Each manuscript is required to contain a summary which will be printed immediately after the title, clearly separated from the rest of the paper. Its main purpose is to inform the reader quickly of the nature and results of the paper; it may also be used as an aid in retrieving information. The length of a summary will clearly depend on the length and difficulty of the paper, but in general it should not exceed 150 words. It should be typed on a separate page, under the heading "Summary," followed by the title of the paper. Formulas should be used as sparingly as possible. The summary should not make reference to results or formulas in the body of the paper—it should be self-contained.

Footnotes. Footnotes should be reduced to a minimum and, where possible, should be replaced by remarks in the text or in the references; formulas in footnotes should be avoided. Footnotes in the text should be identified by superscript numbers and typed together, double-spaced on a separate page.

Key Words. Included as the first footnote on page 1 should be the headings:

American Mathematical Society 1980 subject classifications. Primary —; Secondary—. Key words and phrases.

The classification numbers representing the primary and secondary subjects of the article may be found with instructions for its use in the *Mathematical Reviews Annual Subject Index-1980*. The key words and phrases should describe the subject matter of the article; generally they should be taken from the body of the paper.

Identification of Symbols. Manuscripts for publication should be clearly prepared to insure that all symbols are properly identified. Distinguish between "oh" and "zero"; "ell" and "one"; "epsilon" and "element of"; "kappa" and "kay," etc. Indicate also when special type is required (Greek, German, script, boldface, etc.); other letters will be set in italics. Acronyms should be introduced sparingly.

Figures and Tables. Figures, charts, and diagrams should be prepared in a form suitable for photographic reproduction and should be professionally drawn twice the size they are to be printed. (These need not be submitted until the paper has been accepted for publication.) Tables should be typed on separate pages with accompanying footnotes immediately below the table.

Formulas. Fractions in the text are preferably written with the solidus or negative exponent; thus, $(a + b)/(c + d)$ is preferred to $\frac{a + b}{c + d}$, and

$(2\pi)^{-1}$ or $1/(2\pi)$ to $\frac{1}{2\pi}$. Also, $a^{b(c)}$ and $a_{b(c)}$ are

preferred to a^{bc} and a_{bc} , respectively. Complicated exponentials should be represented with the symbol exp. A fractional exponent is preferable to a radical sign.

References. References should be typed double-spaced and should follow the style:

[5] Doob, J. L. (1944). The elementary Gaussian processes. *Ann. Math. Statist.* 15 229–282.

In textual material, the format "... Doob (1944) ..." is normally preferred to "... Doob [5] ..." Multiple references can be distinguished as "... Doob (1944a) ..." Abbreviations for journals should be taken from a current index issue of *Mathematical Reviews*.

Proofs. Author will ordinarily receive galley proofs. Corrected galley proofs should be sent to the Managing Editor of the *Annals of Probability*. (For current address, see the latest issue of the *Annals*.)

EDITORIAL STAFF

EDITOR

HARRY KESTEN

ASSOCIATE EDITORS

DAVID ALDOUS	MARJORIE G. HAHN	MARK A. PINSKY
SIMEON M. BERMAN	PETER HALL	HERMANN ROST
RENÉ CARMONA	RICHARD HOLLEY	STANLEY SAWYER
BURGESS DAVIS	NOBUYUKI IKEDA	MICHAEL J. SHARPE
C. A. DOLÉANS-DADE	THOMAS G. KURTZ	STEVEN E. SHREVE
H. O. GEORGI	THOMAS M. LIGGETT	MICHAEL WOODROOFE
PRISCILLA GREENWOOD	P. WARWICK MILLAR	

EDITORIAL ASSISTANT

NORMA PRENDERGAST

MANAGING EDITOR

JAGDISH S. RUSTAGI

EDITORIAL ASSISTANTS

DOROTHY GARVIN TONJES

LINDALEE W. BROWNSTEIN

PAST EDITORS

ANNALS OF MATHEMATICAL STATISTICS

H. C. CARVER, 1930-1938
S. S. WILKS, 1938-1949
T. W. ANDERSON, 1950-1952
E. L. LEHMANN, 1953-1955
T. E. HARRIS, 1955-1958

WILLIAM KRUSKAL, 1958-1961
J. L. HODGES, JR., 1961-1964
D. L. BURKHOLDER, 1964-1967
Z. W. BIRNBAUM, 1967-1970
INGRAM OLKIN, 1970-1972

ANNALS OF PROBABILITY
RONALD PYKE, 1972-1975
PATRICK BILLINGSLEY, 1976-1978
R. M. DUDLEY, 1979-1981

ANNALS OF STATISTICS
INGRAM OLKIN, 1972-1973
I. R. SAVAGE, 1974-1976
RUPERT G. MILLER, JR., 1977-1979
DAVID V. HINKLEY, 1980-1982

EDITORIAL POLICY

The main purpose of the *Annals of Probability* and the *Annals of Statistics* is to publish contributions to the theory of probability and statistics and to their applications. The emphasis is on importance and interest, not formal novelty and correctness. Especially appropriate are authoritative expository papers and surveys of areas in vigorous development. All papers are refereed.

IMS INSTITUTIONAL MEMBERS

- AEROSPACE CORPORATION**
El Segundo, California
- ARIZONA STATE UNIVERSITY**
Tempe, Arizona
- BELL TELEPHONE LABORATORIES, TECHNICAL LIBRARY**
Murray Hill, N.J.
- BOWLING GREEN STATE UNIVERSITY, DEPT. OF MATHEMATICS**
Bowling Green, Ohio
- CALIFORNIA STATE UNIVERSITY, FULLERTON, DEPARTMENT OF MATHEMATICS**
Fullerton, California
- CASE WESTERN RESERVE UNIVERSITY, DEPARTMENT OF MATHEMATICS**
Cleveland, Ohio
- CORNELL UNIVERSITY, DEPARTMENT OF MATHEMATICS**
Ithaca, New York
- FLORIDA STATE UNIVERSITY, DEPARTMENT OF STATISTICS**
Tallahassee, Florida
- GENERAL MOTORS CORPORATION, RESEARCH LABORATORIES**
Warren, Michigan
- GEORGE WASHINGTON UNIVERSITY, DEPARTMENT OF STATISTICS**
Washington, D.C.
- INDIANA UNIVERSITY, MATHEMATICS DEPT.**
Bloomington, Indiana
- INTERNATIONAL BUSINESS MACHINES CORPORATION**
Armonk, New York
- IOWA STATE UNIVERSITY, STATISTICAL LABORATORY**
Ames, Iowa
- JOHNS HOPKINS UNIVERSITY, DEPARTMENT OF BIostatISTICS, DEPARTMENT OF MATHEMATICAL SCIENCES**
Baltimore, Maryland
- KANSAS STATE UNIVERSITY, STATISTICS DEPARTMENT**
Manhattan, Kansas
- MARQUETTE UNIVERSITY, MATHEMATICS AND STATISTICS DEPARTMENT**
Milwaukee, Wisconsin
- MASSACHUSETTS INSTITUTE OF TECHNOLOGY MATHEMATICS DEPARTMENT**
Cambridge, Massachusetts
- MIAMI UNIVERSITY, DEPARTMENT OF MATHEMATICS**
Oxford, Ohio
- MICHIGAN STATE UNIVERSITY, DEPARTMENT OF STATISTICS AND PROBABILITY**
East Lansing, Michigan
- NATIONAL SECURITY AGENCY**
Fort George G. Meade, Maryland
- NEW MEXICO STATE UNIVERSITY, DEPARTMENT OF MATHEMATICAL SCIENCES**
Las Cruces, New Mexico
- NORTH CAROLINA STATE UNIVERSITY, DEPARTMENT OF STATISTICS**
Raleigh, North Carolina
- NORTHERN ILLINOIS UNIVERSITY, DEPARTMENT OF MATHEMATICAL SCIENCES**
De Kalb, Illinois
- NORTHWESTERN UNIVERSITY, DEPARTMENT OF MATHEMATICS**
Evanston, Illinois
- OHIO STATE UNIVERSITY, DEPARTMENT OF STATISTICS**
Columbus, Ohio
- OREGON STATE UNIVERSITY, DEPARTMENT OF STATISTICS**
Corvallis, Oregon
- PENNSYLVANIA STATE UNIVERSITY, DEPARTMENT OF STATISTICS**
University Park, Pennsylvania
- PRINCETON UNIVERSITY, DEPARTMENT OF STATISTICS**
Princeton, New Jersey
- PURDUE UNIVERSITY LIBRARIES**
Lafayette, Indiana
- QUEEN'S UNIVERSITY, DEPT. OF MATHEMATICS AND STATISTICS**
Kingston, Ontario, Canada
- RICE UNIVERSITY, DEPARTMENT OF MATHEMATICAL SCIENCES**
Houston, Texas
- THE ROCKEFELLER UNIVERSITY**
New York, New York
- SIMON FRASER UNIVERSITY, MATHEMATICS DEPARTMENT**
Burnaby, Canada
- SOUTHERN ILLINOIS UNIVERSITY, MATHEMATICAL STUDIES**
Edwardsville, Illinois
- SOUTHERN METHODIST UNIVERSITY, DEPARTMENT OF STATISTICS**
Dallas, Texas
- STANFORD UNIVERSITY, GIRSHICK MEMORIAL LIBRARY**
Stanford, California
- STATE UNIVERSITY OF NEW YORK, BUFFALO, DEPARTMENT OF STATISTICS**
Amherst, New York
- TEMPLE UNIVERSITY, MATHEMATICS DEPARTMENT**
Philadelphia, Pa
- TEXAS TECH UNIVERSITY, DEPARTMENT OF MATHEMATICS**
Lubbock, Texas 79409
- YORK UNIVERSITY, DEPARTMENT OF MATHEMATICS**
Downsview, Ontario, Canada

THE TOBACCO INSTITUTE
Washington, D.C.

UNION OIL COMPANY OF CALIFORNIA, UNION
RESEARCH CENTER
Brea, California

UNIVERSITY OF ARIZONA, DEPARTMENT OF
MATHEMATICS AND COMMITTEE ON STA-
TISTICS
Tucson, Arizona

UNIVERSITY OF BRITISH COLUMBIA, DEPART-
MENT OF MATHEMATICS
Vancouver, B.C., Canada

UNIVERSITY OF CALGARY, MATHEMATICS DE-
PARTMENT
Calgary 44, Alberta, Canada

UNIVERSITY OF CALIFORNIA, BERKELEY, STA-
TISTICAL LABORATORY
Berkeley, California

UNIVERSITY OF CALIFORNIA, DAVIS, DIVISION
OF STATISTICS
Davis, California

UNIVERSITY OF GUELPH, MATHEMATICS AND
STATISTICS DEPARTMENT
Guelph, Ontario, Canada

UNIVERSITY OF ILLINOIS AT CHICAGO CIRCLE,
DEPARTMENT OF MATHEMATICS
Chicago, Illinois

UNIVERSITY OF ILLINOIS, MATHEMATICS DEPT.
Urbana, Illinois

UNIVERSITY OF IOWA, DIVISION OF MATHE-
MATICAL SCIENCES
Iowa City, Iowa

UNIVERSITY OF MANITOBA, DEPARTMENT OF
STATISTICS
Winnipeg, Manitoba, Canada

UNIVERSITY OF MARYLAND, DEPARTMENT OF
MATHEMATICS
College Park, Maryland

UNIVERSITY OF MASSACHUSETTS, DEPART-
MENT OF MATHEMATICS AND STATISTICS
Amherst, Massachusetts

UNIVERSITY OF MICHIGAN, DEPARTMENT OF
STATISTICS
Ann Arbor, Michigan

UNIVERSITY OF MINNESOTA, SCHOOL OF STA-
TISTICS
Minneapolis, Minnesota

UNIVERSITY OF MISSOURI, DEPARTMENT OF
STATISTICS
Columbia, Missouri

UNIVERSITY OF MISSOURI AT ROLLA, DEPART-
MENT OF MATHEMATICS
Rolla, Missouri

UNIVERSITY OF MONTREAL, DEPARTMENT OF
MATHEMATICS
Montreal, Quebec, Canada

UNIVERSITY OF NEBRASKA, MATHEMATICS
AND STATISTICS DEPARTMENT
Lincoln, Nebraska

UNIVERSITY OF NEW MEXICO, DEPARTMENT
OF MATHEMATICS AND STATISTICS
Albuquerque, New Mexico

UNIVERSITY OF NORTH CAROLINA, DEPART-
MENT OF STATISTICS
Chapel Hill, North Carolina

UNIVERSITY OF OREGON, MATHEMATICS DE-
PARTMENT
Eugene, Oregon

UNIVERSITY OF OTTAWA, DEPARTMENT OF
MATHEMATICS
Ottawa, Ontario, Canada

UNIVERSITY OF SOUTH CAROLINA, DEPART-
MENT OF MATHEMATICS AND COMPUTER
SCIENCE
Columbia, South Carolina

UNIVERSITY OF TEXAS, DEPARTMENT OF
MATHEMATICS
Austin, Texas

UNIVERSITY OF TEXAS, MATHEMATICS DEPT.
San Antonio, Texas

UNIVERSITY OF VICTORIA, DEPT. OF MATHE-
MATICS
Victoria, British Columbia, Canada

UNIVERSITY OF VIRGINIA, DEPT. OF MATHE-
MATICS
Charlottesville, Virginia

UNIVERSITY OF WASHINGTON, DEPARTMENT
OF MATHEMATICS
Seattle, Washington

UNIVERSITY OF WATERLOO, STATISTICS DE-
PARTMENT
Waterloo, Ont., Canada

UNIVERSITY OF WISCONSIN, MADISON, DE-
PARTMENT OF STATISTICS
Madison, Wisconsin

UNIVERSITY OF WISCONSIN, MILWAUKEE, DE-
PARTMENT OF MATHEMATICS
Milwaukee, Wisconsin

VIRGINIA COMMONWEALTH UNIVERSITY, DE-
PARTMENT OF MATHEMATICAL SCIENCES
Richmond, Virginia

WAYNE STATE UNIVERSITY, DEPARTMENT OF
MATHEMATICS
Detroit, Michigan

WESTINGHOUSE ELECTRIC CORPORATION, RE-
SEARCH LABORATORIES
Pittsburgh, Pennsylvania

The Writings of Leonard Jimmie Savage —A Memorial Selection

The American Statistical Association and
The Institute of Mathematical Statistics
announce publication of the selected works of Jimmie Savage

Contents include:

- 45 selected reprints of papers published between 1940–1977, photographed from the original sources
- Biographical sketches and personal insights by W. Allen Wallis, Frederick Mosteller, Francis Anscombe, and William and Esther Sleator
- Scholarly essay, "L.J. Savage—His Work in Probability and Statistics," by D. V. Lindley
- Complete bibliography of all published papers, books, reviews, and discussions by Savage

736 pages, bound in blue kidskin

Papers included:

A Dynamic Problem in Duopoly
On the Crossing of Extremals at Focal Points
Unbiased Estimates for Certain Binomial Sampling Problems with Applications
The Application of Vectorial Methods to Metric Geometry
A Uniqueness Theorem for Unbiased Sequential Binomial Estimation
Abandoning an Experiment Prior to Completion
Planning Experiments Seeking Maxima
Samuelson's Foundations: Its Mathematics
The Utility Analysis of Choices Involving Risk
Application of the Radon-Nikodym Theorem to the Theory of Sufficient Statistics
Bayes and Minimax Estimates for Quadratic Loss Functions
The Theory of Statistical Decision
On the Set of Values of a Nonatomic, Finitely Additive, Finite Measure
The Expected-Utility Hypothesis and the Measurability of Utility
* Une Axiomatisation de Comportement Raisonnable Face à l'Incertain
Three Problems in Rationing Capital
Symmetric Measures on Cartesian Products

* Reprinted in original language

The Nonexistence of Certain Statistical Procedures in Nonparametric Problems
When Different Pairs of Hypotheses Have the Same Family of Likelihood-Ratio Test Regions
Recent Tendencies in the Foundations of Statistics
Optimal Gambling Systems
The Foundations of Statistics Reconsidered
* Sul Modo di Scegliere le Probabilità Iniziali
* Campi di Applicazione e Tecniche della Statistica
* Uno Sguardo Sulla Statistica di Oggi
* Il Problema delle Strategie Ottime di Giòco
Bayesian Statistics
Bayesian Statistical Inference for Psychological Research
A Tchebycheff-Like Inequality for Stochastic Processes
Finite Stopping Time and Finite Expected Stopping Time
Difficulties in the Theory of Personal Probability
Implications of Personal Probability for Induction
A Geometrical Approach to the Special Stable Distributions
Comments on a Weakened Principle of Conditionality
Reading Suggestions for the Foundations of Statistics
A Generalized Unimodality
* Die Bayessche Entwicklungsstufe der Statistischen Schlussweise
Elicitation of Personal Probabilities and Expectations
The Characteristic Function Characterized and the Momentousness of Moments
The Mathematics of Glottochronology Revisited
Diagnosis and the Bayesian Viewpoint
Inequalities on the Probability Content of Convex Regions for Elliptically Contoured Distributions
Probability in Science: A Personalistic Account
On Rereading R.A. Fisher
The Shifting Foundations of Statistics

Order through IMS.
3401 Investment Blvd., Suite 6, Hayward, CA 94545
(Orders Are Payable in Advance)

\$27.00 (IMS/ASA Member)
\$39.00 (Nonmembers)