THE ANNALS
of
PROBABILITY

An Official Journal of
The Institute of Mathematical Statistics

Articles

Level crossings for random fields ..... Robert J. Adler and A. M. Hasofer 1
A two-dimensional functional permutational central limit theorem for linear rank statistics ..... Pranab Kumar Sen 13
Supercritical age dependent branching processes with generation dependence ..... Dean H. Fearn 27
Convergence of the age distribution in the one-dimensional supercritical age-dependent branching process ..... K. B. Athreya and N. Kaplan 38
Asymptotic moments of random walks with applications to ladder variables and renewal theory ..... Tze' Leung Lai 51
A renewal theorem for curved boundaries and moments of first passage times ..... Michael Woodroofe 67

Short Communications

An almost sure invariance principle for the extrema of certain sample functions ..... Pranab Kumar Sen 81
Simple proof of a result on thinned point processes ..... M. Westcott 89
The ergodic maximal function with cancellation ..... Roger L. Jones 91
Prediction theory and ergodic spectral decompositions ..... Bennett Eisenberg 98
Nonuniform central limit bounds with applications to probabilities of deviations ..... R. Michel 102
An example of a weak martingale ..... Jeremy Berman 107
Another upper bound for the renewal function ..... D. J. Daley 109
An invariance principle for random walk conditioned by a late return to zero ..... W. D. Kaigh 115
Limit laws for maxima and second maxima from strong-mixing processes ..... Toshio Mori 122
The reconstructability of Markov chains ..... Michael W. Chamberlain 127
Almost sure convergence of the quadratic variation of martingales: a counterexample ..... Itrel Monroe 133
Convergence rates for branching processes ..... Søren Asmussen 139
Convergence of conditional p-means given a σ-lattice ..... D. Landers and L. Rogge 147
A note on downcrossings for extremal processes ..... Judah M. Frankel 151

Note

Correction to "A counterexample to Perez's generalization of the Shannon-McMillan theorem ..... John C. Kieffer 153

Vol. 4, No. 1—February 1976

Institute of Mathematical Statistics is collaborating with JSTOR to digitize, preserve, and extend access to *The Annals of Probability.* www.jstor.org

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:

Donald L. Burkholder, Department of Mathematics, University of Illinois, Urbana, Illinois 61801

President-Elect:

C. R. Rao, Indian Statistical Institute, 538 Yojana Bhavan, New Delhi 110001 India

Past President:

Frederick Mosteller, Department of Statistics, Science Center, Room 603, Harvard University, One Oxford Street, Cambridge, Massachusetts 02138

Executive Secretary:

George J. Resnikoff, Dept. of Statistics, California State University, Hayward, 25800 Hillary Street, Hayward, California 94542

Treasurer:

Robert M. Elashoff, IMS Business Office, 1367 Laurel Street, San Carlos, California 94070

Program Secretary:

William L. Harkness, Pennsylvania State University, University Park, Pennsylvania 16801

Editor: *Annals of Statistics*

I. R. Savage, Department of Statistics, P.O. Box 2179, Yale Station, New Haven, Connecticut 06520

Editor: *Annals of Probability*

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

Managing Editor:

Donald R. Truax, Department of Mathematics, University of Oregon, Eugene, Oregon 97403

Membership. Membership dues including a subscription to one *Annals* and *The Institute of Mathematical Statistics Bulletin* are $24.00 per year for residents of the United States or Canada and $16.00 per year for residents of other countries. Special rates of $12.00 per year are available to students. Rates in each category are one-third 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 (six issues per calendar year) of the *Annals of Probability* and the *Annals of Statistics* are each $30.00. Members of the Institute of Mathematical Statistics pay different rates (see above). Single issues are $6.00. 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 4, Number 1, February 1976. Published bimonthly in February, April, June, August, October, and December by The Institute of Mathematical Statistics, IMS Business Office, 1367 Laurel Street, San Carlos, California 94070.

Mail to the *Annals of Probability* should be addressed to either the Editor, Managing Editor or the Treasurer, 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 paid at San Francisco, California and at additional mailing offices

Copyright © 1976 by the Institute of Mathematical Statistics

EDITORIAL STAFF

EDITOR

PATRICK BILLINGSLEY

ASSOCIATE EDITORS

RICHARD E BARLOW
J. R. BLUM
DAVID R. BRILLINGER
JEAN PIERRE CONZE
D. A. DAWSON
R. M. DUDLEY
MEYER DWASS
DAVID L. HANSON
C. C. HEYDE
DONALD L. IGLEHART
SØREN JOHANSEN
J. F. C. KINGMAN
M. R. LEADBETTER
PETER NEY
WALTER PHILIPP
WILLIAM E. PRUITT
G. E. H. REUTER
J. SETHURAMAN
L. A. SHEPP
DAVID O. SIEGMUND
CHARLES J. STONE
JOHN B. WALSH
MICHAEL J. WICHURA
DONALD YLVISAKER

MANAGING EDITOR

D. R. TRUAX

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

ANNALS OF STATISTICS
INGRAM OLKIN, 1972–1973
I. R. SAVAGE, 1974–1976

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 statistcs 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.

NOTICE

Manuscripts submitted to the *Annals of Probability* should now be sent to the Editor at this address:

PATRICK BILLINGSLEY
Department of Statistics
University of Chicago
Chicago, Illinois 60637

Books to be reviewed should be sent to the Associate Editor for book reviews at this address:

MEYER DWASS
Department of Mathematics
Northwestern University
Evanston, Illinois 60201

IMS INSTITUTIONAL MEMBERS

AEROSPACE CORPORATION
El Segundo, California

ARIZONA STATE UNIVERSITY
Tempe, Arizona

ARTHUR D. LITTLE, INC.
Cambridge, Massachusetts

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

CALIFORNIA STATE UNIVERSITY, HAYWARD, DEPARTMENT OF STATISTICS
Hayward, 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

FORD MOTOR COMPANY, ENGINEERING AND RESEARCH LIBRARY
Dearborn, Michigan

GENERAL MOTORS CORPORATION, RESEARCH LABORATORIES
Warren, Michigan

GEORGE WASHINGTON UNIVERSITY, DEPARTMENT OF STATISTICS
Washington, D.C.

INDIANA UNIVERSITY, MATHEMATICS DEPT.
Bloomington, Indiana

INSTITUTE FOR DEFENSE ANALYSES
Arlington, Virginia

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, DEPARTMENT OF STATISTICS
Manhattan, Kansas

MIAMI UNIVERSITY, DEPARTMENT OF MATHEMATICS
Oxford, Ohio

MICHIGAN STATE UNIVERSITY, DEPARTMENT OF STATISTICS AND PROBABILITY
East Lansing, Michigan

NATIONAL INSTITUTE FOR THE DEAF, OFFICE FOR PROGRAM ANALYSIS
Rochester, New York

NATIONAL SECURITY AGENCY
Fort George G. Meade, Maryland

NEW MEXICO STATE UNIVERSITY, DEPARTMENT OF MATHEMATICAL SCIENCES
Las Cruces, New Mexico

NORTHWESTERN UNIVERSITY, DEPARTMENT OF MATHEMATICS
Evanston, Illinois

OHIO STATE UNIVERSITY, DIVISION 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, KINGSTON
Ontario, Canada

RICE UNIVERSITY, DEPARTMENT OF MATHEMATICAL SCIENCES
Houston, Texas

THE ROCKEFELLER UNIVERSITY
New York, New York

SANDIA CORPORATION, SANDIA BASE
Albuquerque, New Mexico

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, Pennsylvania

TEXAS A & M UNIVERSITY, DEPT. OF MATHEMATICS
College Station, Texas

TEXAS TECH UNIVERSITY, DEPARTMENT OF MATHEMATICS
Lubbock, Texas 79409

THE TOBACCO INSTITUTE
Washington, D.C.

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

UNITED STATES ARMY RESEARCH AND DEVELOPMENT CENTER
Aberdeen Proving Ground, Maryland

UNIVERSITY OF ALBERTA, DEPARTMENT OF MATHEMATICS
Edmonton, Alberta, Canada

UNIVERSITY OF ARIZONA, DEPARTMENT OF MATHEMATICS
Tucson, Arizona

UNIVERSITY OF BRITISH COLUMBIA, DEPARTMENT OF MATHEMATICS
Vancouver, B.C., Canada

UNIVERSITY OF CALGARY, MATHEMATICS DEPARTMENT
Calgary 44, Alberta, Canada

UNIVERSITY OF CALIFORNIA, BERKELEY, STATISTICAL LABORATORY
Berkeley, California

UNIVERSITY OF CINCINNATI, DEPARTMENT OF MATHEMATICAL SCIENCES
Cincinnati, Ohio

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 MATHEMATICAL SCIENCES
Iowa City, Iowa

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

UNIVERSITY OF MARYLAND, DEPARTMENT OF MATHEMATICS
College Park, Maryland

UNIVERSITY OF MICHIGAN, DEPARTMENT OF STATISTICS
Ann Arbor, Michigan

UNIVERSITY OF MINNESOTA, SCHOOL OF STATISTICS
Minneapolis, Minnesota

UNIVERSITY OF MISSOURI, DEPARTMENT OF STATISTICS
Columbia, Missouri

UNIVERSITY OF MISSOURI AT ROLLA, DEPARTMENT OF MATHEMATICS
Rolla, Missouri

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

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

UNIVERSITY OF NORTH CAROLINA, DEPARTMENT OF STATISTICS
Chapel Hill, North Carolina

UNIVERSITY OF OREGON, MATHEMATICS DEPARTMENT
Eugene, Oregon

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

UNIVERSITY OF SOUTH CAROLINA, DEPARTMENT OF MATHEMATICS AND COMPUTER SCIENCE
Columbia, South Carolina

UNIVERSITY OF TEXAS, DEPARTMENT OF MATHEMATICS
Austin, Texas

UNIVERSITY OF UTAH, DEPT. OF MATHEMATICS
Salt Lake City, Utah

UNIVERSITY OF VICTORIA, DEPT. OF MATHEMATICS
Victoria, British Columbia, Canada

UNIVERSITY OF WASHINGTON, DEPARTMENT OF MATHEMATICS
Seattle, Washington

UNIVERSITY OF WISCONSIN, MADISON, DEPARTMENT OF STATISTICS
Madison, Wisconsin

UNIVERSITY OF WISCONSIN, MILWAUKEE, DEPARTMENT OF MATHEMATICS
Milwaukee, Wisconsin

VIRGINIA COMMONWEALTH UNIVERSITY, DEPARTMENT OF MATHEMATICAL SCIENCES
Richmond, Virginia

WAYNE STATE UNIVERSITY, DEPARTMENT OF MATHEMATICS
Detroit, Michigan

WEST CHESTER STATE COLLEGE
West Chester, Pennsylvania

WESTINGHOUSE ELECTRIC CORPORATION, RESEARCH LABORATORIES
Pittsburgh, Pennsylvania

YALE UNIVERSITY, STATISTICS DEPARTMENT
New Haven, Connecticut

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. The 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 1970 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, as an Appendix to *Mathematical Reviews* Index to Volume 39, June 1970. (See, also, *The Notices of the American Mathematical Society*, June 1970, pp. 616–618, for more details.) The key words and phrases should describe the subject matter of the article; generally they should be taken from the body of the paper.

List of Symbols. A completely typewritten list of symbols, identified typographically, not mathematically, should be attached to the manuscript on a separate page. Distinguish between "oh" and "zero"; "ell" and "one"; "kappa" and "kay", etc. Indicate also when special type is required (Greek, German, script, boldface, etc.); other letters will be set in italics.

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 *Mathematical Reviews* Index to Volume 40, 1970, pp. 1683–1702.

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*.)