

THE ANNALS of PROBABILITY

AN OFFICIAL JOURNAL OF THE
INSTITUTE OF MATHEMATICAL STATISTICS

Special Invited Paper

Extremal theory for stochastic processes M. R. LEADBETTER AND HOLGER ROOTZÉN 431

Articles

- Rates of convergence for densities in extreme value theory E. OMEY 479
 Approximate tail probabilities for the maxima of some random fields . . . DAVID SIEGMUND 487
 On the maximum sequence in a critical branching process K. B. ATHREYA 502
 Spreading and predictable sampling in exchangeable sequences and
 processes OLAV KALLENBERG 508
 Maximal length of common words among random letter sequences
 SAMUEL KARLIN AND FRIEDEMANN OST 535
 Killing a Markov process under a stationary measure involves creation R. K. GETOOR 564
 Random time changes for processes with random birth and death H. KASPI 586
 Two-parameter Hunt processes and a potential theory G. MAZZIOTTO 600
 Time reversal on Lévy processes JEAN JACOD AND PHILIP PROTTER 620
 Inequalities for multivariate infinitely divisible processes
 LAWRENCE D. BROWN AND YOSEF RINOTT 642
 Inequalities for multivariate compound Poisson distributions RICHARD S. ELLIS 658
 A mini-max variational formula giving necessary and sufficient conditions for
 recurrence or transience of multidimensional diffusion processes ROSS G. PINSKY 662
 The asymptotic distribution of trimmed sums
 SÁNDOR CSÖRGŐ, ERICH HAEUSLER AND DAVID M. MASON 672
 Central limit theorem for an infinite lattice system of interacting diffusion
 processes JEAN-DOMINIQUE DEUSCHEL 700
 A correlation inequality for the symmetric exclusion process ENRIQUE D. ANDJEL 717
 A zero or one law for one dimensional random walks in random environments
 ENRIQUE D. ANDJEL 722
 Random nonlinear wave equations: Propagation of singularities
 RENÉ CARMONA AND DAVID NUALART 730
 The generators of a Gaussian wave associated with the free Markov field
 WEI-SHIH YANG 752
 A multiple stochastic integral with respect to a strictly p -stable random measure
 WIESŁAW KRAKOWIAK AND JERZY SZULGA 764
 Local time for two-parameter continuous martingales with respect to
 the quadratic variation MARTA SANZ 778
 A nonlinear renewal theory CUN-HUI ZHANG 793
 Conditional boundary crossing probabilities, with applications to change-point
 problems BARRY JAMES, KANG LING JAMES AND DAVID SIEGMUND 825
 A best possible improvement of Wald's equation MICHAEL J. KLASS 840
 Independence of order statistics M. FALK AND R.-D. REISS 854
 Convergence to the semicircle law Z. D. BAI AND Y. Q. YIN 863
 Asymptotic optimality and asymptotic equipartition properties of log-optimum
 investment PAUL H. ALGOET AND THOMAS M. COVER 876
 A sandwich proof of the Shannon-McMillan-Breiman theorem
 PAUL H. ALGOET AND THOMAS M. COVER 899
 The cube of a normal distribution is indeterminate CHRISTIAN BERG 910
 Backward limits HERMANN THORISSON 914

Vol. 16, No. 2—April 1988

INSTITUTE OF MATHEMATICAL STATISTICS

(Organized September 12, 1935)

The purpose of the Institute is to foster the development and dissemination of the theory and applications of statistics and probability.

OFFICERS AND EDITORS

- President:** Bradley Efron, Department of Statistics, Sequoia Hall, Stanford University, Stanford, California 94305
- President-Elect:** Ram Gnanadesikan, Morris Research and Engineering Center, Bell Communications Research, 435 South Street, Morristown, New Jersey 07960-1961
- Past President:** Ronald Pyke, Department of Mathematics GN-50, University of Washington, Seattle, Washington 98195
- Executive Secretary:** Peter Purdue, Department of Operations Research, Code 55, Naval Postgraduate School, Monterey, California 93943
- Treasurer:** Nicholas P. Jewell, Group in Biostatistics, University of California, Berkeley. *Please send correspondence to IMS Business Office, 3401 Investment Boulevard #7, Hayward, California 94545*
- Program Secretary:** Lynne Billard, Department of Statistics, University of Georgia, Athens, Georgia 30602
- Editor, *The Annals of Statistics*:** Willem R. van Zwet, Department of Mathematics, University of Leiden, P.O. Box 9512, 2300 RA Leiden, The Netherlands
- Editor, *The Annals of Probability*:** Peter Ney, Department of Mathematics, Van Vleck Hall, University of Wisconsin, 480 Lincoln Drive, Madison, Wisconsin 53706
- Executive Editor, *Statistical Science*:** Morris H. DeGroot, Department of Statistics, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213
- Editor, *The IMS Bulletin*:** George P. H. Styan, Department of Mathematics and Statistics, Burnside Hall, McGill University, 805 Sherbrooke Street West, Montreal PQ, Canada H3A 2K6
- Editor, *The IMS Lecture Notes—Monograph Series*:** Robert J. Serfling, Department of Mathematical Sciences, Johns Hopkins University, Baltimore, Maryland 21218
- Managing Editor:** Paul Shaman, Department of Statistics, University of Pennsylvania, Philadelphia, Pennsylvania 19104
-

Journals. The scientific journals of the Institute are *The Annals of Statistics*, *The Annals of Probability*, and *Statistical Science*. The news organ of the Institute is *The Institute of Mathematical Statistics Bulletin*.

Individual, Institutional, and Corporate Memberships. All individual members receive *The IMS Bulletin* for a basic annual dues rate of \$30. Each member must elect to receive at least one scientific journal for an additional amount, as follows: *Statistical Science* (\$5), one *Annals* (\$15) or both *Annals* (\$25). Dues allocations to each journal are set by Council resolution. Of the total dues paid, \$12 is allocated to *The IMS Bulletin* and the remaining amount is allocated equally among the scientific journal(s) received. Memberships are available at a reduced rate (40% of regular rates) for full-time students, permanent residents of developing countries, and retired members. Retired members may also elect to receive the *Bulletin* only for \$12. *Institutional memberships* are available to nonprofit organizations at \$255 per year and *corporate memberships* are available to other organizations at \$550 per year. Institutional and corporate memberships include two multiple-readership copies of all IMS journals in addition to other benefits specified for each category (details available from the IMS Business Office).

Individual and General Subscriptions. Subscriptions are available on a calendar-year basis. *Individual subscriptions* are for the personal use of the subscriber and must be in the name of, paid directly by, and mailed to an individual. Individual subscriptions for 1988 are available to both *Annals* and *Statistical Science* (\$96), one *Annals* and *Statistical Science* (\$60), both *Annals* (\$72), one *Annals* (\$45), *Statistical Science* (\$30), and *The IMS Bulletin* (\$20). *General subscriptions* are for libraries, institutions, and any multiple-readership use. For 1988, all general subscriptions to one or both *Annals* automatically include one subscription to *Statistical Science*. General subscriptions for 1988 are available to both *Annals* and *Statistical Science* (\$170), one *Annals* and *Statistical Science* (\$100), *Statistical Science* only (\$45), and *The IMS Bulletin* (\$25). Air mail rates for overseas delivery of general subscriptions are \$40 per title.

Permissions policy. Authorization to photocopy items for internal or personal use, or the internal or personal use of specific clients, is granted by the Institute of Mathematical Statistics, provided that the base fee of \$5.00 per copy, plus \$.00 per page is paid directly to the Copyright Clearance Center, 27 Congress Street, Salem, Massachusetts 01970. For those organizations that have been granted a photocopy license by CCC, a separate system of payment has been arranged. The fee code for users of the Transactional Reporting Service is: 0091-1798/88 \$5.00 + .00.

Correspondence. Mail to IMS should be sent to the IMS Business Office (membership, subscriptions, claims, copyright permissions, advertising, back issues), the Editor of the appropriate journal (submissions, editorial content), or the Managing Editor (production).

***The Annals of Probability* (ISSN 0091-1798),** Volume 16, Number 2, April, 1988. Published in January, April, July and October by the Institute of Mathematical Statistics, 3401 Investment Boulevard #7, Hayward, California 94545. Second-class postage paid at Hayward, California and at additional mailing offices. **Postmaster:** Send address changes to *The Annals of Probability*, Institute of Mathematical Statistics, 3401 Investment Boulevard #7, Hayward, California 94545.

EDITORIAL STAFF

EDITOR

PETER NEY

ASSOCIATE EDITORS

MICHAEL AIZENMAN
ERWIN BOLTHAUSEN
DONALD DAWSON
ALEJANDRO DE ACOSTA
RICHARD DURRETT
K. BRUCE ERICKSON
WENDELL FLEMING
GEOFFREY GRIMMETT

PETER HALL
NARESH C. JAIN
FRANK KELLY
M. R. LEADBETTER
JAMES D. KUELBS
PETER MAJOR
MICHEL MÉTIVIER
CHARLES M. NEWMAN
ESA NUMMELIN

JIM PITMAN
PHILIP PROTTER
TOKUZO SHIGA
DANIEL W. STROOCK
S. R. S. VARADHAN
WIM VERVAAT
RUTH J. WILLIAMS
MICHAEL WOODROOFE

BOOK REVIEWS

THOMAS G. KURTZ

EDITORIAL ASSISTANT

LUANNE L. SCHMIDT

MANAGING EDITOR

PAUL SHAMAN

EDITORIAL ASSISTANT

TAMMY MORROW

PAST EDITORS

THE 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

THE ANNALS OF PROBABILITY

RONALD PYKE, 1972–1975
PATRICK BILLINGSLEY, 1976–1978
R. M. DUDLEY, 1979–1981
HARRY KESTEN, 1982–1984
THOMAS M. LIGGETT, 1985–1987

THE ANNALS OF STATISTICS

INGRAM OLKIN, 1972–1973
I. R. SAVAGE, 1974–1976
RUPERT G. MILLER, JR., 1977–1979
DAVID V. HINKLEY, 1980–1982
MICHAEL D. PERLMAN, 1983–1985

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; formal novelty and mathematical correctness alone are not sufficient. Especially appropriate are authoritative expository papers and surveys of areas in vigorous development. All papers are refereed.

NOTICE

Manuscripts submitted for publication in *The Annals of Probability* should be sent to the Editor at the following address:

Peter Ney
Department of Mathematics
Van Vleck Hall
University of Wisconsin
480 Lincoln Drive
Madison, Wisconsin 53706

IMS CORPORATE MEMBERS

THE AEROSPACE CORPORATION
Los Angeles, California

AT & T BELL LABORATORIES
Murray Hill, New Jersey

BELL COMMUNICATIONS RESEARCH
Morristown, New Jersey

GENERAL MOTORS CORPORATION
Research Laboratories
Warren, Michigan

INTERNATIONAL BUSINESS MACHINES CORP
Thomas J. Watson Research Center
Yorktown Heights, New York

SPRING-VERLAG NEW YORK INCORPORATED
New York, New York

IMS INSTITUTIONAL MEMBERS

ACADEMIA SINICA
Inst of Statistics
Taipei, Taiwan

ARIZONA STATE UNIVERSITY
Dept of Mathematics
Tempe, Arizona

AUSTRALIAN NATIONAL UNIVERSITY
Canberra, ACT, Australia

BOWLING GREEN STATE UNIVERSITY
Dept of Mathematics and Statistics
Bowling Green, Ohio

**CALIFORNIA STATE UNIVERSITY
AT FULLERTON**
Depts of Math and Management Science
Fullerton, California

CASE WESTERN RESERVE UNIVERSITY
Dept of Mathematics and Statistics
Cleveland, Ohio

CENTERS FOR DISEASE CONTROL
Atlanta, Georgia

**CENTRE INTERNATIONAL DE
RECONTRE MATH**
Marseille, France

CORNELL UNIVERSITY
Dept of Mathematics
Ithaca, New York

FLORIDA STATE UNIVERSITY
Dept of Statistics
Tallahassee, Florida

GEORGE WASHINGTON UNIVERSITY
Dept of Statistics
Washington, DC

HARVARD UNIVERSITY
Dept of Statistics
Cambridge, Massachusetts

INDIANA UNIVERSITY
Dept of Mathematics
Bloomington, Indiana

INSTITUTO MEXICANO DEL PETROLEO
Mexico, DF, Mexico

IOWA STATE UNIVERSITY
Dept of Stat and Statistical Lab
Ames, Iowa

JOHNS HOPKINS UNIVERSITY
Dept of Biostatistics
Baltimore, Maryland

KANSAS STATE UNIVERSITY
Dept of Statistics
Manhattan, Kansas

MARA INSTITUTE OF TECHNOLOGY
Selangor, Malaysia

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Dept of Mathematics
Cambridge, Massachusetts

MIAMI UNIVERSITY
Dept of Mathematics and Statistics
Oxford, Ohio

MICHIGAN STATE UNIVERSITY
Dept of Statistics and Probability
East Lansing, Michigan

NATIONAL SECURITY AGENCY
Fort George G. Meade, Maryland

NEW MEXICO STATE UNIVERSITY
Dept of Mathematical Sciences
Las Cruces, New Mexico

NORTH CAROLINA STATE UNIVERSITY
Dept of Statistics
Raleigh, North Carolina

NORTHERN ILLINOIS UNIVERSITY
Dept of Mathematical Sciences
DeKalb, Illinois

OHIO STATE UNIVERSITY
Dept of Statistics
Columbus, Ohio

OREGON STATE UNIVERSITY
Dept of Statistics
Corvallis, Oregon

PENNSYLVANIA STATE UNIVERSITY
Dept of Statistics
University Park, Pennsylvania

PRINCETON UNIVERSITY LIBRARY
Princeton, New Jersey

PURDUE UNIVERSITY LIBRARY
West Lafayette, Indiana

QUEEN'S UNIVERSITY
Dept of Mathematics and Statistics
Kingston, Ontario, Canada

RICE UNIVERSITY
Dept of Mathematical Sciences
Houston, Texas

THE ROCKEFELLER UNIVERSITY LIBRARY
New York, New York

SIMON FRASER UNIVERSITY
Dept of Mathematics and Statistics
Burnaby, British Columbia, Canada

SOUTHERN ILLINOIS UNIVERSITY
Dept of Mathematics and Statistics
Edwardsville, Illinois

SOUTHERN METHODIST UNIVERSITY
Dept of Statistics
Dallas, Texas

STANFORD UNIVERSITY
Dept of Statistics
Stanford, California

TEMPLE UNIVERSITY
Dept of Mathematics
Philadelphia, Pennsylvania

TEXAS TECH UNIVERSITY
Dept of Mathematics
Lubbock, Texas

UNIVERSITY OF ARIZONA
Dept of Mathematics
Tucson, Arizona

UNIVERSITY OF BRITISH COLUMBIA
Dept of Statistics
Vancouver, British Columbia, Canada

UNIVERSITY OF CALGARY
Div of Statistics
Calgary, Alberta, Canada

UNIVERSITY OF CALIFORNIA
Dept of Statistics
Berkeley, California

UNIVERSITY OF CALIFORNIA
Div of Statistics
Davis, California

UNIVERSITY OF FLORIDA
Dept of Statistics
Gainesville, Florida

UNIVERSITY OF GEORGIA
Dept of Statistics
Athens, Georgia

UNIVERSITY OF ILLINOIS
Dept of Statistics
Champaign, Illinois

UNIVERSITY OF ILLINOIS AT CHICAGO
Dept of Math, Stat, and Comp Sci
Chicago, Illinois

UNIVERSITY OF IOWA
Dept of Statistics and Acturial Sci
Iowa City, Iowa

UNIVERSITY OF MANITOBA
Dept of Statistics
Winnipeg, Manitoba, Canada

UNIVERSITY OF MARYLAND
Dept of Mathematics
College Park, Maryland

UNIVERSITY OF MASSACHUSETTS
Dept of Mathematics and Statistics
Amherst, Massachusetts

UNIVERSITY OF MICHIGAN
Dept of Statistics
Ann Arbor, Michigan

UNIVERSITY OF MINNESOTA
School of Statistics
Minneapolis, Minnesota

UNIVERSITY OF MISSOURI AT COLUMBIA
Dept of Statistics
Columbia, Missouri

UNIVERSITY OF MONTREAL
Dept of Mathematics
Montreal, Quebec, Canada

UNIVERSITY OF NEBRASKA
Dept of Mathematics and Statistics
Lincoln, Nebraska

UNIVERSITY OF NEW MEXICO
Dept of Mathematics and Statistics
Albuquerque, New Mexico

UNIVERSITY OF NORTH CAROLINA
Dept of Statistics
Chapel Hill, North Carolina

UNIVERSITY OF OREGON
Dept of Mathematics
Eugene, Oregon

UNIVERSITY OF OTTAWA
Dept of Mathematics
Ottawa, Ontario, Canada

UNIVERSITY OF SOUTH CAROLINA
Dept of Statistics
Columbia, South Carolina

UNIVERSITY OF STOCKHOLM
Inst of Actuarial Math and Math Stat
Stockholm, Sweden

UNIVERSITY OF TEXAS AT AUSTIN
Dept of Mathematics
Austin, Texas

UNIVERSITY OF TEXAS AT SAN ANTONIO
Div of Math, Comp Sci, and Systems Design
San Antonio, Texas

UNIVERSITY OF VICTORIA
Dept of Mathematics
Victoria, British Columbia, Canada

UNIVERSITY OF VIRGINIA
Dept of Mathematics
Charlottesville, Virginia

UNIVERSITY OF WASHINGTON
Depts of Statistics and Mathematics
Seattle, Washington

UNIVERSITY OF WATERLOO
Dept of Statistics and Actuarial Sci
Waterloo, Ontario, Canada

VIRGINIA COMMONWEALTH UNIVERSITY
Dept of Mathematical Sciences
Richmond, Virginia

**VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY**
Dept of Statistics
Blacksburg, Virginia

WAYNE STATE UNIVERSITY
Dept of Mathematics
Detroit, Michigan

YORK UNIVERSITY
Dept of Mathematics
Downsview, Ontario, Canada

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*.) Three copies should be submitted 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. All copies must be completely legible. When technical reports are submitted, all extraneous sheets and covers must be removed. Typists should check an issue of the *Annals* for style.

Submission of Reference Papers. Two copies of unpublished or not easily available papers cited in the manuscript should be submitted with the manuscript.

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.

Abbreviated Title. An abbreviated title to be used as a running head is also required. This should normally not exceed 35 characters. For example, an article with the title "A Limit Theorem for Conditioned Recurrent Random Walk Attracted to a Stable Law" could have 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.

Affiliation. Indicate your present institutional affiliation as you would like it to appear. List your permanent mailing address after the references.

Summary. Each manuscript is required to contain a summary, clearly separated from the rest of the paper, which will be printed immediately after the title. 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. Formulas should be used as sparingly as possible within the summary. The summary should not make reference to results or formulas in the body of the paper—it should be self-contained.

Footnotes. Footnotes should not be used, except as described under Title Page Footnotes below. Such information should be included within the text.

Title Page Footnotes. Included as a 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.

Acknowledgment of support. Grants and contracts should also be included in this footnote.

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"; "summation" and "capital sigma," etc. Indicate also when special type is required (Greek, German, script, boldface, etc.); unless indicated otherwise, formula letters will be set in italics. Acronyms should be introduced sparingly. Any handwritten symbols should be clearly identified.

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.) The printer does not improve upon the quality of the figures submitted. 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^{b^c} and a_{b^c} , 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:

Révész, P. (1982). On the increments of Wiener and related processes. *Ann. Probab.* **10** 613–622.

In textual material, the format "... Révész (1982)..." should be used. Multiple references can be distinguished as "... Révész (1982a)..." Abbreviations for journals should be taken from a current index issue of *Mathematical Reviews*.

Galley Proofs. The author will ordinarily receive galley proofs. Corrected galley proofs should be sent to: AOP Redactory, Science Typographers, Inc., 15 Industrial Boulevard, Medford, NY 11763.