

QUARTERLY
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SPECIAL ISSUE
CURRENT AND FUTURE CHALLENGES
IN THE APPLICATIONS OF MATHEMATICS

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QUARTERLY OF APPLIED MATHEMATICS

The QUARTERLY prints original papers in applied mathematics which have an intimate connection with applications. It is expected that each paper will be of a high scientific standard; that the presentation will be of such character that the paper can be easily read by those to whom it would be of interest; and that the mathematical argument, judged by the standard of the field of application, will be of an advanced character.

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In accordance with their general policy, the Editors welcome particularly contributions which will be of interest both to mathematicians and to scientists or engineers. Authors will receive galley proof only. The author's institution will be requested to pay a publication charge of \$30 per page which, if honored, entitles the author to 100 free reprints. Detailed instructions will be sent with galley proofs.

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SPECIAL ISSUE
CURRENT AND FUTURE CHALLENGES
IN THE APPLICATIONS OF MATHEMATICS



William Prager

Founder and first Chairman, Division of Applied Mathematics
Founding Editor, Quarterly of Applied Mathematics

Preface

The Division of Applied Mathematics at Brown University celebrated last year its 50th Anniversary. A birthday is a time for reflection, assessments and planning for the future, for individuals as well as for institutions. In the Division's case, this was done in the form of a Symposium "Current and Future Challenges in the Applications of Mathematics", in which distinguished scientists communicated their scientific work as well as their views on different areas of Applied Mathematics.

We are fortunate to be able to reproduce here the texts of most of the talks given and believe that the papers in this volume contain not only the authors' scientific contributions but also indications of the future of Applied Mathematics.

We wish to express our thanks to the speakers, the organizers and the sponsors who made the Symposium possible.

David Gottlieb, Chairman
Division of Applied Mathematics
Brown University

Editorial Note

Because of the long and intimate association of the Quarterly with the Division of Applied Mathematics, it was again deemed appropriate—as it was at the 25th Anniversary—to devote an issue to the invited papers presented at the Symposium. We are grateful to the staff of the American Mathematical Society for the skill and dedication they brought to this particularly challenging production task. The papers are printed in the order in which they were delivered. Manuscripts were received from all speakers except, unfortunately, from Drs. Azencott, Lions, and Shor.

Many persons and organizations contributed to the success of the Symposium. We should like to thank former President Vartan Gregorian, who provided the necessary seed money with a grant from his contingency fund; Hirsh Cohen ('48 AM, '50 Ph.D.), who, as its Vice President, enabled us to obtain a major grant from the Alfred P. Sloan Foundation; George M. C. Fisher ('64 ScM, '66 Ph.D.), C.E.O. of Kodak, and his wife Ann for a generous contribution; and the program officers of the Office of Naval Research, the Army Research Office, and the Air Force Office of Scientific Research (Drs. André van Tilborg, Robert Launer, and Charles J. Holland '72 Ph.D., respectively) for grants in support.

The staff of the Division, particularly Janice D'Amico as Secretary of the Symposium, were unfailingly helpful and bore up patiently under the many unusual demands made on them.

Last but not least I should like to thank my wife Christine for her constant advice, encouragement and partnership in the preparation of the Symposium.

Walter Freiberger
Managing Editor

Symposium Committee

Constantine Dafermos
Walter Freiberger (Chairman)
David Mumford

An International Symposium on Current and Future Challenges in Applied Mathematics

to mark the 50th Anniversary of the Division of Applied Mathematics

Session I: Thursday, May 29th, 9 a.m.

Introductions: Walter Freiberger, Professor of Applied Mathematics

Welcome on behalf of the Division of Applied Mathematics: Philip Davis, Professor Emeritus of Applied Mathematics

Welcome on behalf of the University: James Pomerantz, Professor of Cognitive and Linguistic Science and Provost of the University;

Welcome on behalf of the Alfred P. Sloan Foundation: Hirsh Cohen, Ph.D. '50 (Applied Mathematics), Vice-President, Alfred P. Sloan Foundation

Session Chairman: Donald Marsh, Frank L. Day Professor of Biology, Professor of Medical Science and Dean of Biological and Medical Sciences

1. Peter Lax, Professor of Mathematics, Courant Institute, New York University
The beginnings of Applied Mathematics after the Second World War
2. Ulf Grenander, L. Herbert Ballou University Professor Emeritus and Professor Emeritus of Applied Mathematics; and Michael Miller, Professor and Director, Center for Imaging Science, Washington University, St. Louis
Computational anatomy: An emerging discipline

Session II: Thursday, May 29th, 1:30 p.m.

Session Chairman: Leon Cooper, J. Thomas Watson, Sr. Professor of Science, Professor of Physics, and Director, Institute for Brain and Neural Systems; Nobel Laureate

3. Stephen A. Ross, Franco Modigliani Professor of Finance and Economics, Sloan School, Massachusetts Institute of Technology
The mathematics of finance: Pricing derivatives
4. Peter Shor, Member, Technical Staff, AT&T Bell Laboratories
Quantum computing
5. Nancy Kopell, Professor of Mathematics, Boston University
Networks of neurons as dynamical systems: from biophysics to geometry

Symposium Dinner: Sayles Hall 6:30 p.m.

Reminiscences of the early days of the Division

Moderator: Herbert Greenberg, Ph.D. '46 (Applied Mathematics)
Dean of Mathematical Sciences, Emeritus, University of Denver

Session III: Friday, May 30th, 8:30 a.m.

Session Chairman: Wendell Fleming, University Professor Emeritus, Professor Emeritus of Mathematics and Applied Mathematics

6. Robert Azencott, Professor and Director, Mathematics Department, École Normale Supérieure de Cachan
Neural networks and complexity theory: the impact of stochastic models for learning tasks
7. John Ball, F.R.S., Professor of Mathematics, Oxford University
The calculus of variations and materials science
8. James Glimm, Professor of Applied Mathematics, State University of New York, Stony Brook, and David Sharp, Los Alamos National Laboratory
Stochastic methods for the prediction of complex multiscale phenomena

Session IV: Friday, May 30th, 1:30 p.m.

Session Chairman: George Carrier, T. Jefferson Coolidge Professor of Applied Mathematics, Emeritus, Harvard University

9. Pierre-Louis Lions, Professor of Mathematics, University of Paris:
On compressible Euler and Navier-Stokes equations
10. Alexandre Chorin, Professor of Mathematics, University of California, Berkeley
New perspectives in turbulence
11. J. Trevor Stuart, F.R.S., Professor of Theoretical Fluid Mechanics, Imperial College of Science, Technology and Medicine, London
Mathematics applied in fluid motion

Session V: Saturday, May 31st, 9 a.m.

Session Chairman: David Mumford, University Professor and Professor of Applied Mathematics, Brown University

12. Persi Diaconis, George Vasmer Leverett Professor of Mathematics, Harvard University
A place for philosophy? The rise of modeling in statistical science
13. Professor Sir Michael Atiyah, O.M., F.R.S., Master, Trinity College, Cambridge; Immediate Past President, Royal Society
Mathematics and the real world

Note: President Vartan Gregorian will confer the degree of Doctor of Science, Honoris Causa, on Sir Michael Atiyah before Sir Michael's lecture.



Some of the participants (see page 817)



Some of the "Golden Agers" (see page 817)



President Vartan Gregorian, Sir Michael Atiyah,
and Chancellor Artemis W. Joukowsky



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SUGGESTIONS CONCERNING THE PREPARATION OF MANUSCRIPTS FOR THE QUARTERLY OF APPLIED MATHEMATICS

The editors will appreciate the authors' cooperation in taking note of the following directions for the preparation of manuscripts. These directions have been drawn up with a view toward eliminating unnecessary correspondence, avoiding the return of papers for changes, and reducing the charges made for "author's corrections."

Manuscripts: Manuscripts should be typewritten double-spaced on one side only. Marginal instructions to the typesetter should be written in pencil to distinguish them clearly from the body of the text. The author should keep a complete copy.

The papers should be submitted in final form. Only typographical errors should be corrected in proof; composition charges for any major deviations from the manuscript will be passed on to the author.

Titles: The title should be brief but express adequately the subject of the paper. The name and initials of the author should be written as he/she prefers; all titles and degrees or honors will be omitted. The name of the organization with which the author is associated should be given in a separate line following his/her name.

Mathematical Work: As far as possible, formulas should be typewritten; Greek letters and other symbols not available on the average typewriter should be inserted using either instant lettering or by careful insertion in ink. Manuscripts containing pencilled material other than marginal instructions to the typesetter will not be accepted.

The difference between capital and lower-case letters should be clearly shown; care should be taken to avoid confusion between zero (0) and the letter O, between the numeral one (1), the letter l and the prime ('), between alpha and a, kappa and k, mu and u, nu and v, eta and n.

The level of subscripts, exponents, subscripts to subscripts, and exponents to exponents should be clearly indicated.

Single embellishments over individual letters are allowed; the only embellishment allowed above groups of letters is the overbar.

Double embellishments are not allowed. These may be replaced by superscripts following the symbols.

Complicated exponents and subscripts should be avoided. Any complicated expression that recurs frequently should be represented by a special symbol.

For exponentials with lengthy or complicated exponents the symbol exp should be used, particularly if such exponentials appear in the body of the text. Thus,

$$\exp[(a^2 + b^2)^{1/2}] \text{ is preferable to } e^{[a^2 + b^2]^{1/2}}.$$

Fractions in the body of the text and fractions occurring in the numerators or denominators of fractions should be written with the solidus. Thus,

$$\frac{\cos(x/2b)}{\cos(a/2b)} \text{ is preferable to } \frac{\cos \frac{x}{2b}}{\cos \frac{a}{2b}}.$$

In many instances the use of negative exponents permits saving of space. Thus,

$$\int u^{-1} \sin u \, du \text{ is preferable to } \int \frac{\sin u}{u} \, du.$$

Whereas the intended grouping of symbols in handwritten formulas can be made clear by slight variations in spacing, this procedure is not acceptable in typeset formulas. To avoid misunderstanding, the order of symbols should therefore be carefully considered. Thus,

$$(a + bx) \cos t \text{ is preferable to } \cos t(a + bx).$$

Figures: Figures should be drawn in black ink with clean, unbroken lines; do not use ball point pen. The paper should be of a nonabsorbant quality so that the ink does not spread and produce fuzzy lines. If the figures are intended for reduction, they should be drawn with heavy enough lines so that they do not become flimsy at the desired reduction. The notation should be of professional quality and in proportion for the expected reduction size. Figures that are unsuitable for reproduction will be returned to the author for redrawing. Legends accompanying figures should be written on a separate sheet.

Bibliography: References should be grouped together in a Bibliography at the end of the manuscript. References in text to the Bibliography should be made by numerals between square brackets.

The following examples show the desired arrangements: (for books S. Timoshenko, *Strength of Materials*, vol. 2, Macmillan and Co., London, 1931, p. 237; for periodicals Lord Rayleigh, *On the flow of viscous liquids, especially in three dimensions*, Phil. Mag. (5) 36, 354-372 (1893)). Note that the number of the series is not separated by commas from the name of the periodical or the number of the volume.

Authors' initials should precede their names rather than follow them.

In quoted titles of books or papers, capital letters should be used only where the language requires this. Thus, *On the flow of viscous fluids* is preferable to *On the Flow of Viscous Fluids*, but the corresponding German title would have to be rendered as *Über die Stromung zaher Flüssigkeiten*.

Titles of books or papers should be quoted in the original language (with an English translation added in parentheses, if this seems desirable), but only English abbreviations should be used for bibliographical details such as ed., vol., no., chap., p.

Footnotes: As far as possible, footnotes should be avoided. Footnotes containing mathematical formulas are not acceptable.

Abbreviations: Much space can be saved by the use of standard abbreviations such as Eq., Eqs., Fig., Sec., Art., etc. These should be used, however, only if they are followed by a reference number. Thus, "Eq. (25)" is acceptable but not "the preceding Eq." Moreover, if any one of these terms occurs as the first word of a sentence, it should be spelled out.

Special abbreviations should be avoided. Thus "boundary conditions" should always be spelled out and not be abbreviated as "b.c." even if this special abbreviation is defined somewhere in the text.

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