

# $L^2$ -MULTIVARIATE APPROXIMATION THEORY\*

MARTIN H. SCHULTZ†

**1. Introduction.** This paper is concerned with multivariate analogues of many standard results in the  $L^2$ -approximation theory of real-valued functions of a real variable, cf. [2], [3], [7], [11] and [15]. In this paper, whenever we speak of a function, we shall always mean a real-valued function. Theorems 2.1 and 2.2 of § 2 enable us to deduce results about multivariate approximation in rectangular parallelepipeds from corresponding single variable results. In § 3 and § 4, we state and prove asymptotic bounds for the distance, in  $L^2$  and various Sobolev type spaces, of a given smooth multivariate function from various finite-dimensional subspaces, i.e., if  $B$  is a real Banach space,  $f \in B$ , and  $C$  is a chosen set of finite-dimensional subspaces,  $S$ , of  $B$ , then we give upper bounds for the quantities  $E(f, S, B) \equiv \inf_{y \in S} \|f - y\|_B$  for all  $S \in C$ . Subspaces consisting of multivariate trigonometric polynomials, multivariate algebraic polynomials, or multivariate  $L$ -splines, are studied in detail.

In § 5, we apply the results of § 3 and § 4 to the study of “ $h$ -asymptotically optimal approximation schemes” in Sobolev spaces. These schemes include the Ritz method for approximating the solution of the Neumann problem for the Poisson equation for sufficiently smooth domains in  $R^N$ , cf. [9].

We end this section by recalling some multivariate notation which will be used throughout this paper, cf. [18]. For any  $x \equiv (x_1, \dots, x_N) \in R^N$ ,  $|x| \equiv (x_1^2 + \dots + x_N^2)^{1/2}$ . If  $\alpha \equiv (\alpha_1, \dots, \alpha_N)$  is an  $N$ -tuple with nonnegative integer components, then

$$D^\alpha \equiv D_1^{\alpha_1} \cdots D_N^{\alpha_N} \equiv \frac{\partial^{\alpha_1}}{\partial x_1^{\alpha_1}} \cdots \frac{\partial^{\alpha_N}}{\partial x_N^{\alpha_N}}$$

and  $|\alpha| \equiv \alpha_1 + \dots + \alpha_N$ . If  $\Omega \subset R^N$  is a bounded measurable set,  $m$  a nonnegative integer, and  $1 < p < \infty$ ,  $W^{m,p}(\Omega)$  denotes the space of  $L^p(\Omega)$  functions which have weak derivatives of order up to  $m$  in  $L^p(\Omega)$ ,

$$\|f\|_{W^{m,p}(\Omega)} \equiv \left( \sum_{|\alpha| \leq m} \|D^\alpha f\|_{L^p(\Omega)}^p \right)^{1/p}$$

for all  $f \in W^{m,p}(\Omega)$ , and  $W_0^{m,p}(\Omega)$  denotes the closure of  $C_0^\infty(\Omega)$  with respect to the Sobolev norm  $\|\cdot\|_{W^{m,p}(\Omega)}$ .

If  $-\infty < a < b < \infty$  and  $t$  is any positive integer,  $K^t(a, b)$  is the set of all functions  $f \in C^{t-1}[a, b]$  such that  $D^{t-1}f$  is absolutely continuous and  $D^t f \in L^2(a, b)$ . If  $-\infty < a_i < b_i < \infty$  for  $1 \leq i \leq N$ ,  $H \equiv \prod_{i=1}^N [a_i, b_i]$ , and  $t$  is any positive integer,  $K^t(H)$  is the set of all functions  $f \in C^{t-1}(H)$ , such that  $D_i^{t-1}f$  is absolutely continuous for  $1 \leq i \leq N$  and  $D_i^t f \in L^2(H)$  for  $1 \leq i \leq N$ ,  $K_n^t(H)$

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# Multivariate Approximation Theory 2

**E. W. Cheney**



## **Multivariate Approximation Theory 2:**

Multivariate Approximation Theory II Schempp,Zeller,2012-12-06 The Third International Symposium on Multivariate Approximation Theory was held at the Oberwolfach Mathematical Research Institute Black Forest February 8-12 1982 The preceding conferences on this topic were held in 1976 and 1979 The conference brought together 50 mathematicians from 14 countries These Proceedings form a record of most of the papers presented at the Symposium The topics treated cover different problems on multivariate approximation theory such as new results concerning approximation by polynomials in Sobolev spaces biorthogonal systems and orthogonal series of functions in several variables multivariate spline functions group theoretic and functional analytic methods positive linear operators error estimates for approximation procedures and cubature formulae Boolean methods in multivariate interpolation and the numerical application of summation procedures Special emphasis was posed on the application of multivariate approximation in various fields of science One mathematician was sorely missed at the Symposium Professor Arthur Sard who had actively taken part in the earlier conferences passed away in August of 1980 Since he was a friend of many of the participants the editors wish to dedicate these Proceedings to the memory of this distinguished mathematician A brief appreciation of his life and mathematical work appears as well

Constructive Theory of Functions of Several Variables Edited by W. Schempp and Karl Zeller Lecture Notes in Mathematics Vol. 1111 *Multivariate Approximation Theory IV* CHUI,SCHEMP,ZELLER,2013-03-08 Multivariate Approximation Theory forms a rapidly evolving field in Applied Mathematics The reason for its particular current interest lies in its impact on Computer Aided Geometric Design CAGD Image Processing Pattern Recognition and Multidimensional Signal Processing Multivariate Bernstein polynomials and box splines for example play an important role in CAGD Conversely the highly important filter bank design problem of signal processing for instance gives rise to a new family of multivariate approximating functions the Gabor wavelets with interesting technological and biological applications The conferences on Multivariate Approximation Theory held at the Mathematical Research Institute at Oberwolfach Black Forest in 1976 1979 1982 1985 and 1989 reflect the progress made in this area and related fields The present volume which is a continuation of the preceding volumes Constructive Theory of Functions of Several Variables Lecture Notes in Mathematics 571 1977 Multivariate Approximation Theory ISNM 51 1979 Multivariate Approximation Theory II ISNM 61 1982 Multivariate Approximation Theory III ISNM 75 1985 is based on the conference held on February 12-18 1989 It includes most of the lectures presented at the Oberwolfach meeting and reveals the wide spectrum of activities in the field of multivariate approximation The organizers are grateful to the Director of the Oberwolfach Mathematical Research Institute Professor Dr M. Barner and his staff for providing the facilities and to Dr G. Baszenski Professor Dr F. J. Delvos Dr H. G. Gruber Dr J. J. M. van der Veken

**Multivariate Approximation Theory II : Proceedings of the Conference Held at the Mathematical Research Institute at Oberwolfach** Walter Schempp,1982 *Multivariate Approximation Theory* E. W. Cheney,1986-10-01 This monograph deals with the development of algorithms or the derivation

of approximations from linear projections      **Multivariate Approximation Theory III** SCHEMPP,ZELLER,2013-03-07 The Fourth International Symposium on Multivariate Approximation Theory was held at the Oberwolfach Mathematical Research Institute Black Forest W Germany during the week of January 20 26 1985 The preceding conferences on this topic were held in 1976 1979 and 1982 We were pleased to have more than 50 mathematicians from 13 countries in attendance The program included 40 lectures These Proceedings form a record of most of the papers presented at the Symposium The topics treated cover different problems on multivariate approximation such as polynomial approximation on simplices multivariate splines box splines dimension of spline spaces blending methods multivariate Hermite interpolation data smoothing and surface representation and multivariate summation methods We would like to thank the director of the Oberwolfach Mathematical Research Institute Prof Dr M Barner and his staff for providing the facilities Of the people who gave their time to help make this conference a success we would like to mention in particular Prof Dr F J Delvos Siegen Dr G Baszenski College Station Texas and Dipl Math H Nienhaus Siegen Finally our thanks are due to Carl Einsele of Birkhauser Publishers for his valuable cooperation      Acta Numerica 1993: Volume 2 Arie Iserles,1993-04-30 Continuing the tradition established with the 1992 volume this 1993 s Acta Numerica presents six invited papers on a broad range of topics from numerical analysis Papers treat each topic at a level intelligible by any numerical analyst from graduate student to professional      **Handbook of Splines** Gheorghe Micula,Sanda Micula,2012-12-06 The purpose of this book is to give a comprehensive introduction to the theory of spline functions together with some applications to various fields emphasizing the significance of the relationship between the general theory and its applications At the same time the goal of the book is also to provide new material on spline function theory as well as a fresh look at old results being written for people interested in research as well as for those who are interested in applications The theory of spline functions and their applications is a relatively recent field of applied mathematics In the last 50 years spline function theory has undergone a wonderful development with many new directions appearing during this time This book has its origins in the wish to adequately describe this development from the notion of spline introduced by I J Schoenberg 1901 1990 in 1946 to the newest recent theories of spline wavelets or spline fractals Isolated facts about the functions now called splines can be found in the papers of L Euler A Lebesgue G Birkhoff J

**Topics in Multivariate Approximation** C. K. Chui,L. L. Schumaker,F.I. Utreras,2014-05-10 Topics in Multivariate Approximation contains the proceedings of an international workshop on multivariate approximation held at the University of Chile in Santiago Chile on December 15 19 1986 Leading researchers in the field discussed several problem areas related to multivariate approximation and tackled topics ranging from multivariate splines and fitting of scattered data to tensor approximation methods and multivariate polynomial approximation Numerical grid generation and finite element methods were also explored along with constrained interpolation and smoothing Comprised of 22 chapters this book first describes the application of Boolean methods of approximation in combination with the theory of right invertible operators to bivariate

Fourier expansions The reader is then introduced to ill posed problems in multivariate approximation interpolation of scattered data by radial functions and shape preserving surface interpolation Subsequent chapters focus on approximation by harmonic functions numerical generation of nested series of general triangular grids triangulation methods and inequalities arising from best local approximations in rectangles A bibliography of multivariate approximation concludes the book This monograph will be of interest to mathematicians

**Computational Geometry - Proceedings Of The Workshop** A Conte, F Fontanella, I Galligani, V Demichelis, 1993-08-31 This volume focuses on the more recent results in computational geometry such as algorithms for computer pictures of algebraic surfaces the dimensionality paradigm and medial axis transform in geometric and solid modeling stationary and non stationary subdivision schemes for the generation of curves and surfaces minimum norm networks in CAGD knot removal and constrained knot removal for spline curves blossoming in CAGD triangulation methods geometric modeling

**Computation of Curves and Surfaces** Wolfgang Dahmen, Mariano Gasca, Charles A. Micchelli, 2012-12-06 Assembled here is a collection of articles presented at a NATO ADVANCED STUDY INSTITUTE held at Puerto de la Cruz Tenerife Spain during the period of July 10th to 21st 1989 In addition to the editors of these proceedings Professor Larry L Schumaker from Vanderbilt University Nashville Tennessee served as a member of the international organizing committee The contents of the contributions fall within the heading of COMPUTATION OF CURVES AND SURFACES and therefore address mathematical and computational issues pertaining to the display modeling interrogation and representation of complex geometrical objects in various scientific and technical environments As is the intent of the NATO ASI program the meeting was two weeks in length and the body of the scientific activities was organized around prominent experts Each of them presented lectures on his current research activity We were fortunate to have sixteen distinguished invited speakers representing nine NATO countries W Bohm Federal Republic of Germany C de Boor USA C K Chui USA W Dahmen Federal Republic of Germany F Fontanella Italy M Gasca Spain R Goldman Canada T N T Goodman UK J A Gregory UK C Hoffman USA J Hoschek Federal Republic of Germany A Le Mehaute France T Lyche Norway C A Micchelli USA L L Schumaker USA C Traas The Netherlands The audience consisted of both young researchers as well as established scientists from twelve NATO countries and several non NATO countries

*Topics in Numerical Analysis* P.R. Turner, 2006-11-15

**Proceedings of the Second International Colloquium on Numerical Analysis** D. Bainov, V. Covachev, 2020-05-18 No detailed description available for Proceedings of the Second International Colloquium on Numerical Analysis

**Encyclopaedia of Mathematics** M. Hazewinkel, 2013-12-01

[Encyclopaedia of Mathematics](#) Michiel Hazewinkel, 2012-12-06 This ENCYCLOPAEDIA OF MATHEMATICS aims to be a reference work for all parts of mathematics It is a translation with updates and editorial comments of the Soviet Mathematical Encyclopaedia published by Soviet Encyclopaedia Publishing House in five volumes in 1977 1985 The annotated translation consists of ten volumes including a special index volume There are three kinds of articles in this ENCYCLOPAEDIA First of all there are survey type articles

dealing with the various main directions in mathematics where a rather fine subdivision has been used. The main requirement for these articles has been that they should give a reasonably complete up to date account of the current state of affairs in these areas and that they should be maximally accessible. On the whole these articles should be understandable to mathematics students in their first specialization years to graduates from other mathematical areas and depending on the specific subject to specialists in other domains of science, engineers and teachers of mathematics. These articles treat their material at a fairly general level and aim to give an idea of the kind of problems, techniques and concepts involved in the area in question. They also contain background and motivation rather than precise statements of precise theorems with detailed definitions and technical details on how to carry out proofs and constructions.

***Geometric Modeling*** Hans Hagen, Dieter Roller, 2012-12-06 This book is based on lectures presented at an international workshop on geometric modeling held at Hewlett Packard GmbH in Boblingen FRG in June 1990. International experts from academia and industry were selected to speak on the most interesting topics in geometric modeling. The resulting papers published in this volume give a state of the art survey of the relevant problems and issues. The following topics are discussed: Methods for constructing surfaces on surfaces, four different solutions to the multidimensional problem of constructing an interpolant from surface data are provided. Surfaces in solid modeling: current results on the implementation of free form solids in three well established solid models are reviewed. Box splines and applications: an introduction to box spline methods for the representation of surfaces is given. Basic properties of box splines are derived and refinement and evaluation methods for box splines are presented in detail. Shape preserving properties: the construction of non rectangular box spline surfaces, applications to surface modeling and imbedding problems are discussed. Advanced computer graphics techniques for volume visualization: the steps to be executed in the visualization process of volume data are described and tools are discussed that assist in handling this data. Rational B splines: an introduction to the representation of curves and surfaces using rational B splines is given together with a critical evaluation of their potential for industrial application.

***Advances in Multivariate Approximation*** Werner Haußmann, Kurt Jetter, Manfred Reimer, 1999-11-12 This volume deals with main results of the 3rd International Conference on Multivariate Approximation organized by the University of Dortmund. Special emphasis is put on the following topics: Interpolation and approximation on spheres and balls, approximation by solutions of differential equations, construction of node systems, scattered data techniques.

***Mathematical Methods for Curves and Surfaces II*** Morten Dæhlen, Tom Lyche, Larry L. Schumaker, 1998 Contains more than fifty carefully refereed and edited full length papers on the theory and applications of mathematical methods arising out of the Fourth International Conference on Mathematical Methods in Computer Aided Geometric Design held in Lillehammer Norway in July 1997.

***Topics in Multivariate Approximation and Interpolation*** Kurt Jetter, Martin Buhmann, Werner Haussmann, Robert Schaback, Joachim Stoeckler, 2005-11-15 This book is a collection of eleven articles written by leading experts and dealing with special topics in Multivariate Approximation and

Interpolation The material discussed here has far reaching applications in many areas of Applied Mathematics such as in Computer Aided Geometric Design in Mathematical Modelling in Signal and Image Processing and in Machine Learning to mention a few The book aims at giving a comprehensive information leading the reader from the fundamental notions and results of each field to the forefront of research It is an ideal and up to date introduction for graduate students specializing in these topics and for researchers in universities and in industry A collection of articles of highest scientific standard An excellent introduction and overview of recent topics from multivariate approximation A valuable source of references for specialists in the field A representation of the state of the art in selected areas of multivariate approximation A rigorous mathematical introduction to special topics of interdisciplinary research

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Multivariate Approximation and Applications N. Dyn, 2001-05-17 Approximation theory in the multivariate setting has many applications including numerical analysis wavelet analysis signal processing geographic information systems computer aided geometric design and computer graphics This advanced introduction to multivariate approximation and related topics consists of nine articles written by leading experts surveying many of the new ideas and their applications Each article takes the reader to the forefront of research and ends with a comprehensive bibliography

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## **Table of Contents Multivariate Approximation Theory 2**

1. Understanding the eBook Multivariate Approximation Theory 2
  - The Rise of Digital Reading Multivariate Approximation Theory 2
  - Advantages of eBooks Over Traditional Books
2. Identifying Multivariate Approximation Theory 2
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Multivariate Approximation Theory 2
  - User-Friendly Interface
4. Exploring eBook Recommendations from Multivariate Approximation Theory 2
  - Personalized Recommendations
  - Multivariate Approximation Theory 2 User Reviews and Ratings
  - Multivariate Approximation Theory 2 and Bestseller Lists
5. Accessing Multivariate Approximation Theory 2 Free and Paid eBooks
  - Multivariate Approximation Theory 2 Public Domain eBooks
  - Multivariate Approximation Theory 2 eBook Subscription Services
  - Multivariate Approximation Theory 2 Budget-Friendly Options



6. Navigating Multivariate Approximation Theory 2 eBook Formats
  - ePub, PDF, MOBI, and More
  - Multivariate Approximation Theory 2 Compatibility with Devices
  - Multivariate Approximation Theory 2 Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Multivariate Approximation Theory 2
  - Highlighting and Note-Taking Multivariate Approximation Theory 2
  - Interactive Elements Multivariate Approximation Theory 2
8. Staying Engaged with Multivariate Approximation Theory 2
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Multivariate Approximation Theory 2
9. Balancing eBooks and Physical Books Multivariate Approximation Theory 2
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Multivariate Approximation Theory 2
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Multivariate Approximation Theory 2
  - Setting Reading Goals Multivariate Approximation Theory 2
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Multivariate Approximation Theory 2
  - Fact-Checking eBook Content of Multivariate Approximation Theory 2
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements

- Interactive and Gamified eBooks

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