

Numerical Solution of PDEs

3.1 SOME PDE BASICS

Our physical world is most generally described in scientific and engineering terms with respect to three-dimensional space and time, which is commonly referred to as *space-time*. An *evolution* equation is a *partial differential equation* (PDE) that describes mathematically the evolution over space and time of a physical system or process. PDEs are therefore among the most widely used forms of mathematics in many disciplines. As a consequence, methods for the solution of PDEs, such as the method of lines (MOL) [Sch-91], are of broad interest in science and engineering. Our main focus will be on MOL.

As a basic illustrative example of a PDE, we consider

$$\frac{\partial u}{\partial t} = D \frac{\partial^2 u}{\partial x^2}, \quad (3.1)$$

where

- u is a dependent variable (dependent on x and t)
- t is an independent variable representing time
- x is an independent variable representing one dimension of three-dimensional space
- D real positive constant, explained later.

Note that eqn. (3.1) has two independent variables, x and t , which is the reason it is classified as a PDE (any differential equation with *more than one independent variable is a PDE*). A differential equation with only one independent variable is generally termed an *ordinary differential equation* (ODE); we will consider ODEs later as part of the MOL.

Equation (3.1) is termed the *diffusion equation* or *heat equation*. When applied to heat transfer, it is *Fourier's second law*; the dependent variable u is temperature and D is the *thermal diffusivity*. When eqn. (3.1) is applied to mass diffusion, it is *Fick's second law*; u is mass concentration and D is the *coefficient of diffusion* or the *diffusivity*.

The symbol $\frac{\partial u}{\partial t}$ is a partial derivative of u with respect to t (x is held constant when taking the derivative, which is why *partial* is used to describe this derivative). Equation (3.1) is *first order in t* because the highest order partial derivative in t is first order; it is *second order in x* because the highest order derivative in x is second order. Equation (3.1)

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Peter Deufilhard, Martin Weiser



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Adaptive Numerical Solution of PDEs Peter Deuflhard, Martin Weiser, 2012-08-31 This book deals with the general topic Numerical solution of partial differential equations PDEs with a focus on adaptivity of discretizations in space and time By and large introductory textbooks like Numerical Analysis in Modern Scientific Computing by Deuflhard and Hohmann should suffice as a prerequisite The emphasis lies on elliptic and parabolic systems Hyperbolic conservation laws are treated only on an elementary level excluding turbulence Numerical Analysis is clearly understood as part of Scientific Computing The focus is on the efficiency of algorithms i.e. speed reliability and robustness which directly leads to the concept of adaptivity in algorithms The theoretical derivation and analysis is kept as elementary as possible Nevertheless required somewhat more sophisticated mathematical theory is summarized in comprehensive form in an appendix Complex relations are explained by numerous figures and illustrating examples Non trivial problems from regenerative energy nanotechnology surgery and physiology are inserted The text will appeal to graduate students and researchers on the job in mathematics science and technology Conceptually it has been written as a textbook including exercises and a software list but at the same time it should be well suited for self study

Modeling, Mesh Generation, and Adaptive Numerical Methods for Partial Differential Equations Ivo Babuska, Joseph E. Flaherty, William D. Henshaw, John E. Hopcroft, Joseph E.

Olinger, Tayfun Tezduyar, 2012-12-06 With considerations such as complex dimensional geometries and nonlinearity the computational solution of partial differential systems has become so involved that it is important to automate decisions that have been normally left to the individual This book covers such decisions 1 mesh generation with links to the software generating the domain geometry 2 solution accuracy and reliability with mesh selection linked to solution generation This book is suited for mathematicians computer scientists and engineers and is intended to encourage interdisciplinary interaction between the diverse groups

Modeling, Mesh Generation, and Adaptive Numerical Methods for Partial Differential Equations Ivo Babuska, Joseph E. Flaherty, William D. Henshaw, 1995-07-14 [Adaptive Method of Lines](#) A. Vande Wouwer, Ph. Saucez, W.E. Schiesser, 2001-04-18 The general Method of Lines MOL procedure provides a flexible format for the solution of all the major classes of partial differential equations PDEs and is particularly well suited to evolutionary nonlinear wave PDEs Despite its utility however there are relatively few texts that explore it at a more advanced level and reflect the method s

Numerical Solution of PDEs Using Adaptive Finite Difference Methods Yiqi Qiu, 1997

Adaptive Multilevel Solution of Nonlinear Parabolic PDE Systems Jens Lang, 2013-06-29 Nowadays there is an increasing emphasis on all aspects of adaptively generating a grid that evolves with the solution of a PDE Another challenge is to develop efficient higher order one step integration methods which can handle very stiff equations and which allow us to accommodate a spatial grid in each time step without any specific difficulties In this monograph a combination of both error controlled grid refinement and one step methods of Rosenbrock type is presented It is my intention to impart the beauty and

complexity found in the theoretical investigation of the adaptive algorithm proposed here in its realization and in solving non trivial complex problems I hope that this method will find many more interesting applications Berlin Dahlem May 2000 Jens Lang Acknowledgements I have looked forward to writing this section since it is a pleasure for me to thank all friends who made this work possible and provided valuable input I would like to express my gratitude to Peter Deuflhard for giving me the opportunity to work in the field of Scientific Computing I have benefited immensely from his help to get the right perspectives and from his continuous encouragement and support over several years He certainly will forgive me the use of Rosenbrock methods rather than extrapolation methods to integrate in time Handbook of Grid Generation Joe F. Thompson, Bharat K. Soni, Nigel P. Weatherill, 1998-12-29 Handbook of Grid Generation addresses the use of grids meshes in the numerical solutions of partial differential equations by finite elements finite volume finite differences and boundary elements Four parts divide the chapters structured grids unstructured grids surface definition and adaption quality An introduction to each section provides a roadmap through the material This handbook covers Fundamental concepts and approaches Grid generation process Essential mathematical elements from tensor analysis and differential geometry particularly relevant to curves and surfaces Cells of any shape Cartesian structured curvilinear coordinates unstructured tetrahedra unstructured hexahedra or various combinations Separate grids overlaid on one another communicating data through interpolation Moving boundaries and internal interfaces in the field Resolving gradients and controlling solution error Grid generation codes both commercial and freeware as well as representative and illustrative grid configurations Handbook of Grid Generation contains 37 chapters as well as contributions from more than 100 experts from around the world comprehensively evaluating this expanding field and providing a fundamental orientation for practitioners

Multiscale Wavelet Methods for Partial Differential Equations Wolfgang Dahmen, Andrew Kurdila, Peter Oswald, 1997-08-13 This latest volume in the Wavelets Analysis and Its Applications Series provides significant and up to date insights into recent developments in the field of wavelet constructions in connection with partial differential equations Specialists in numerical applications and engineers in a variety of fields will find Multiscale Wavelet for Partial Differential Equations to be a valuable resource Covers important areas of computational mechanics such as elasticity and computational fluid dynamics Includes a clear study of turbulence modeling Contains recent research on multiresolution analyses with operator adapted wavelet discretizations Presents well documented numerical experiments connected with the development of algorithms useful in specific applications *Parallel Solution of Partial Differential Equations* Petter Bjørstad, Mitchell Luskin, 2012-12-06 This IMA Volume in Mathematics and its Applications PARALLEL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS is based on the proceedings of a workshop with the same title The workshop was an integral part of the 1996-97 IMA program on MATHEMATICS IN HIGH PERFORMANCE COMPUTING I would like to thank Petter Bjørstad of the Institutt for Informatikk University of Bergen and Mitchell Luskin of the School of Mathematics University of

Minnesota for their excellent work as organizers of the meeting and for editing the proceedings I also take this opportunity to thank the National Science Foundation NSF Department of Energy DOE and the Army Research Office ARO whose financial support made the workshop possible Willard Miller Jr Professor and Director v PREFACE The numerical solution of partial differential equations has been of major importance to the development of many technologies and has been the target of much of the development of parallel computer hardware and software Parallel computers offer the promise of greatly increased performance and the routine calculation of previously intractable problems The papers in this volume were presented at the IMA workshop on the Parallel Solution of PDE held during June 9-13 1997 The workshop brought together leading numerical analysts computer scientists and engineers to assess the state of the art and to consider future directions

Adaptive Method of Lines A. Vande Wouwer, Ph. Saucez, W.E. Schiesser, 2001-04-18 The general Method of Lines MOL procedure provides a flexible format for the solution of all the major classes of partial differential equations PDEs and is particularly well suited to evolutionary nonlinear wave PDEs Despite its utility however there are relatively few texts that explore it at a more advanced level and reflect the methods

Approximation Theory XV: San Antonio 2016 Gregory E. Fasshauer, Larry L. Schumaker, 2017-07-19 These proceedings are based on papers presented at the international conference Approximation Theory XV which was held May 22-25 2016 in San Antonio Texas The conference was the fifteenth in a series of meetings in Approximation Theory held at various locations in the United States and was attended by 146 participants The book contains longer survey papers by some of the invited speakers covering topics such as compressive sensing isogeometric analysis and scaling limits of polynomials and entire functions of exponential type The book also includes papers on a variety of current topics in Approximation Theory drawn from areas such as advances in kernel approximation with applications approximation theory and algebraic geometry multivariate splines for applications practical function approximation approximation of PDEs wavelets and framelets with applications approximation theory in signal processing compressive sensing rational interpolation spline approximation in isogeometric analysis approximation of fractional differential equations numerical integration formulas and trigonometric polynomial approximation

Discontinuous Galerkin Methods Bernardo Cockburn, George E. Karniadakis, Chi-Wang Shu, 2012-12-06 A class of finite element methods the Discontinuous Galerkin Methods DGM has been under rapid development recently and has found its use very quickly in such diverse applications as aeroacoustics semiconductor device simulation turbomachinery turbulent flows materials processing MHD and plasma simulations and image processing While there has been a lot of interest from mathematicians physicists and engineers in DGM only scattered information is available and there has been no prior effort in organizing and publishing the existing volume of knowledge on this subject In May 24-26 1999 we organized in Newport Rhode Island USA the first international symposium on DGM with equal emphasis on the theory numerical implementation and applications Eighteen invited speakers leaders in the field and thirty two contributors presented various aspects and addressed open issues on

DGM In this volume we include forty nine papers presented in the Symposium as well as a survey paper written by the organizers All papers were peer reviewed A summary of these papers is included in the survey paper which also provides a historical perspective of the evolution of DGM and its relation to other numerical methods We hope this volume will become a major reference in this topic It is intended for students and researchers who work in theory and application of numerical solution of convection dominated partial differential equations The papers were written with the assumption that the reader has some knowledge of classical finite elements and finite volume methods

Wavelets Theory and Its Applications

Mani Mehra,2018-11-03 This book provides comprehensive information on the conceptual basis of wavelet theory and its applications Maintaining an essential balance between mathematical rigour and the practical applications of wavelet theory the book is closely linked to the wavelet MATLAB toolbox which is accompanied wherever applicable by relevant MATLAB codes The book is divided into four parts the first of which is devoted to the mathematical foundations The second part offers a basic introduction to wavelets The third part discusses wavelet based numerical methods for differential equations while the last part highlights applications of wavelets in other fields The book is ideally suited as a text for undergraduate and graduate students of mathematics and engineering

Spectral and High Order Methods for Partial Differential

Equations ICOSAHOM 2018 Spencer J. Sherwin,David Moxey,Joaquim Peiró,Peter E. Vincent,Christoph

Schwab,2020-08-11 This open access book features a selection of high quality papers from the presentations at the International Conference on Spectral and High Order Methods 2018 offering an overview of the depth and breadth of the activities within this important research area The carefully reviewed papers provide a snapshot of the state of the art while the extensive bibliography helps initiate new research directions

Operations Research Proceedings 2005

Hans-Dietrich Haasis,Herbert Kopfer,Jörn Schönberger,2006-09-12 This volume contains a selection of 128 papers presented in lectures during the international scientific symposium Operations Research 2005 OR 2005 held at the University of Bremen September 7 9 2005 This international conference took place under the auspices of the German Operations Research Society GOR The symposium had about 600 participants from countries all over the world It attracted academics and practitioners working in various fields of Operations Research and provided them with the most recent advances in Operations Research as well as related areas in Economics Mathematics and Computer Science including the special interest streams Logistics and New Maritime Businesses The program consisted of 3 plenary and 15 semi plenary talks and about 400 contributed presentations selected by the program committee to be presented in 20 sections

High-Order Methods for Computational Physics Timothy J. Barth,Herman Deconinck,2013-03-09 The development of high order accurate numerical discretization techniques for irregular domains and meshes is often cited as one of the remaining challenges facing the field of computational fluid dynamics In structural mechanics the advantages of high order finite element approximation are widely recognized This is especially true when high order element approximation is combined with element refinement h p

refinement In computational fluid dynamics high order discretization methods are infrequently used in the computation of compressible fluid flow The hyperbolic nature of the governing equations and the presence of solution discontinuities makes high order accuracy difficult to achieve Consequently second order accurate methods are still predominately used in industrial applications even though evidence suggests that high order methods may offer a way to significantly improve the resolution and accuracy for these calculations To address this important topic a special course was jointly organized by the Applied Vehicle Technology Panel of NATO's Research and Technology Organization RTO the von Karman Institute for Fluid Dynamics and the Numerical Aerospace Simulation Division at the NASA Ames Research Center The NATO RTO sponsored course entitled Higher Order Discretization Methods in Computational Fluid Dynamics was held September 14-18 1998 at the von Karman Institute for Fluid Dynamics in Belgium and September 21-25 1998 at the NASA Ames Research Center in the United States

Advances in Computer Methods for Partial Differential Equations, 1987

Hygro-Thermo-Magneto-Electro-Elastic Theory of Anisotropic Doubly-Curved Shells Francesco Tornabene, 2023-10-13

This book aims to present in depth several Higher order Shear Deformation Theories HSDTs by means of a unified approach for studying the Hygro Thermo Magneto Electro Elastic Theory of Anisotropic Doubly Curved Shells In particular a general coupled multifield theory regarding anisotropic shell structures is provided The three dimensional multifield problem is reduced in a two dimensional one following the principles of the Equivalent Single Layer ESL approach and the Equivalent Layer Wise ELW approach setting a proper configuration model According to the adopted configuration assumptions several Higher order Shear Deformation Theories HSDTs are obtained Furthermore the strong and weak formulations of the corresponding governing equations are discussed and illustrated The approach presented in this volume is completely general and represents a valid tool to investigate the physical behavior of many arbitrarily shaped structures An isogeometric mapping procedure is also illustrated to this aim Special attention is given also to advanced and innovative constituents such as Carbon Nanotubes CNTs Variable Angle Tow VAT composites and Functionally Graded Materials FGMs In addition several numerical applications are used to support the theoretical models Accurate efficient and reliable numerical techniques able to approximate both derivatives and integrals are considered which are respectively the Differential Quadrature DQ and Integral Quadrature IQ methods The Theory of Composite Thin Shells is derived in a simple and intuitive manner from the theory of thick and moderately thick shells First order Shear Deformation Theory or Reissner Mindlin Theory In particular the Kirchhoff Love Theory and the Membrane Theory for composite shells are shown Furthermore the Theory of Composite Arches and Beams is also exposed In particular the equations of the Timoshenko Theory and the Euler Bernoulli Theory are directly deduced from the equations of singly curved shells of translation and of plates

Meshfree Methods for Partial Differential Equations IX Michael Griebel, Marc Alexander Schweitzer, 2019-06-19 This volume collects selected papers presented at the Ninth International Workshop on Meshfree Methods held in Bonn Germany in September 2017 They address

various aspects of this very active research field and cover topics from applied mathematics physics and engineering The numerical treatment of partial differential equations with meshfree discretization techniques has been a very active research area in recent years While the fundamental theory of meshfree methods has been developed and considerable advances of the various methods have been made many challenges in the mathematical analysis and practical implementation of meshfree methods remain This symposium aims to promote collaboration among engineers mathematicians and computer scientists and industrial researchers to address the development mathematical analysis and application of meshfree and particle methods especially to multiscale phenomena It continues the 2 year cycled Workshops on Meshfree Methods for Partial Differential Equations Turbulent Flow Computation D. Drikakis, Bernard Geurts, 2006-04-11 In various branches of fluid mechanics our understanding is inhibited by the presence of turbulence Although many experimental and theoretical studies have significantly helped to increase our physical understanding a comprehensive and predictive theory of turbulent flows has not yet been established Therefore the prediction of turbulent flow relies heavily on simulation strategies The development of reliable methods for turbulent flow computation will have a significant impact on a variety of technological advancements These range from aircraft and car design to turbomachinery combustors and process engineering Moreover simulation approaches are important in materials sign prediction of biologically relevant flows and also significantly contribute to the understanding of environmental processes including weather and climate forecasting The material that is compiled in this book presents a coherent account of contemporary computational approaches for turbulent flows It aims to provide the reader with information about the current state of the art as well as to stimulate directions for future research and development The book puts particular emphasis on computational methods for incompressible and compressible turbulent flows as well as on methods for analysing and quantifying numerical errors in turbulent flow computations In addition it presents turbulence modelling approaches in the context of large eddy simulation and unfolds the challenges in the field of simulations for multiphase flows and computational fluid dynamics CFD of engineering flows in complex geometries Apart from reviewing main research developments new material is also included in many of the chapters

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