

Modified Equation

- In order to determine the dominant error term of a finite difference equation, Taylor series expansions are substituted back into the finite difference equation and, after some algebraic manipulation, the so-called modified equation is obtained.
- To illustrate the procedure, the following FTCS-Explicit scheme is considered as a numerical solution of the parabolic equation.

$$u_j^{n+1} = u_j^n + d(u_{j+1}^n - 2u_j^n + u_{j-1}^n) \quad \text{where} \quad d = \frac{\nu \Delta t}{(\Delta y)^2}$$

The following Taylor series expansions

$$u_j^{n+1} = u_j^n + \Delta t \left(\frac{\partial u}{\partial t} \right) + \frac{(\Delta t)^2}{2} \left(\frac{\partial^2 u}{\partial t^2} \right) + \frac{(\Delta t)^3}{3!} \left(\frac{\partial^3 u}{\partial t^3} \right) + \frac{(\Delta t)^4}{4!} \left(\frac{\partial^4 u}{\partial t^4} \right) + O(\Delta t)^5$$

$$u_{j\pm 1}^n = u_j^n \pm \Delta y \left(\frac{\partial u}{\partial y} \right) + \frac{(\Delta y)^2}{2} \left(\frac{\partial^2 u}{\partial y^2} \right) \pm \frac{(\Delta y)^3}{3!} \left(\frac{\partial^3 u}{\partial y^3} \right) + \frac{(\Delta y)^4}{4!} \left(\frac{\partial^4 u}{\partial y^4} \right) \pm O(\Delta y)^5$$

are substituted back into the FTCS scheme to obtain the modified equation.

Dr. Ahmed M. Elsayed

Dividing by Δt the following equation is obtained

$$\begin{aligned} & \frac{\partial u}{\partial t} + \frac{(\Delta t)}{2} \left(\frac{\partial^2 u}{\partial t^2} \right) + \frac{(\Delta t)^2}{3!} \left(\frac{\partial^3 u}{\partial t^3} \right) + \frac{(\Delta t)^3}{4!} \left(\frac{\partial^4 u}{\partial t^4} \right) + O(\Delta t)^4 \\ &= \nu \left[\left(\frac{\partial^2 u}{\partial y^2} \right) + \frac{(\Delta y)^2}{12} \left(\frac{\partial^4 u}{\partial y^4} \right) + O(\Delta y)^4 \right] \end{aligned}$$

This equation can be written as

$$\frac{\partial u}{\partial t} - \nu \left(\frac{\partial^2 u}{\partial y^2} \right) = - \frac{(\Delta t)}{2} \left(\frac{\partial^2 u}{\partial t^2} \right) + \frac{\nu(\Delta y)^2}{12} \left(\frac{\partial^4 u}{\partial y^4} \right) + O[(\Delta t)^2, (\Delta y)^4]$$

Truncation error

To check the consistency of the scheme

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**Pierpaolo Esposito, Nassif
Ghoussoub, Yujin Guo**



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Elliptic Partial Differential Equations Qing Han, 2011 *Elliptic Partial Differential Equations* by Qing Han and FangHua Lin is one of the best textbooks I know It is the perfect introduction to PDE In 150 pages or so it covers an amazing amount of wonderful and extraordinary useful material I have used it as a textbook at both graduate and undergraduate levels which is possible since it only requires very little background material yet it covers an enormous amount of material In my opinion it is a must read for all interested in analysis and geometry and for all of my own PhD students it is indeed just that I cannot say enough good things about *Lectures on Elliptic Partial Differential Equations* Luigi Ambrosio, Alessandro Carlotto, Annalisa

Massaccesi, 2019-01-10 The book originates from the Elliptic PDE course given by the first author at the Scuola Normale Superiore in recent years It covers the most classical aspects of the theory of Elliptic Partial Differential Equations and Calculus of Variations including also more recent developments on partial regularity for systems and the theory of viscosity solutions *Analysis and Numerics of Partial Differential Equations* Franco Brezzi, Piero Colli Franzone, Ugo Pietro

Gianazza, Gianni Gilardi, 2012-12-22 This volume is a selection of contributions offered by friends collaborators past students in memory of Enrico Magenes The first part gives a wide historical perspective of Magenes work in his 50 year mathematical career the second part contains original research papers and shows how ideas methods and techniques introduced by Magenes and his collaborators still have an impact on the current research in Mathematics *Mathematical Analysis of*

Partial Differential Equations Modeling Electrostatic MEMS Pierpaolo Esposito, Nassif Ghoussoub, Yujin Guo, 2010 Micro and nanoelectromechanical systems MEMS and NEMS which combine electronics with miniature size mechanical devices are essential components of modern technology This title offers an introduction to many methods of nonlinear analysis and PDEs through the analysis of a set of equations that have enormous practical significance **Classical and Multilinear**

Harmonic Analysis: Volume 1 Camil Muscalu, Wilhelm Schlag, 2013-01-31 This two volume text in harmonic analysis introduces a wealth of analytical results and techniques It is largely self contained and will be useful to graduate students and researchers in both pure and applied analysis Numerous exercises and problems make the text suitable for self study and the classroom alike This first volume starts with classical one dimensional topics Fourier series harmonic functions Hilbert transform Then the higher dimensional Calder n Zygmund and Littlewood Paley theories are developed Probabilistic methods and their applications are discussed as are applications of harmonic analysis to partial differential equations The volume concludes with an introduction to the Weyl calculus The second volume goes beyond the classical to the highly contemporary and focuses on multilinear aspects of harmonic analysis the bilinear Hilbert transform Coifman Meyer theory Carleson s resolution of the Lusin conjecture Calder n s commutators and the Cauchy integral on Lipschitz curves The material in this volume has not previously appeared together in book form **Function Spaces and Partial Differential Equations** Ali

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Analysis Camil Muscalu, Wilhelm Schlag, 2013-01-31 This contemporary graduate level text in harmonic analysis introduces the reader to a wide array of analytical results and techniques **Geometric Partial Differential Equations** Antonin Chambolle, Matteo Novaga, Enrico Valdinoci, 2014-01-17 This book is the outcome of a conference held at the Centro De Giorgi of the Scuola Normale of Pisa in September 2012 The aim of the conference was to discuss recent results on nonlinear partial differential equations and more specifically geometric evolutions and reaction diffusion equations Particular attention was paid to self similar solutions such as solitons and travelling waves asymptotic behaviour formation of singularities and qualitative properties of solutions These problems arise in many models from Physics Biology Image Processing and Applied Mathematics in general and have attracted a lot of attention in recent years Semilinear Elliptic Equations for Beginners Marino Badiale, Enrico Serra, 2010-12-07 Semilinear elliptic equations are of fundamental importance for the study of geometry physics mechanics engineering and life sciences The variational approach to these equations has experienced spectacular success in recent years reaching a high level of complexity and refinement with a multitude of applications Additionally some of the simplest variational methods are evolving as classical tools in the field of nonlinear differential equations This book is an introduction to variational methods and their applications to semilinear elliptic problems Providing a comprehensive overview on the subject this book will support both student and teacher engaged in a first course in nonlinear elliptic equations The material is introduced gradually and in some cases redundancy is added to stress the fundamental steps in theory building Topics include differential calculus for functionals linear theory and existence theorems by minimization techniques and min max procedures Requiring a basic knowledge of Analysis Functional Analysis and the most common function spaces such as Lebesgue and Sobolev spaces this book will be of primary use to graduate students based in the field of nonlinear partial differential equations It will also serve as valuable reading for final year undergraduates seeking to learn about basic working tools from variational methods and the management of certain types of nonlinear problems Stable Solutions of Elliptic Partial Differential Equations Louis Dupaigne, 2011-03-15 Stable solutions

are ubiquitous in differential equations. They represent meaningful solutions from a physical point of view and appear in many applications including mathematical physics, combustion, phase transition theory, and geometry of minimal surfaces. *Stable Solutions of Elliptic Partial Differential Equations* offers a self-contained presentation of the notion of stability in elliptic partial differential equations (PDEs). The central questions of regularity and classification of stable solutions are treated at length. Specialists will find a summary of the most recent developments of the theory such as nonlocal and higher order equations. For beginners, the book walks you through the fine versions of the maximum principle, the standard regularity theory for linear elliptic equations, and the fundamental functional inequalities commonly used in this field. The text also includes two additional topics: the inverse square potential and some background material on submanifolds of Euclidean space.

Analysis and Partial Differential Equations Thomas Alazard, 2024-09-25. This textbook provides a modern introduction to advanced concepts and methods of mathematical analysis. The first three parts of the book cover functional analysis, harmonic analysis, and microlocal analysis. Each chapter is designed to provide readers with a solid understanding of fundamental concepts while guiding them through detailed proofs of significant theorems. These include the universal approximation property for artificial neural networks, Brouwer's domain invariance theorem, Nash's implicit function theorem, Calderón's reconstruction formula, and wavelets. Wiener's Tauberian theorem, Hörmander's theorem of propagation of singularities, and proofs of many inequalities centered around the works of Hardy, Littlewood, and Sobolev. The final part of the book offers an overview of the analysis of partial differential equations. This vast subject is approached through a selection of major theorems such as the solution to Calderón's problem, De Giorgi's regularity theorem for elliptic equations, and the proof of a Strichartz-Bourgain estimate. Several renowned results are included in the numerous examples. Based on courses given successively at the École Normale Supérieure in France (ENS Paris and ENS Paris-Saclay) and at Tsinghua University, the book is ideally suited for graduate courses in analysis and PDE. The prerequisites in topology and real analysis are conveniently recalled in the appendix.

Elliptic Differential Operators and Spectral Analysis D. E. Edmunds, W.D. Evans, 2018-11-20. This book deals with elliptic differential equations, providing the analytic background necessary for the treatment of associated spectral questions and covering important topics previously scattered throughout the literature. Starting with the basics of elliptic operators and their naturally associated function spaces, the authors then proceed to cover various related topics of current and continuing importance. Particular attention is given to the characterisation of self-adjoint extensions of symmetric operators acting in a Hilbert space, and for elliptic operators, the realisation of such extensions in terms of boundary conditions. A good deal of material not previously available in book form, such as the treatment of the Schauder estimates, is included. Requiring only basic knowledge of measure theory and functional analysis, the book is accessible to graduate students and will be of interest to all researchers in partial differential equations. The reader will value its self-contained, thorough, and unified presentation of the modern theory of elliptic operators.

Handbook of Calculus of Variations for

Absolute Beginners Lorenzo Brasco, 2025-04-30 The book aims at endowing any student with a survival toolkit to start safely diving into the realm of Calculus of Variations In summary the latter is a part of mathematical analysis devoted to minimization maximization problems A great effort has been made to present the themes and methods considered in the book in the simplest possible way the reader will not find here general statements or proofs based on general abstract theories In contrast the main focus of the book is on introducing some key concepts from scratch by means of simple and meaningful explicit examples including for instance the classical isoperimetric and brachistocrone problems as well as the boundary value problem for harmonic functions In particular the book is mainly but not exclusively designed to smoothly introduce the reader to the so called Direct Method of the Calculus of Variations which is a central concept in the field Accordingly a good part of the book is devoted to discussing spaces of weakly differentiable functions i e Sobolev and Lipschitz functions which are essential tools of the Direct Method A long list of problems will guide the student through the study of the subject Almost all the problems come with their fully detailed solutions The book is complemented by four appendices which contribute to making it self contained as well as to deepening the study of certain parts Despite being designed for students even the researchers in the field could find a reading of the book profitable at least for certain parts concerning the properties of Sobolev spaces functional inequalities of the Sobolev Poincaré type tricks to handle nonlinear elliptic PDEs and a gentle introduction to some techniques of modern regularity theory for elliptic PDEs

Functional Spaces for the Theory of Elliptic Partial Differential Equations Françoise Demengel, Gilbert Demengel, 2012-01-24 The theory of elliptic boundary problems is fundamental in analysis and the role of spaces of weakly differentiable functions also called Sobolev spaces is essential in this theory as a tool for analysing the regularity of the solutions This book offers on the one hand a complete theory of Sobolev spaces which are of fundamental importance for elliptic linear and non linear differential equations and explains on the other hand how the abstract methods of convex analysis can be combined with this theory to produce existence results for the solutions of non linear elliptic boundary problems The book also considers other kinds of functional spaces which are useful for treating variational problems such as the minimal surface problem The main purpose of the book is to provide a tool for graduate and postgraduate students interested in partial differential equations as well as a useful reference for researchers active in the field Prerequisites include a knowledge of classical analysis differential calculus Banach and Hilbert spaces integration and the related standard functional spaces as well as the Fourier transformation on the Schwartz space There are complete and detailed proofs of almost all the results announced and in some cases more than one proof is provided in order to highlight different features of the result Each chapter concludes with a range of exercises of varying levels of difficulty with hints to solutions provided for many of them

Computation and Visualization of Geometric Partial Differential Equations Christopher Tiee, 2015-08-09 This is an extended version of my PhD thesis which extends the theory of finite element exterior calculus FEEC to parabolic evolution equations In the extended version I explore

some more precise visualizations of the defined quantities as well as explain how the modern theory of functional analysis applies In the main part I extend the theory of approximating evolution equations in Euclidean space using FEEC to hypersurfaces After these main results I describe some possible extensions to nonlinear equations A few appendices detail one of the original motivations for getting into this theory in the first place canonical geometries given as steady state solutions and extremals of certain functionals

Regularity Techniques for Elliptic PDEs and the Fractional Laplacian Pablo Raúl Stinga,2024-07-02 Regularity Techniques for Elliptic PDEs and the Fractional Laplacian presents important analytic and geometric techniques to prove regularity estimates for solutions to second order elliptic equations both in divergence and nondivergence form and to nonlocal equations driven by the fractional Laplacian The emphasis is placed on ideas and the development of intuition while at the same time being completely rigorous The reader should keep in mind that this text is about how analysis can be applied to regularity estimates Many methods are nonlinear in nature but the focus is on linear equations without lower order terms thus avoiding bulky computations The philosophy underpinning the book is that ideas must be flushed out in the cleanest and simplest ways showing all the details and always maintaining rigor Features Self contained treatment of the topic Bridges the gap between upper undergraduate textbooks and advanced monographs to offer a useful accessible reference for students and researchers Replete with useful references

Research in Mathematics of Materials Science Malena I. Español,Marta Lewicka,Lucia Scardia,Anja Schlömerkemper,2022-09-27 This volume highlights contributions of women mathematicians in the study of complex materials and includes both original research papers and reviews The featured topics and methods draw on the fields of Calculus of Variations Partial Differential Equations Functional Analysis Differential Geometry and Topology as well as Numerical Analysis and Mathematical Modelling Areas of applications include foams fluid solid interactions liquid crystals shape memory alloys magnetic suspensions failure in solids plasticity viscoelasticity homogenization crystallization grain growth and phase field models

Contemporary Research in Elliptic PDEs and Related Topics Serena Dipierro,2019-07-12 This volume collects contributions from the speakers at an INdAM Intensive period held at the University of Bari in 2017 The contributions cover several aspects of partial differential equations whose development in recent years has experienced major breakthroughs in terms of both theory and applications The topics covered include nonlocal equations elliptic equations and systems fully nonlinear equations nonlinear parabolic equations overdetermined boundary value problems maximum principles geometric analysis control theory mean field games and bio mathematics The authors are trailblazers in these topics and present their work in a way that is exhaustive and clearly accessible to PhD students and early career researcher As such the book offers an excellent introduction to a variety of fundamental topics of contemporary investigation and inspires novel and high quality research

Nonlinear Dispersive Waves and Fluids Avy Soffer,2019-03-12 This volume contains the proceedings of the AMS Special Session on Spectral Calculus and Quasilinear Partial Differential Equations and the AMS Special Session on

PDE Analysis on Fluid Flows which were held in January 2017 in Atlanta Georgia These two sessions shared the underlying theme of the analysis aspect of evolutionary PDEs and mathematical physics The articles address the latest trends and perspectives in the area of nonlinear dispersive equations and fluid flows The topics mainly focus on using state of the art methods and techniques to investigate problems of depth and richness arising in quantum mechanics general relativity and fluid dynamics

Analysis of Monge-Ampère Equations Nam Q. Le, 2024-03-07 This book presents a systematic analysis of the Monge Ampère equation the linearized Monge Ampère equation and their applications with emphasis on both interior and boundary theories Starting from scratch it gives an extensive survey of fundamental results essential techniques and intriguing phenomena in the solvability geometry and regularity of Monge Ampère equations It describes in depth diverse applications arising in geometry fluid mechanics meteorology economics and the calculus of variations The modern treatment of boundary behaviors of solutions to Monge Ampère equations a very important topic of the theory is thoroughly discussed The book synthesizes many important recent advances including Savin's boundary localization theorem spectral theory and interior and boundary regularity in Sobolev and Hölder spaces with optimal assumptions It highlights geometric aspects of the theory and connections with adjacent research areas This self contained book provides the necessary background and techniques in convex geometry real analysis and partial differential equations presents detailed proofs of all theorems explains subtle constructions and includes well over a hundred exercises It can serve as an accessible text for graduate students as well as researchers interested in this subject

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