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.

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

The following Taylor series expansions

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

$$u_{j\pm1}^n = u_j^n \pm \Delta y\left(\frac{\partial u}{\partial y}\right) + \frac{(\Delta y)^2}{2}\left(\frac{\partial^2 u}{\partial y^2}\right) \pm \frac{(\Delta y)^3}{3!}\left(\frac{\partial^3 u}{\partial y^3}\right) + \frac{(\Delta y)^4}{4!}\left(\frac{\partial^4 u}{\partial y^4}\right) + O(\Delta y)^5$$

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

Dr. Ahmed M. Elsayed

Dividing by Δt the following equation is obtained

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

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

This equation can be written as

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

Truncation error

<u>To check the consistency of the scheme</u>

Elliptic Partial Differential Equations Courant Lecture Notes In Mathematics

Luigi Ambrosio,Alessandro Carlotto,Annalisa Massaccesi

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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 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

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

Function Spaces and Partial Differential Equations Ali Taheri,2015-07-30 This is a book written primarily for graduate students and early researchers in the fields of Analysis and Partial Differential Equations PDEs Coverage of the material is

essentially self contained extensive and novel with great attention to details and rigour The strength of the book primarily lies in its clear and detailed explanations scope and coverage highlighting and presenting deep and profound inter connections between different related and seemingly unrelated disciplines within classical and modern mathematics and above all the extensive collection of examples worked out and hinted exercises There are well over 700 exercises of varying level leading the reader from the basics to the most advanced levels and frontiers of research The book can be used either for independent study or for a year long graduate level course In fact it has its origin in a year long graduate course taught by the author in Oxford in 2004 5 and various parts of it in other institutions later on A good number of distinguished researchers and faculty in mathematics worldwide have started their research career from the course that formed the basis for this book **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 **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 Calder n s reconstruction formula and wavelets Wiener s Tauberian theorem H rmander 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 Calder n s problem De Giorgi s regularity theorem for elliptic equations and the proof of a Strichartz Bourgain

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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   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   **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,2024-06-21 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   **Elliptic Regularity Theory by Approximation Methods** Edgard A. Pimentel,2022-09-29 Presenting the basics of elliptic PDEs in connection with regularity theory the book bridges fundamental breakthroughs such as the Krylov Safonov and Evans Krylov results Caffarelli s regularity theory and

the counterexamples due to Nadirashvili and Vl du and modern developments including improved regularity for flat solutions and the partial regularity result After presenting this general panorama accounting for the subtleties surrounding C viscosity and Lp viscosity solutions the book examines important models through approximation methods The analysis continues with the asymptotic approach based on the recession operator After that approximation techniques produce a regularity theory for the Isaacs equation in Sobolev and H lder spaces Although the Isaacs operator lacks convexity approximation methods are capable of producing H lder continuity for the Hessian of the solutions by connecting the problem with a Bellman equation To complete the book degenerate models are studied and their optimal regularity is described **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

Partial Differential Equations Lawrence C. Evans,2022-03-22 This is the second edition of the now definitive text on partial differential equations PDE It offers a comprehensive survey of modern techniques in the theoretical study of PDE with particular emphasis on nonlinear equations Its wide scope and clear exposition make it a great text for a graduate course in PDE For this edition the author has made numerous changes including a new chapter on nonlinear wave equations more than 80 new exercises several new sections a significantly expanded bibliography About the First Edition I have used this book for both regular PDE and topics courses It has a wonderful combination of insight and technical detail Evans book is evidence of his mastering of the field and the clarity of presentation Luis Caffarelli University of Texas It is fun to teach from Evans book It explains many of the essential ideas and techniques of partial differential equations Every graduate student in analysis should read it David Jerison MIT I usePartial Differential Equationsto prepare my students for their Topic exam which is a requirement before starting working on their dissertation The book provides an excellent account of PDE s I am very happy with the preparation it provides my students Carlos Kenig University of Chicago Evans book has already attained the status of a classic It is a clear choice for students just learning the subject as well as for experts who wish to broaden their knowledge An outstanding reference for many aspects of the field Rafe Mazzeo Stanford University **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   **Qualitative Analysis of Nonlinear Elliptic Partial Differential Equations** Vicenţiu Rădulescu,2008 This book provides a comprehensive introduction to the mathematical theory of nonlinear problems described by elliptic partial differential equations These equations can be seen as nonlinear versions of the classical Laplace equation and they appear as mathematical models in different branches of physics chemistry biology genetics and engineering and are also relevant in differential geometry and relativistic physics Much of the modern theory of such equations is based on the calculus of variations and functional analysis Concentrating on single valued or multivalued elliptic equations with nonlinearities of various types the aim of this volume is to obtain sharp existence or nonexistence results as well as decay rates for general classes of solutions Many technically relevant questions are presented and analyzed in detail A systematic picture of the most relevant phenomena is obtained for the equations under study including bifurcation stability asymptotic analysis and optimal regularity of solutions The method of presentation should appeal to readers with different backgrounds in functional analysis and nonlinear partial differential equations All chapters include detailed heuristic arguments providing thorough motivation of the study developed later on in the text in relationship with concrete processes arising in applied sciences A systematic description of the most relevant singular phenomena described in this volume includes existence or nonexistence of solutions unicity or multiplicity properties bifurcation and asymptotic analysis and optimal regularity The book includes an extensive bibliography and a rich index thus allowing for quick orientation among the vast collection of literature on the mathematical theory of nonlinear phenomena described by elliptic partial differential equations   **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 Poincar type tricks to handle nonlinear elliptic PDEs and a gentle introduction to some techniques of modern regularity theory for elliptic PDEs

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