

*22 Divided differences. The divided difference of order $k > 1$ of $f(x)$ is defined by

$$f[a_1, \dots, a_k] = \frac{f[a_2, \dots, a_k] - f[a_1, \dots, a_{k-1}]}{a_k - a_1} \quad \text{with } f[a_1] = f(a_1)$$

(a) Prove that

$$f[a_1, \dots, a_k] = \sum_{i=1}^k \frac{f(a_i)}{(a_i - a_1) \cdots (a_i - a_{i-1})(a_i - a_{i+1}) \cdots (a_i - a_k)}$$

and thus deduce that the order of the arguments in a divided difference is immaterial.

(b) Use the data of Example 3.1 to generate a divided-difference table analogous to the difference table of Fig. 3.1.

(c) Show that

$$f[a_1, \dots, a_{k-1}, x] = f[a_1, \dots, a_k] + (x - a_k)f[a_1, \dots, a_k, x]$$

and use this result to derive the formula

$$f(x) = f[a_1] + (x - a_1)f[a_1, a_2] + (x - a_1)(x - a_2)f[a_1, a_2, a_3] \\ + \cdots + (x - a_1)(x - a_2) \cdots (x - a_{n-1})f[a_1, \dots, a_n] + E(x)$$

where

$$E(x) = p_n(x)f[a_1, \dots, a_n, x]$$

This formula is called *Newton's divided-difference interpolation formula*.

(d) Deduce from part (c) that $(x - a_k)f[a_1, \dots, a_n, x] \rightarrow 0$ as $x \rightarrow a_k$, $k = 1, \dots, n$.

(e) Use this result to show that this formula must be algebraically equivalent to the Lagrangian interpolation formula which uses the tabular points a_1, \dots, a_n . Thus deduce that

$$f[a_1, \dots, a_n, x] = \frac{1}{n!} f^{(n)}(\xi)$$

where ξ is in the interval spanned by a_1, \dots, a_n and x .

(f) Use the results of parts (c) and (e) to show that as $a_i \rightarrow a$, $i = 1, \dots, n$, the Newton divided-difference formula and therefore the Lagrangian formula are both equivalent to a Taylor series with remainder.

(g) Use Newton's divided-difference formula and the table of part (b) to approximate $\ln .60$. Compare the result with Example 3.1.

(h) When the tabular points are equally spaced, show that

$$f[a_1, \dots, a_k] = \frac{1}{(k-1)!h^{k-1}} \Delta^{k-1} f_1$$

and thus use part (c) to derive Newton's forward formula.



Numerical Calculus

William Edmund Milne



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Numerical Calculus William Edmund Milne, 2015-12-08 The calculus of finite differences is here treated thoroughly and clearly by one of the leading American experts in the field of numerical analysis and computation The theory is carefully developed and applied to illustrative examples and each chapter is followed by a set of helpful exercises The book is especially designed for the use of actuarial students statisticians applied mathematicians and any scientists forced to seek numerical solutions It presupposes only a knowledge of algebra analytic geometry trigonometry and elementary calculus The object is definitely practical for while numerical calculus is based on the concepts of pure mathematics it is recognized that the worker must produce a numerical result Originally published in 1949 The Princeton Legacy Library uses the latest print on demand technology to again make available previously out of print books from the distinguished backlist of Princeton University Press These editions preserve the original texts of these important books while presenting them in durable paperback and hardcover editions The goal of the Princeton Legacy Library is to vastly increase access to the rich scholarly heritage found in the thousands of books published by Princeton University Press since its founding in 1905

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Numerical Calculus William Edmund Milne, 1949

Numerical Calculus D. James Benton, 2018-03-28 Before the advent of sophisticated programs capable of performing calculus symbolically numerical differentiation and integration provided a means of solving seemingly intractable equations Numerical methods can still be an efficient means of solving many such problems but the real advantage of Numerical Calculus will always be in solving those problems that have no closed form solution and these are legion This book is filled with practical examples code and spreadsheets I trust you will find it useful I assume that you already have a command of analytical calculus and so I will jump right in to the numerical

Exercises of Numerical Calculus with Solutions in MATLAB/OCTAVE Stefano De Marchi, Davide Poggiali, 2014

Mathematical Analysis and Numerical Methods for Science and Technology Robert Dautray, Jacques-Louis Lions, 1999-11-23 The advent of high speed computers has made it possible for the first time to calculate values from models accurately and rapidly Researchers and engineers thus have a crucial means of using numerical results to modify and adapt arguments and experiments along the way Every facet of technical and industrial

activity has been affected by these developments The objective of the present work is to compile the mathematical knowledge required by researchers in mechanics physics engineering chemistry and other branches of application of mathematics for the theoretical and numerical resolution of physical models on computers Since the publication in 1924 of the *Methoden der mathematischen Physik* by Courant and Hilbert there has been no other comprehensive and up to date publication presenting the mathematical tools needed in applications of mathematics in directly implementable form **Numerical Methods for Fractional Calculus** Changpin Li,Fanhai Zeng,2015-05-19 *Numerical Methods for Fractional Calculus* presents numerical methods for fractional integrals and fractional derivatives finite difference methods for fractional ordinary differential equations FODEs and fractional partial differential equations FPDEs and finite element methods for FPDEs The book introduces the basic definitions and properties **Numerical Methods in Scientific Computing:** Germund Dahlquist,Ake Bjorck,2008-09-04 This work addresses the increasingly important role of numerical methods in science and engineering It combines traditional and well developed topics with other material such as interval arithmetic elementary functions operator series convergence acceleration and continued fractions **Numerical Calculus** William Edmund Milne,1949

Fractional Calculus: Models And Numerical Methods Dumitru Baleanu,Kai Diethelm,Enrico Scalas,Juan J Trujillo,2012-01-27 The subject of fractional calculus and its applications that is convolution type pseudo differential operators including integrals and derivatives of any arbitrary real or complex order has gained considerable popularity and importance during the past three decades or so mainly due to its applications in diverse fields of science and engineering These operators have been used to model problems with anomalous dynamics however they also are an effective tool as filters and controllers and they can be applied to write complicated functions in terms of fractional integrals or derivatives of elementary functions and so on This book will give readers the possibility of finding very important mathematical tools for working with fractional models and solving fractional differential equations such as a generalization of Stirling numbers in the framework of fractional calculus and a set of efficient numerical methods Moreover we will introduce some applied topics in particular fractional variational methods which are used in physics engineering or economics We will also discuss the relationship between semi Markov continuous time random walks and the space time fractional diffusion equation which generalizes the usual theory relating random walks to the diffusion equation These methods can be applied in finance to model tick by tick log price fluctuations in insurance theory to study ruin as well as in macroeconomics as prototypical growth models All these topics are complementary to what is dealt with in existing books on fractional calculus and its applications This book was written with a trade off in mind between full mathematical rigor and the needs of readers coming from different applied areas of science and engineering In particular the numerical methods listed in the book are presented in a readily accessible way that immediately allows the readers to implement them on a computer in a programming language of their choice Numerical code is also provided **Applied Numerical Methods for Chemical Engineers** Navid

Mostoufi, Alkis Constantinides, 2022-05-22 Applied Numerical Methods for Chemical Engineers emphasizes the derivation of a variety of numerical methods and their application to the solution of engineering problems with special attention to problems in the chemical engineering field. These algorithms encompass linear and nonlinear algebraic equations, eigenvalue problems, finite difference methods, interpolation, differentiation, and integration, ordinary differential equations, boundary value problems, partial differential equations, and linear and nonlinear regression analysis. MATLAB is adopted as the calculation environment throughout the book because of its ability to perform all the calculations in matrix form, its large library of built-in functions, its strong structural language, and its rich graphical visualization tools. Through this book, students and other users will learn about the basic features, advantages, and disadvantages of various numerical methods, learn and practice many useful m-files developed for different numerical methods, in addition to the MATLAB built-in solvers, develop and set up mathematical models for problems commonly encountered in chemical engineering, and solve chemical engineering related problems through examples and after-chapter problems with MATLAB by creating application m-files. Clearly and concisely develops a variety of numerical methods and applies them to the solution of chemical engineering problems. These algorithms encompass linear and nonlinear algebraic equations, eigenvalue problems, finite difference methods, interpolation, linear and nonlinear regression analysis, differentiation, and integration, ordinary differential equations, boundary value problems, and partial differential equations. Includes systematic development of the calculus of finite differences and its application to the integration of differential equations and a detailed discussion of nonlinear regression analysis with powerful programs for implementing multivariable nonlinear regression and statistical analysis of the results. Makes extensive use of MATLAB and Excel with most of the methods discussed implemented into general MATLAB functions. All the MATLAB language scripts developed are listed in the text and included in the book's companion website. Includes numerous real-world examples and homework problems drawn from the field of chemical and biochemical engineering.

An Introduction to Numerical Methods and Analysis James F. Epperson, 2021-07-21 The new edition of the popular introductory textbook on numerical approximation methods and mathematical analysis with a unique emphasis on real-world application. An Introduction to Numerical Methods and Analysis helps students gain a solid understanding of a wide range of numerical approximation methods for solving problems of mathematical analysis. Designed for entry-level courses on the subject, this popular textbook maximizes teaching flexibility by first covering basic topics before gradually moving to more advanced material in each chapter and section. Throughout the text, students are provided clear and accessible guidance on a wide range of numerical methods and analysis techniques, including root finding, numerical integration, interpolation, solution of systems of equations, and many others. This fully revised third edition contains new sections on higher-order difference methods, the bisection and inertia method for computing eigenvalues of a symmetric matrix, a completely re-written section on different methods for Poisson equations, and spectral methods for higher-dimensional problems. New problem sets ranging in difficulty from simple

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Numerical Methods for Stochastic Partial Differential Equations with White Noise Zhongqiang Zhang, George Em Karniadakis, 2017-09-01 This book covers numerical methods for stochastic partial differential equations with white noise using the framework of Wong Zakai approximation The book begins with some motivational and background material in the introductory chapters and is divided into three parts Part I covers numerical stochastic ordinary differential equations Here the authors start with numerical methods for SDEs with delay using the Wong Zakai approximation and finite difference in time Part II covers temporal white noise Here the authors consider SPDEs as PDEs driven by white noise where discretization of white noise Brownian motion leads to PDEs with smooth noise which can then be treated by numerical methods for PDEs In this part recursive algorithms based on Wiener chaos expansion and stochastic collocation methods are presented for linear stochastic advection diffusion reaction equations In addition stochastic Euler equations are exploited as an application of stochastic collocation methods where a numerical comparison with other integration methods in random space is made Part III covers spatial white noise Here the authors discuss numerical methods for nonlinear elliptic equations as well as other equations with additive noise Numerical methods for SPDEs with multiplicative noise are also discussed using the Wiener chaos expansion method In addition some SPDEs driven by non Gaussian white noise are discussed and some model reduction methods based on Wick Malliavin calculus are presented for generalized polynomial chaos expansion methods Powerful techniques are provided for solving stochastic partial differential equations This book can be considered as self contained Necessary background knowledge is presented in the appendices Basic knowledge of probability theory and stochastic calculus is presented in Appendix A In Appendix B some semi analytical methods for SPDEs are presented In Appendix C an introduction to Gauss quadrature is provided In Appendix D all the conclusions which are needed for proofs are presented and in Appendix E a method to compute the convergence rate empirically is included In addition the authors provide a thorough review of the topics both theoretical and computational exercises in the book with practical discussion of the effectiveness of the methods Supporting Matlab files are made available to help illustrate some of the concepts further

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Intelligent Numerical Methods: Applications to Fractional Calculus George A. Anastassiou,Ioannis K. Argyros,2015-12-07 In this monograph the authors present Newton type Newton like and other numerical methods which involve fractional derivatives and fractional integral operators for the first time studied in the literature All for the purpose to solve numerically equations whose associated functions can be also non differentiable in the ordinary sense That is among others extending the classical Newton method theory which requires usual differentiability of function Chapters are self contained and can be read independently and several advanced courses can be taught out of this book An extensive list of references is given per chapter The book s results are expected to find applications in many areas of applied mathematics stochastics computer science and engineering As such this monograph is suitable for researchers graduate students and seminars of the above subjects also to be in all science and engineering libraries

Numerical Methods for Engineering and Data Science Rolf Wuthrich,Carole El Ayoubi,2025-05-22 Numerical Methods for Engineering and Data Science guides students in implementing numerical methods in engineering and in assessing their limitations and accuracy particularly using algorithms from the field of machine learning The textbook presents key principles building upon the fundamentals of engineering mathematics It explores classical techniques for

solving linear and nonlinear equations computing definite integrals and differential equations Emphasis is placed on the theoretical underpinnings with an in depth discussion of the sources of errors and in the practical implementation of these using Octave Each chapter is supplemented with examples and exercises designed to reinforce the concepts and encourage hands on practice The second half of the book transitions into the realm of machine learning The authors introduce basic concepts and algorithms such as linear regression and classification As in the first part of this book a special focus is on the solid understanding of errors and practical implementation of the algorithms In particular the concepts of bias variance and noise are discussed in detail and illustrated with numerous examples This book will be of interest to students in all areas of engineering alongside mathematicians and scientists in industry looking to improve their knowledge of this important field

Numerical Methods that Work Forman S. Acton, 1990 A commonsense approach to numerical algorithms for the solution of equations *A First Course in Numerical Methods* Uri M. Ascher, Chen Greif, 2011-07-14 Offers students a practical knowledge of modern techniques in scientific computing *Numerical Methods for Engineering* Karl F. Warnick, 2020-09-26 The revised and updated second edition of this textbook teaches students to create computer codes used to engineer antennas microwave circuits and other critical technologies for wireless communications and other applications of electromagnetic fields and waves Worked code examples are provided for MATLAB technical computing software

Numerical Methods Germund Dahlquist, Åke Björck, 2012-04-26 Substantial detailed and rigorous readers for whom the book is intended are admirably served MathSciNet Mathematical Reviews on the Web American Mathematical Society Practical text strikes fine balance between students requirements for theoretical treatment and needs of practitioners with best methods for large and small scale computing Prerequisites are minimal calculus linear algebra and preferably some acquaintance with computer programming Text includes many worked examples problems and an extensive bibliography

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