The Numerical Integration of Ordinary Differential Equations†

By C. W. Gear

Abstract. Multistep methods for initial value problems are expressed in a matrix form. The application of such methods to higher-order equations is studied with the result that new techniques for both first- and higher-order equations are found. The direct approach to higher-order equations is believed to offer speed and accuracy advantages; some numerical evidence is presented. The new technique applied to first-order equations is a slight extension of the conventional multistep method and avoids the Dahlquist [2] stability theorem, that is, these new k-step methods are of order $2k$ and yet convergent. The matrix formalism introduced provides an easy mechanism for examining the equivalence of methods as introduced by Descloux [3]. It is pointed out that the new first-order method on k- steps, Adams' method on $(2k - 1)$-steps and Nordsieck's [7] method with $2k$ components are equivalent to each other. In fact, all methods discussed can be placed in equivalence classes so that theorems need only be proved for one member of each class. The choice between the members of a class can be made on the basis of round-off errors and amount of computation only. Arguments are given in favor of the extension of Nordsieck's method for general use because of its speed and applicability to higher order problems directly. The theorems ensuring convergence and giving the asymptotic form of the error are stated. The proofs can be found in a cited report.

1. Introduction. This paper is concerned with the integration of initial value problems for a system of ordinary differential equations of the form

$$(1.1) \qquad y_i^{(p_i)} = f_i(x, y_1, \cdots, y_1^{(p_1-1)}, y_2, \cdots, y_s^{(p_s-1)}), \qquad i = 1, 2, \cdots, s,$$

where $y^{(k)} = d^k y/dx^k$. The motivation for the work was to try and integrate such equations directly rather than as a larger system of first-order equations. The study led to a matrix representation for multistep methods that is an extension of a similar representation due to Descloux [3]. This representation provides a unified approach to equations of all orders; it is sufficient and easier to study it in detail for first-order equations. The usual theorems of stability and convergence, etc. are stated for general higher-order systems in Section 5. The proofs can be found in Gear [5].

2. Multistep Methods. The equation $y' = f(x, y)$ is frequently integrated numerically by a predictor-corrector algorithm of the following form:

Let $x_n = x_0 + nh$ where h is the step size, and let y_n and y_n' be approximations to the values of $y(x_n)$ and $dy(x_n)/dx$ obtained in some manner. The values of y and y' at x_{n+1} are found by the sequence of steps: predictor formula

$$(2.1) \qquad y_{n+1}^{(0)} = \sum_{j=1}^{i} (\alpha_j^* y_{n-j+1} + \beta_j^* h y_{n-j+1}'),$$

Numerical Integration Of Differential Equations

Michael Anthony Celia,William Guerin Gray

Numerical Integration Of Differential Equations:

Geometric Numerical Integration Ernst Hairer,Christian Lubich,Gerhard Wanner,2006-05-18 This book covers numerical methods that preserve properties of Hamiltonian systems reversible systems differential equations on manifolds and problems with highly oscillatory solutions It presents a theory of symplectic and symmetric methods which include various specially designed integrators as well as discusses their construction and practical merits The long time behavior of the numerical solutions is studied using a backward error analysis combined with KAM theory **Numerical Integration of Differential Equations** National Research Council (U.S.). Committee on Numerical Integration,Albert Arnold Bennett,William Edmund Milne,Harry Bateman,1933 *Numerical Methods for Differential Equations* J.R. Dormand,2018-05-04 With emphasis on modern techniques Numerical Methods for Differential Equations A Computational Approach covers the development and application of methods for the numerical solution of ordinary differential equations Some of the methods are extended to cover partial differential equations All techniques covered in the text are on a program disk included with the book and are written in Fortran 90 These programs are ideal for students researchers and practitioners because they allow for straightforward application of the numerical methods described in the text The code is easily modified to solve new systems of equations Numerical Methods for Differential Equations A Computational Approach also contains a reliable and inexpensive global error code for those interested in global error estimation This is a valuable text for students who will find the derivations of the numerical methods extremely helpful and the programs themselves easy to use It is also an excellent reference and source of software for researchers and practitioners who need computer solutions to differential equations **Numerical Integration of Differential Equations and Large Linear Systems** J. Hinze,2006-11-15 **Numerical Methods for Ordinary Differential Equations** David F. Griffiths,Desmond J. Higham,2010-11-11 Numerical Methods for Ordinary Differential Equations is a self contained introduction to a fundamental field of numerical analysis and scientific computation Written for undergraduate students with a mathematical background this book focuses on the analysis of numerical methods without losing sight of the practical nature of the subject It covers the topics traditionally treated in a first course but also highlights new and emerging themes Chapters are broken down into lecture sized pieces motivated and illustrated by numerous theoretical and computational examples Over 200 exercises are provided and these are starred according to their degree of difficulty Solutions to all exercises are available to authorized instructors The book covers key foundation topics o Taylor series methods o Runge Kutta methods o Linear multistep methods o Convergence o Stability and a range of modern themes o Adaptive stepsize selection o Long term dynamics o Modified equations o Geometric integration o Stochastic differential equations The prerequisite of a basic university level calculus class is assumed although appropriate background results are also summarized in appendices A dedicated website for the book containing extra information can be found via www springer com **Numerical Integration of Differential**

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equations SDE These approximations represent two fundamental aspects in the contemporary theory of SDE Firstly the construction of numerical methods for such systems is important as the solutions provided serve as characteristics for a number of mathematical physics problems Secondly the employment of probability representations together with a Monte Carlo method allows us to reduce the solution of complex multidimensional problems of mathematical physics to the integration of stochastic equations Along with a general theory of numerical integrations of such systems both in the mean square and the weak sense a number of concrete and sufficiently constructive numerical schemes are considered Various applications and particularly the approximate calculation of Wiener integrals are also dealt with This book is of interest to graduate students in the mathematical physical and engineering sciences and to specialists whose work involves differential equations mathematical physics numerical mathematics the theory of random processes estimation and control theory *A Concise Introduction to Geometric Numerical Integration* Sergio Blanes,Fernando Casas,2017-11-22 Discover How Geometric Integrators Preserve the Main Qualitative Properties of Continuous Dynamical Systems A Concise Introduction to Geometric Numerical Integration presents the main themes techniques and applications of geometric integrators for researchers in mathematics physics astronomy and chemistry who are already familiar with numerical tools for solving differential equations It also offers a bridge from traditional training in the numerical analysis of differential equations to understanding recent advanced research literature on numerical geometric integration The book first examines high order classical integration methods from the structure preservation point of view It then illustrates how to construct high order integrators via the composition of basic low order methods and analyzes the idea of splitting It next reviews symplectic integrators constructed directly from the theory of generating functions as well as the important category of variational integrators The authors also explain the relationship between the preservation of the geometric properties of a numerical method and the observed favorable error propagation in long time integration The book concludes with an analysis of the applicability of splitting and composition methods to certain classes of partial differential equations such as the Schr dinger equation and other evolution equations The motivation of geometric numerical integration is not only to develop numerical methods with improved qualitative behavior but also to provide more accurate long time integration results than those obtained by general purpose algorithms Accessible to researchers and post graduate students from diverse backgrounds this introductory book gets readers up to speed on the ideas methods and applications of this field Readers can reproduce the figures and results given in the text using the MATLAB programs and model files available online **Numerical Methods for Differential Equations and Applications** Liviu Gr. Ixaru,1984-08-31 **Numerical Methods for Differential Equations** Michael Anthony Celia,William Guerin Gray,1992 Senior Graduate level text covering numerical methods used to solve ordinary and partial differential equations in science and engineering Emphasis is on problem solving as a means of gaining a deeper understanding of the fundamental concepts Not a cookbook of formulas Topics include an introduction to

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The book is written in the lucid style characteristic of the author and combines enlightening explanations with rigorous and precise analysis In addition to these anticipated features the book breaks new ground by including the latest results on the highly efficient G symplectic methods which compete strongly with the well known symplectic Runge Kutta methods for long term integration of conservative mechanical systems This third edition of Numerical Methods for Ordinary Differential Equations will serve as a key text for senior undergraduate and graduate courses in numerical analysis and is an essential resource for research workers in applied mathematics physics and engineering

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Table of Contents Numerical Integration Of Differential Equations

1. Understanding the eBook Numerical Integration Of Differential Equations
    - The Rise of Digital Reading Numerical Integration Of Differential Equations
    - Advantages of eBooks Over Traditional Books
2. Identifying Numerical Integration Of Differential Equations
    - 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 Numerical Integration Of Differential Equations
    - User-Friendly Interface
4. Exploring eBook Recommendations from Numerical Integration Of Differential Equations
    - Personalized Recommendations
    - Numerical Integration Of Differential Equations User Reviews and Ratings
    - Numerical Integration Of Differential Equations and Bestseller Lists
5. Accessing Numerical Integration Of Differential Equations Free and Paid eBooks
    - Numerical Integration Of Differential Equations Public Domain eBooks
    - Numerical Integration Of Differential Equations eBook Subscription Services
    - Numerical Integration Of Differential Equations Budget-Friendly Options
6. Navigating Numerical Integration Of Differential Equations eBook Formats

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