

# NUMERICAL METHODS

C / RAPPY EXAM 12 / 11/19 / 2022 [20.000]

## LEAST SQUARES REGRESSION

Goal: minimize the sum of the squares of the residual errors.



$$S_r = \sum_{i=1}^n d_i = \sum_{i=1}^n (y_i - a_0 - a_1 x_i)$$

$$S_r^2 = \sum_{i=1}^n (y_i - a_0 - a_1 x_i)^2$$

$$a_0 = \frac{\sum y_i}{n} \quad a_1 = \frac{\sum x_i y_i - \frac{(\sum x_i)(\sum y_i)}{n}}{\sum x_i^2 - \frac{(\sum x_i)^2}{n}}$$

## STANDARD ERROR:

$$S_{y_1} = \sqrt{\frac{S_r}{n-2}} \quad S_{y_2} = \sqrt{\frac{S_r (1-x^2)}{n-2}}$$

## STANDARD DEVIATION:

$$S_y = \sqrt{\frac{S_r}{n-1}} \quad S_x = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

$$a_0 = \bar{y} - a_1 \bar{x}$$

## POLYNOMIAL QUADRATIC REGRESSION:



$$S_r = \sum_{i=1}^n (y_i - a_0 - a_1 x_i - a_2 x_i^2)^2$$

Take derivatives of  $S_r$  to find the error.

$$\frac{\partial S_r}{\partial a_0} = -2(\sum y_i - \sum a_0 - a_1 \sum x_i - a_2 \sum x_i^2) = 0$$

$$\frac{\partial S_r}{\partial a_1} = -2(\sum x_i y_i - \sum a_0 \sum x_i - a_1 \sum x_i^2 - a_2 \sum x_i^3) = 0$$

$$\frac{\partial S_r}{\partial a_2} = -2(\sum x_i^2 y_i - \sum a_0 \sum x_i^2 - a_1 \sum x_i^3 - a_2 \sum x_i^4) = 0$$

$$\begin{bmatrix} \sum 1 & \sum x_i & \sum x_i^2 \\ \sum x_i & \sum x_i^2 & \sum x_i^3 \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum x_i y_i \\ \sum x_i^2 y_i \end{bmatrix}$$

Use Gauss-Jordan elimination to solve for  $a_0, a_1, a_2$ .

## INTERPOLATION

Use a polynomial  $P(x)$



## ODE'S

### Euler's Method

$$\frac{dy}{dx} = f(x,y) \quad y_{n+1} = y_n + f(x_n, y_n) \Delta x$$

### Runge-Kutta Method

$$y' = f(x,y)$$

$$k_1 = f(x_n, y_n)$$

$$k_2 = f(x_n + \frac{1}{2}\Delta x, y_n + \frac{1}{2}\Delta x k_1)$$

$$k_3 = f(x_n + \Delta x, y_n + \Delta x k_2)$$

$$y_{n+1} = y_n + \Delta x \left( \frac{1}{6} k_1 + \frac{4}{6} k_2 + \frac{1}{6} k_3 \right)$$

Taylor Series:  
 $y(x+\Delta x) = y(x) + \Delta x y'(x) + \frac{\Delta x^2}{2} y''(x) + \dots$   
 $y(x+\Delta x) = y(x) + f(x,y) \Delta x$

### Classic 4th order Runge-Kutta

$$y_{n+1} = y_n + \Delta x \left( \frac{1}{4} k_1 + \frac{3}{4} k_2 + 2k_3 + k_4 \right)$$

$$k_1 = f(x_n, y_n)$$

$$k_2 = f(x_n + \frac{1}{2}\Delta x, y_n + \frac{1}{2}\Delta x k_1)$$

$$k_3 = f(x_n + \Delta x, y_n + \Delta x k_2)$$

$$k_4 = f(x_n + \Delta x, y_n + \Delta x k_3)$$

## PDE'S

### Finite Difference Method



## EIGEN VALUES

$$A = \begin{bmatrix} a & b \\ c & d \end{bmatrix}$$

$$\det(A - \lambda I) = \det \begin{bmatrix} a-\lambda & b \\ c & d-\lambda \end{bmatrix} = (a-\lambda)(d-\lambda) - bc = 0$$

$$\lambda^2 - (a+d)\lambda + (ad-bc) = 0$$

$$\lambda = \frac{(a+d) \pm \sqrt{(a+d)^2 - 4(ad-bc)}}{2}$$

$$A = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} a-\lambda & b \\ c & d-\lambda \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} a-\lambda & b \\ c & d-\lambda \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$x_1 = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$$

$$\begin{bmatrix} a-\lambda & b \\ c & d-\lambda \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$x_2 = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

**RIGHT BOUNDARY BC**

Top boundary:  $T = T_0$

Bottom boundary:  $T = T_1$

Central difference:  $\frac{\partial^2 T}{\partial x^2} = \frac{T_{i+1} - 2T_i + T_{i-1}}{\Delta x^2}$

Right boundary:  $T_N = T_1$

Left boundary:  $T_0 = T_0$

**LEFT BOUNDARY BC**

Top boundary:  $T = T_0$

Bottom boundary:  $T = T_1$

Central difference:  $\frac{\partial^2 T}{\partial x^2} = \frac{T_{i+1} - 2T_i + T_{i-1}}{\Delta x^2}$

Left boundary:  $T_0 = T_0$

Right boundary:  $T_N = T_1$

**TOP BOUNDARY BC**

Top boundary:  $T = T_0$

Bottom boundary:  $T = T_1$

Central difference:  $\frac{\partial^2 T}{\partial x^2} = \frac{T_{i+1} - 2T_i + T_{i-1}}{\Delta x^2}$

Top boundary:  $T_0 = T_0$

Bottom boundary:  $T_N = T_1$

**BOTTOM BOUNDARY BC**

Top boundary:  $T = T_0$

Bottom boundary:  $T = T_1$

Central difference:  $\frac{\partial^2 T}{\partial x^2} = \frac{T_{i+1} - 2T_i + T_{i-1}}{\Delta x^2}$

Top boundary:  $T_0 = T_0$

Bottom boundary:  $T_N = T_1$

**5th row of a matrix**

$$\begin{bmatrix} 0 & -1 & 0 & -1 & 0 & -1 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ u_6 \\ u_7 \\ u_8 \\ u_9 \end{bmatrix} = 0$$

**[A] MATRIX:**

Centered finite-diff eqn:

$$-u_{i-1} + 4u_i - u_{i+1} = -2\Delta x^2 f_i$$

Top boundary:

$$-u_{i-1} - u_i + 4u_{i+1} - 2u_{i+2} = -2\Delta x^2 f_{i+1}$$

Bottom boundary:

$$-u_{i-1} - u_i + 4u_{i+1} - 2u_{i+2} = -2\Delta x^2 f_{i+1}$$

**FINITE DIFFS:**

Centered finite-diff eqn:

$$f(x) = \frac{f(x+\Delta x) - f(x-\Delta x)}{2\Delta x}$$

$$f(x) = \frac{f(x+\Delta x) + 3f(x) - 3f(x-\Delta x) + f(x)}{4\Delta x}$$

# Analysis Of Numerical Methods

**James F. Epperson**



## **Analysis Of Numerical Methods:**

*Analysis of Numerical Methods* Eugene Isaacson, Herbert Bishop Keller, 1994-06-07 This excellent text for advanced undergraduate and graduate students covers norms numerical solutions of linear systems and matrix factoring eigenvalues and eigenvectors polynomial approximation and more Many examples and problems 1966 edition [An Introduction to Numerical Analysis](#) Kendall Atkinson, 1989-01-17 This edition of the standard introductory textbook on numerical analysis has been revised and updated to include optimization trigonometric interpolation and the fast Fourier transform numerical differentiation the method of lines and boundary value problems **An Introduction to Numerical Methods and Analysis** James F. Epperson, 2013-10-07 Praise for the First Edition outstandingly appealing with regard to its style contents considerations of requirements of practice choice of examples and exercises Zentralblatt MATH carefully structured with many detailed worked examples The Mathematical Gazette The Second Edition of the highly regarded An Introduction to Numerical Methods and Analysis provides a fully revised guide to numerical approximation The book continues to be accessible and expertly guides readers through the many available techniques of numerical methods and analysis An Introduction to Numerical Methods and Analysis Second Edition reflects the latest trends in the field includes new material and revised exercises and offers a unique emphasis on applications The author clearly explains how to both construct and evaluate approximations for accuracy and performance which are key skills in a variety of fields A wide range of higher level methods and solutions including new topics such as the roots of polynomials spectral collocation finite element ideas and Clenshaw Curtis quadrature are presented from an introductory perspective and the Second Edition also features Chapters and sections that begin with basic elementary material followed by gradual coverage of more advanced material Exercises ranging from simple hand computations to challenging derivations and minor proofs to programming exercises Widespread exposure and utilization of MATLAB An appendix that contains proofs of various theorems and other material The book is an ideal textbook for students in advanced undergraduate mathematics and engineering courses who are interested in gaining an understanding of numerical methods and numerical analysis [Numerical Methods for Two-Point Boundary-Value Problems](#) Herbert B. Keller, 2018-11-14 Elementary yet rigorous this concise treatment is directed toward students with a knowledge of advanced calculus basic numerical analysis and some background in ordinary differential equations and linear algebra 1968 edition **Theory and Applications of Numerical Analysis** G. M. Phillips, Peter J. Taylor, 1996-07-05 Theory and Applications of Numerical Analysis is a self contained Second Edition providing an introductory account of the main topics in numerical analysis The book emphasizes both the theorems which show the underlying rigorous mathematics and the algorithms which define precisely how to program the numerical methods Both theoretical and practical examples are included a unique blend of theory and applications two brand new chapters on eigenvalues and splines inclusion of formal algorithms numerous fully worked examples a large number of problems many with solutions **Numerical Analysis Or**

**Numerical Method in Symmetry** Clemente Cesarano,2020-02-21 This Special Issue focuses mainly on techniques and the relative formalism typical of numerical methods and therefore of numerical analysis more generally These fields of study of mathematics represent an important field of investigation both in the field of applied mathematics and even more exquisitely in the pure research of the theory of approximation and the study of polynomial relations as well as in the analysis of the solutions of the differential equations both ordinary and partial derivatives Therefore a substantial part of research on the topic of numerical analysis cannot exclude the fundamental role played by approximation theory and some of the tools used to develop this research In this Special Issue we want to draw attention to the mathematical methods used in numerical analysis such as special functions orthogonal polynomials and their theoretical tools such as Lie algebra to study the concepts and properties of some special and advanced methods which are useful in the description of solutions of linear and nonlinear differential equations A further field of investigation is dedicated to the theory and related properties of fractional calculus with its adequate application to numerical methods

**Numerical Analysis** Walter Gautschi,2011-12-06 Revised and updated this second edition of Walter Gautschi s successful Numerical Analysis explores computational methods for problems arising in the areas of classical analysis approximation theory and ordinary differential equations among others Topics included in the book are presented with a view toward stressing basic principles and maintaining simplicity and teachability as far as possible while subjects requiring a higher level of technicality are referenced in detailed bibliographic notes at the end of each chapter Readers are thus given the guidance and opportunity to pursue advanced modern topics in more depth Along with updated references new biographical notes and enhanced notational clarity this second edition includes the expansion of an already large collection of exercises and assignments both the kind that deal with theoretical and practical aspects of the subject and those requiring machine computation and the use of mathematical software Perhaps most notably the edition also comes with a complete solutions manual carefully developed and polished by the author which will serve as an exceptionally valuable resource for instructors

**Analysis of Numerical Methods** Eugene Isaacson,Herbert Bishop Keller,1966

**Introduction to Numerical Methods** Peter Stark,1970 This text is for an introductory course in what is commonly called numerical analysis numerical methods or even numerical calculus While it parallels the development in Course B4 on Numerical Calculus in the proposed Curriculum in Computer Science issued by the Association for Computing Machinery this book is designed for any science or engineering student who has completed his first course in calculus and who has at least a passing knowledge of elementary computer programming in FORTRAN This is a practical book for the student who in addition to seeing the theory of numerical methods also likes to see the results the predominant emphasis is on specific methods and computer solutions It often points out where the theory departs from practice and it illustrates each method of computer solution by an actual computer program and its results

**B-Series** John C. Butcher,2022-04-02 B series also known as Butcher series are an algebraic tool for analysing solutions to ordinary differential equations including

approximate solutions Through the formulation and manipulation of these series properties of numerical methods can be assessed Runge Kutta methods in particular depend on B series for a clean and elegant approach to the derivation of high order and efficient methods However the utility of B series goes much further and opens a path to the design and construction of highly accurate and efficient multivalued methods This book offers a self contained introduction to B series by a pioneer of the subject After a preliminary chapter providing background on differential equations and numerical methods a broad exposition of graphs and trees is presented This is essential preparation for the third chapter in which the main ideas of B series are introduced and developed In chapter four algebraic aspects are further analysed in the context of integration methods a generalization of Runge Kutta methods to infinite index sets Chapter five on explicit and implicit Runge Kutta methods contrasts the B series and classical approaches Chapter six on multivalued methods gives a traditional review of linear multistep methods and expands this to general linear methods for which the B series approach is both natural and essential The final chapter introduces some aspects of geometric integration from a B series point of view Placing B series at the centre of its most important applications makes this book an invaluable resource for scientists engineers and mathematicians who depend on computational modelling not to mention computational scientists who carry out research on numerical methods in differential equations In addition to exercises with solutions and study notes a number of open ended projects are suggested This combination makes the book ideal as a textbook for specialised courses on numerical methods for differential equations as well as suitable for self study

**Introduction to Precise Numerical Methods** Oliver

Aberth,2007-04-11 Precise numerical analysis may be defined as the study of computer methods for solving mathematical problems either exactly or to prescribed accuracy This book explains how precise numerical analysis is constructed The book also provides exercises which illustrate points from the text and references for the methods presented Clearer simpler descriptions and explanations of the various numerical methods Two new types of numerical problems accurately solving partial differential equations with the included software and computing line integrals in the complex plane

*A Friendly Introduction to Numerical Analysis* Brian Bradie,2006 An introduction to the fundamental concepts and techniques of

numerical analysis and numerical methods Application problems drawn from many different fields aim to prepare students to use the techniques covered to solve a variety of practical problems

*Analysis of Numerical Methods*,1994 **Numerical**

**Methods for Ordinary Differential Equations** John C. Butcher,2008-04-15 In recent years the study of numerical methods for solving ordinary differential equations has seen many new developments This second edition of the author's pioneering text is fully revised and updated to acknowledge many of these developments It includes a complete treatment of linear multistep methods whilst maintaining its unique and comprehensive emphasis on Runge Kutta methods and general linear methods Although the specialist topics are taken to an advanced level the entry point to the volume as a whole is not especially demanding Early chapters provide a wide ranging introduction to differential equations and difference equations

together with a survey of numerical differential equation methods based on the fundamental Euler method with more sophisticated methods presented as generalizations of Euler. Features of the book include Introductory work on differential and difference equations. A comprehensive introduction to the theory and practice of solving ordinary differential equations numerically. A detailed analysis of Runge Kutta methods and of linear multistep methods. A complete study of general linear methods from both theoretical and practical points of view. The latest results on practical general linear methods and their implementation. A balance between informal discussion and rigorous mathematical style. Examples and exercises integrated into each chapter enhancing the suitability of the book as a course text or a self study treatise. Written in a lucid style by one of the worlds leading authorities on numerical methods for ordinary differential equations and drawing upon his vast experience this new edition provides an accessible and self contained introduction ideal for researchers and students following courses on numerical methods engineering and other sciences

**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

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**Classical and Modern Numerical Analysis** Azmy S. Ackleh, Edward James Allen, R. Baker Kearfott, Padmanabhan Seshaiyer, 2009-07-20 *Classical and Modern Numerical Analysis: Theory, Methods and Practice* provides a sound foundation in numerical analysis for more specialized topics such as finite element theory, advanced numerical linear algebra and optimization. It prepares graduate students for taking doctoral examinations in numerical analysis. The text covers the main areas of introductory numerical analysis including the solution of nonlinear equations, numerical linear algebra, ordinary differential equations, approximation theory, numerical integration and boundary

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